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CONFERENCE PROCEEDINGS

26th ANNUAL CONFERENCE OF THE INTERNATIONAL GROUP FOR LEAN CONSTRUCTION

Chennai, India, 16th to 22nd July, 2018

"EVOLVING LEAN CONSTRUCTION TOWARDS MATURE PRODUCTION MANAGEMENT ACROSS CULTURES AND FRONTIERS"

Organised by

Indian Institute of Technology Madras, Chennai

Conference Partner

ILCE | INSTITUTE FOR LEAN CONSTRUCTION EXCELLENCE

Editor and Scientific Chair:
Dr. Vicente A González

Conference Chairs:
Prof. N Raghavan
Prof. Koshy Varghese

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VOLUME 1 & 2

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Proceedings of

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A Note from the Organisers

The Annual Conference of the International group for Lean Construction (IGLC) is an important activity of IGLC and the 26th Annual Conference is being held in India for the first time, in the city of Chennai, as IGLC 2018. Lean Construction is a nascent practice in India but the concept of Lean is slowly, but steadily, taking roots in this country. An organisation called Institute for Lean Construction Excellence (ILCE) formed by Construction Industry organisations along with IIT Madras as the Knowledge Partner has been spearheading the spread of Lean Construction in India. India has a booming infrastructure construction market and Lean practices could be of great help to have better control on the project management of these projects. Two Indian Lean Construction Conferences, ILCC 2015 and ILCC 2017, have been conducted as National Conferences, with some international participation also. Pursuant to a fervent desire in the Indian Lean community to get international association, a bid was made for the Annual Conference of IGLC to be conducted in India and was granted, leading to the genesis of IGLC 2018.

It has been a fond hope of the Indian Lean community that the international conference will give a great fillip to the Lean movement in India and these hopes have not been belied: Some 25 contributions, the largest number of accepted contributions from a single country this year, out of a total of 132 contributions, have been from India. 30 Posters out of a total of 45 are also being presented from India. These significant numbers do auger well for the future of Lean Construction in India.

The Workshop Day anchored by Dr. Tariq Abdelhamid and Dr Paz Arroyo is also featuring a couple of Lean project management practitioners, Puneet Narang and Yash Singh, to share the Indian experience. The Industry Day has four Panel discussions comparing international practices and Indian practices in Lean construction. A Summer School for Doctoral research scholars is also being organised for two days after the main Conference. Here again many Indian scholars are attending apart from international scholars. As has been the practice in previous conferences, a galaxy of international Lean specialists have agreed to be on the panel of Faculty Advisers for the School.

The IGLC 2018 organisers have been working for the last few years to bring IGLC to India and to generate a good bit of enthusiasm in the local Indian community and these have indeed come about quite well. With the ice so broken, hopefully the Indian Lean community will be a significant participant in future IGLC events!

As part of the organizing efforts, the Conference Proceedings running to about 1400 pages in two volumes and the A3 Compilation covering 132 papers have been compiled and printed. The present publication also covers the Conference Souvenir and Compilation of 45 Posters. The Organisers have made a sincere attempt to put together a Conference which would be of multifarious interests to the IGLC community, apart from being merely another technical event, and they hope that the community will also feel the same way after it attends the event! The various features of the Conference are being listed in the Conference Souvenir as they may be out of place in this technical compendium.

The Organisers extend a very warm Welcome to the international Lean community to take part in the technical deliberations in the week-long event here and also enjoy the leisure time in the other interesting activities planned.

With best wishes to all the Delegates for an enjoyable stay at IGLC 2018

Prof. N.Raghavan
Prof. Koshy Varghese
Indian Institute of Technology Madras, India
IGLC 2018 Organising Chairs
with IGLC 2018 Organising Team

Preface

The Annual Conference of the International Group for Lean Construction (IGLC), the main IGLC activity, has run without interruption since its inception in 1993. The IGLC represents a network of practitioners and academics working in architecture, engineering and construction (AEC) who are passionate about Lean Construction and feel that the AEC industry has to be radically revamped so that it can respond to the global challenges ahead. The IGLC goal is to meet customer demands more effectively and to dramatically enhance the AEC process and product during the delivery of a project. In this regard, the IGLC has been developing new principles and methods tailored to the AEC industry that reflect a fundamental transformation in product development and production management. Originally, the IGLC began a progressive adoption of Lean Production principles and methods that proved to be very successful in manufacturing. The IGLC emphasises the development of theory because the paucity of a production management theory is an impediment to progress in the AEC industry. Today, and with the tireless work of the IGLC, Lean Construction has evolved and matured as a production management theory for the AEC industry in its own right. It does not only consider production-related matters, but it has also incorporated new research domains that now form part of the "Lean Construction body of knowledge", such as human and social aspects of organisations, the synergies with information technology (IT) and sustainability, health and safety, and education.

The venues for the IGLC conference have alternated between the five continents. The 26th Annual IGLC Conference is being held in Chennai, India, with the main theme being "Evolving Lean Construction – Towards Mature Production Management across Cultures and Frontiers". This conference will be bringing together a large number of practitioners and academics who will present their research and industry findings.

One hundred and seventy-five full papers were initially submitted to the conference. International experts (academics and practitioners) kindly undertook the review and assessment of the submitted papers using a double-blind peer review process. The final decision on papers' acceptance was jointly made by the track chairs and the scientific chair based on these assessments. Finally, 132 papers were accepted from 29 countries, which is a great outcome for the first IGLC conference to be held in India. The papers have been organised into ten tracks: Contract and Cost Management; Enabling Lean with IT; Lean Theory; People Culture and Change; Product Development and Design Management;

Production Planning and Control; Production System Design; Safety, Quality and Green-Lean; Supply Chain Management and Off-Site Construction; and Teaching Lean Construction. A summary of the submitted and accepted papers by track is shown in table 1.

Table 1: Papers submitted and accepted to IGLC-26

Track	**Papers Submitted**	**Papers Accepted As**			
		Research	**Industry**	**Poster**	**Total**
Contract and Cost Management	10	5		1	6
Enabling Lean with IT	23	11	4	4	19
Lean Theory	19	10		1	11
People Culture & Change	30	21	3	3	27
Product Development & Design Management	19	14		3	17
Production Planning & Control	31	19	4	4	27
Production System Design	12	5		2	7
Safety, Quality & Green-Lean	13	6	2		8
Supply Chain Management and Off-Site Construction	12	3	1	1	5
Teaching Lean Construction	6	3		2	5
Total	**175**	**97**	**14**	**21**	**132**

This year's conference proceedings considered three categories of papers: technical (research), industry and posters, an approach already adopted in some previous IGLC conferences (e.g. IGLC 2015 in Perth, Australia). Industry papers represent contributions that follow the general structure of a technical paper but have an emphasis on the practical side of Lean Construction and the resulting industry insight. In this year's proceedings, the track chairs and the scientific chair decided to include posters as papers. Generally speaking, posters constitute borderline papers reflecting Lean research with potential for future development. In that respect, it was considered that allowing early-career researchers to publish posters as papers will encourage the dissemination of Lean Construction ideas among young researchers, which could have a powerful and positive impact on their future careers as lean researchers and champions. The presentation of posters will take place in a special session arranged by the local organisers and will be developed in conjunction with the main conference presentations.

Table 2 shows a summary of the accepted papers sorted by country. I would like to thank the international experts for reviewing these 132 papers. Their efforts helped to ensure that the papers accepted for this conference were of a high standard. I would also like to thank the authors for addressing the reviewers' comments accordingly. This guaranteed that the best possible papers were finally included in the conference proceedings.

Table 2: Papers accepted by country to IGLC-26

Country[a]	**Papers published**
India	25
Norway	15
United States	13
Brazil	12
United Kingdom	12
Germany	11
Chile	6
Lebanon	6
Finland	3
New Zealand	3
Ireland	2
Italy	2
Netherlands	2
Singapore	2
South Africa	2
Sri Lanka	2
Sweden	2
Colombia	1

Denmark	1
Egypt	1
France	1
Ghana	1
Hong Kong	1
Israel	1
Japan	1
Jordan	1
Peru	1
Malaysia	1
Taiwan	1
Total	**132**

[a] Country of the first author's institution

Finally, I would like to acknowledge the support of the area track chairs during the editorial process and for all their invaluable and hard work "behind the scenes". The track chairs are as follows: Savio Melo (Contract and Cost Management), Bhargav Dave (Enabling Lean with IT), Olli Seppänen (Lean Theory), James Smith (People Culture & Change), Paz Arroyo (Product Development & Design Management), Farook Hamzeh (Production Planning & Control), Frode Drevland (Production System Design), Tarcisio Saurin (Safety, Quality & Green-Lean), Thais Alves (Supply Chain Management and Off-Site Construction), and Min Liu (Teaching Lean Construction).

Auckland 7th of July, 2018
Vicente A González, Editor and Scientific Chair IGLC-26

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A LEAN PERSPECTIVE OF STAKEHOLDER INTEGRATION IN PUBLIC PRIVATE PARTNERSHIPS

Zeina Malaeb[1] and Farook Hamzeh[2]

ABSTRACT

The Special Purpose Vehicle (SPV) is the party representing the private sector in a Public Private Partnership (PPP), and combines a number of stakeholders including equity shareholders, designers, contractors, and service providers under one umbrella. Consequently, the key to ensuring successful project delivery is achieving an efficient integration of the different SPV stakeholders involved, to deliver the project as a unified entity. However, the SPV’s stakeholder management role is highly under-investigated in the literature, and no studies have attempted to explore SPV stakeholder integration. This highlights a significant need to do so, considering that the former is both a prerequisite and a driver of PPP project success. This research aims to address this need through generating a list of SPV characteristics that reflect stakeholder collaboration and developing Critical Success Factors (CSFs) to measure the level of SPV stakeholder integration, based on concepts projected from the Integrated Project Delivery (IPD) system. The aforementioned factors relate to the project’s organization structures, commercial frameworks, and operating systems and processes. This research is the first of its kind that aims to investigate the SPV’s integration level, from a holistic IPD perspective, as an enabler of successful relationship management.

KEYWORDS

Collaboration, Critical Success Factors (CSFs), Integrated Project Delivery (IPD), Public Private Partnership (PPP), Stakeholder Integration.

INTRODUCTION

A Public Private Partnership (PPP) describes a procurement route that involves two main entities, the public sector and the private sector, for the provision of a public asset or service. PPP projects offer a range of benefits as they allow the public sector to utilize the private sector’s skills and expertise in project delivery and benefit from private financing,

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on one hand, and offer improvements in project implementation time, whole life-cycle costs, and service quality, on the other (Leiringer, 2006; Liu et al., 2015). Being different from traditional project delivery routes, PPPs encompass a number of distinct features, stemming from their long-term nature, bundling of project functions, complex contractual agreements, and distinct risk allocation formulas (Grimsey and Lewis, 2004). A fundamental characteristic of a PPP is the presence of the Special Purpose Vehicle (SPV), which is the project company representing the private sector, formed especially to undertake the PPP project. This entity takes responsibility for the project through its financing, design, construction and subsequent operation and maintenance stages, over a long period of time (20-30 years) (Gomez and Gambo, 2016). In order to fulfil these functions, the SPV is structured as a consortium, combining under one umbrella a number of key stakeholders, mainly equity shareholders, designers, construction contractors, and operations and maintenance contractors. Significantly, the combination of stakeholders under one SPV calls for several unique features, namely: early stakeholder involvement, alignment of stakeholder goals and interests, stakeholder integration, collaborative working, innovation potential, and long-term commitment, among others (Fischbacher and Beaumont, 2003; Leiringer, 2006; Sainati et al., 2017).

Both the PPP delivery system and the SPV procurement structure necessitate that the aforementioned stakeholders collaborate together to deliver the project successfully as an integrated team. PPP project success is strongly affected by the level of stakeholder integration as PPPs necessitate solid collaboration for successful service delivery. Evaluating PPP success therefore requires a comprehensive evaluation of the SPV team, specifically in terms of stakeholder integration. However, the SPV’s stakeholder management role is highly under investigated in the literature and there exists a gap regarding its internal stakeholder relationships and interactions. In fact, PPP researchers state that project management studies have never focused expressively on SPVs and the existing literature fails to efficiently address inherent relational matters, as there is a lack of knowledge concerning PPP stakeholders (McErlane et al., 2016; Sainati et al., 2017). Therefore, there is a need to investigate and evaluate the efficiency of the SPV’s management role, in terms of stakeholder integration, seeing that it is both a driver and a prerequisite for PPP project success. Considering the significance of stakeholder integration for the SPV, and thus its connection to the Integrated Project Delivery (IPD) system, added to the fact that literature on the latter is rich with research on integration, there is an opportunity for projecting such concepts onto the SPV evaluation framework.

This research aims to address this need through identifying the core characteristics of SPV procurement that reflect stakeholder collaboration and correlate it to integrated project delivery, and developing Critical Success Factors (CSFs) to measure the level of SPV stakeholder integration, based on concepts projected from the IPD system. The aforementioned factors relate to the project’s organization structures, commercial frameworks, and operating systems and processes. This research is the first of its kind that aims to investigate the SPV’s integration level, from a holistic IPD perspective, as an enabler of successful relationship management. This paper first presents the adopted research methodology. Following, the main features of SPV project delivery and its correlation to integrated project delivery systems are delineated. Next, the paper discusses the three fundamental families that contribute to integrated project delivery systems: organization structures, commercial frameworks, and operating systems and processes. Finally, the identified critical success factors are presented, classified, and linked as per the three aforementioned families.

RESEARCH OBJECTIVES AND METHODOLOGY

The objectives of this research are two-fold: identifying features of PPP projects that tie them to integrated project delivery systems, and developing a list of CSFs to measure SPV stakeholder integration. The research methodology is delineated in Figure 1 below. After identifying the main SPV characteristics, CSFs that serve as indicators of SPV stakeholder integration are developed. The main studies used as a basis for collecting and generating CSFs are: Aapaoja et al. (2013), Baiden et al. (2006), Cheung et al. (2006), Ibrahim et al. (2013), and Thomsen et al. (2009). The final CSFs are then filtered, grouped, and sorted in terms compatible with SPV project delivery as under the project delivery system’s organization structures, commercial frameworks, and operating systems and processes.

Figure 1: Research Methodology

CHARACTERISTICS OF THE SPECIAL PURPOSE VEHICLE (SPV)

SPV project delivery is characterized by several distinct features which impact stakeholder collaboration and correlate it to integrated project delivery systems. These collaboration characteristics are mapped and linked to inherent features of PPP projects in this section.

ALIGNMENT OF STAKEHOLDER GOALS AND INTERESTS

The SPV design enables better alignment of stakeholder interests, as a function of the both its contractual schemes and stakeholder organization structures (Sainati et al, 2017). The primary reason driving this alignment of interests is the involvement of the major stakeholders, mainly the Design-Build (DB) contractor and Operations and Maintenance (O&M) contractor, in project financing. This approach necessitates that contractors and service providers sponsor the SPV and take stakes in it as a sign of committing to the PPP project. Involving the contractors in project funding is equivalent to strengthening their association with the project. This generates a connectivity between project funders and service providers, and bridges the gap between them. In addition, as the SPV is to operate the project for a long period of time after construction, it would be acting as a quasi-project-owner during that period. Consequently, the roles of “project owner”, “project contractor”, and “project operator” become integrated, within the SPV structure. This would instigate the SPV to consider what is best for the project during the design and construction stages, as it bears the resulting consequences throughout project operation. Additionally, as all the major stakeholders on the project are incorporated under the umbrella of this SPV and deliver the project as one unified body, an environment of joint responsibility and shared risk management is created. This not only causes the alignment of interests between the different key stakeholders, but also causes their alignment with the overall project interests, which is of even greater importance.

WHOLE-LIFE CYCLE APPROACH

The whole-life cycle approach adopted by the SPV shareholders is a function of three main features: designing for service delivery, bundling project functions, and long term contracts.

Design for Service Delivery

PPP projects encompass a feature that goes past the mere delivery of an asset, but rather focuses on the delivery of a continuous service (Grimsey and Lewis, 2004; World Bank, 2009). The main distinction that characterizes service delivery performance is its requirement for considering serviceability issues in the design phase of the project, since this initial phase affects all the consequent phases, primarily in terms of costs (Tranfield et al, 2005). Therefore, the SPV, in designing for the delivery of the required service, would adopt whole-life cycle costing.

Bundling Project Functions

A main feature of PPPs is the bundling of major project phases or functions (World Bank, 2017). This refers to the combination of the design, construction, and operations and maintenance stages in specific. This bundling encourages the SPV to consider implications of its decisions on different stages of the project which leads to the adoption of whole-life cycle costing (Chan and Cheung, 2014; World Bank, 2009). Therefore, the optimization of costs is happening at the overall project level instead of the individual phase levels. In lean terms, this is a shift from the traditional concept of transformation and local optimization to the global perspectives of flow and value generation.

Long Term Contracts

PPP projects are characterized by the long-term nature of their contracts. These long term commitments act as incentives for the private party to account for service delivery cost when designing the project. A long-term contract generates a longer term commitment, which places capital at risk and is presumed to force the private stakeholders to produce a facility that is durable and functional while minimizing life cycle costs (Leiringer, 2006).

COLLABORATIVE ENVIRONMENTS

PPP projects create collaborative environments, stemming mainly from the early involvement of stakeholders, design for service delivery, and the organization structure of the SPV.

Early Stakeholder Involvement

One distinctive feature of PPP projects is the early involvement of all key stakeholders in project delivery. In other words, from day one, the designer, constructor, and operator, are all on board in the SPV. Involving participants early on has been associated with a number of advantages. For instance, it allows for synthesis in planning the design and implementation stages, as their separation has proven to significantly reduce the potential of enhancing project performance (Fischbacher and Beaumont, 2003). This permits the provision of input by downstream participants into upstream design and construction stages. In addition, this removes organizational barriers to facilitate the flow of information across boundaries, cross-organizational thinking, and collective problem solving. Moreover, through efficient inclusion, it is possible to develop a series of partnership benefits that include generating a holistic approach that improves service quality, encouraging innovation and creativity, and enhancing organizational learning through knowledge transfer (Fischbacher and Beaumont, 2003; Leiringer, 2006).

Design for Service Delivery and SPV Structure

Designing for service delivery necessitates high levels of team working, communication, and collaboration throughout the project, in order to optimize the continuous provision of services. PPP project success is highly dependent on the quality of integration and collaboration within the SPV organization. The structure of the SPV is characterized by involving the major project stakeholders under one umbrella. It is designed, in concept, to foster such integrative and cooperative efforts across the different teams involved to deliver successful outcomes.

THE LINK BETWEEN PPP AND IPD

The PPP characteristics discussed above bear significant association with those of integrated project delivery systems. PPP projects, and SPV functions in particular, seem to be founded on the concept of team integration as both a driver and prerequisite to project success. In fact, performance levels in infrastructure development are seen to depend as much on enhanced project cultures and integrated teamwork as they do on improved structures and systems (Kumaraswamy et al., 2007). PPPs, being of a long term nature, provide opportunities to generate, mature, and sustain cooperation and also for the benefits to materialize (Kumaraswamy and Anvuur, 2008). Furthermore, researchers have stressed on the need for close collaboration and team integration between PPP participants, citing formal incentive agreements as a driver for the former (Walker and Jacobsson, 2014). SPV stakeholder integration appears to be a fundamental cornerstone of the PPP delivery system, which brings forwards its correlation to other forms of collaborative project delivery. The IPD system is one such project delivery route that stresses the significance of stakeholder integration as a necessity for successful project delivery.

FOUNDATIONS OF INTEGRATED PROJECT DELIVERY

The IPD system describes that the factors for realizing efficient stakeholder integration stem from three foundations: organization structures, commercial frameworks, and operating systems and processes (Thomsen et al., 2009).

Organization Structures

IPD requires a drastic change in the organization structure through the formation of integrated teams. Key contractors are engaged early on and collaborate with the designer by providing input on cost, constructability, and value, with the goal of decreasing negative iterations throughout the design process. Stakeholders cooperate in making decisions and solving problems. This creates a "project culture" that encourages collaborative working as a unified integrated team. Another fundamental organizational feature of the IPD is what is termed the Core Group, an executive team responsible for the day-to-day management and leadership on a project. What is special about this team is that in integrates members from the different key stakeholders in the decision making process. These people do not only serve as managers, but also as leaders that are responsible for driving and committing to the IPD system. In IPD, project organizations change from silos to integrated, high performance teams. A transformation of the organization structure is the essential starting point to effectively implement an integrated form of project delivery (Thomsen et al., 2009).

Commercial Frameworks

The commercial structure on traditionally procured construction projects is built to drive the local optimization of individual stakeholders' interests, with each party looking out for its own well-being and disregarding others' interests. A key missing aspect is the alignment of stakeholder goals and objectives with the overall project objectives. In order to ensure this alignment is in place, a commercial framework is required that addresses the risk allocation and compensation structures amongst participants. For instance, the IPD contract calls for collective risk management, as opposed to each party managing its own risks. Through risk sharing, all the stakeholders actively collaborate in effectively identifying and collectively managing risks, which benefits the project as a whole. Another type of incentive introduced in these commercial frameworks is the "pain sharing and gain sharing" agreement. The idea is that all participating team members mutually share the risk of cost overruns and mutually benefit from cost savings in any part of the project. Again, this leads to a shift in mindset from each party looking out for itself to all parties looking out for the project. All involved stakeholders are part of one team with one goal, which is successful project delivery. The relationships between these major stakeholders shift from self-protecting and risk shifting to team-based ones, aligning the participants through incentives carefully chosen to encourage collective risk management and whole project optimization (Thomsen et al., 2009).

Operating Systems and Processes

Even with integrated teams and sufficient commercial terms in place, operating systems and processes that either facilitate or hinder collaboration can make-or-break an integrated project delivery system. The systems that project stakeholders rely on must be integration-compatible and able to encompass stakeholder cooperation. Another requirement is utilizing technologies to ensure effective interaction and communication between project participants. In addition, certain project processes and mechanisms must exist that manage the interactions among stakeholders and nurture the integration potential of the project. These processes, which stem from the lean construction philosophy, promise to overcome the shortfalls of those employed in traditional project delivery systems. Examples of these processes are: integrated setting of project goals and objectives, collective decision making and integrated project management, collaborative planning with key project stakeholders, and involving the last planner in the planning process. These processes and systems must be designed to add value, foster collaboration, increase reliability, and allow for continuous improvement (Thomsen et al., 2009).

DEVELOPED FACTORS

The final set of developed factors, as belonging to the organization structures, commercial frameworks, and the operating systems and processes groupings, are presented in Figures 2, 3, and 4.These factors are inspired from research on project and stakeholder integration, as specified in the methodology section, and on concepts from the IPD philosophy as discussed above. They are further developed and grouped under the three families previously presented. They indicate general requirements to be adopted by PPP project delivery systems to achieve optimal stakeholder integration and also act as indicators of the actual integration level achieved on a project.

CONCLUSION AND FUTURE WORK

The features of the SPV, acting as a consortium combining the parties involved in PPP project delivery, bear significant similarities to the IPD system. Consequently, it is both interesting and significant to study this specific procurement route from a lean perspective, a topic no studies to date have focused on. This paper presents the main features of SPV procurement that correlate it to integrated project delivery and subsequently develops critical success factors to measure SPV stakeholder integration. This research is part of a wider thesis study that seeks to develop a comprehensive “SPV Health Check” tool, utilizing the aforementioned factors, to give an indicator of the level of integration within the SPV. Its contribution is noteworthy in introducing the lean vein into the PPP procurement route and evaluating PPP project success in terms of integration criteria.

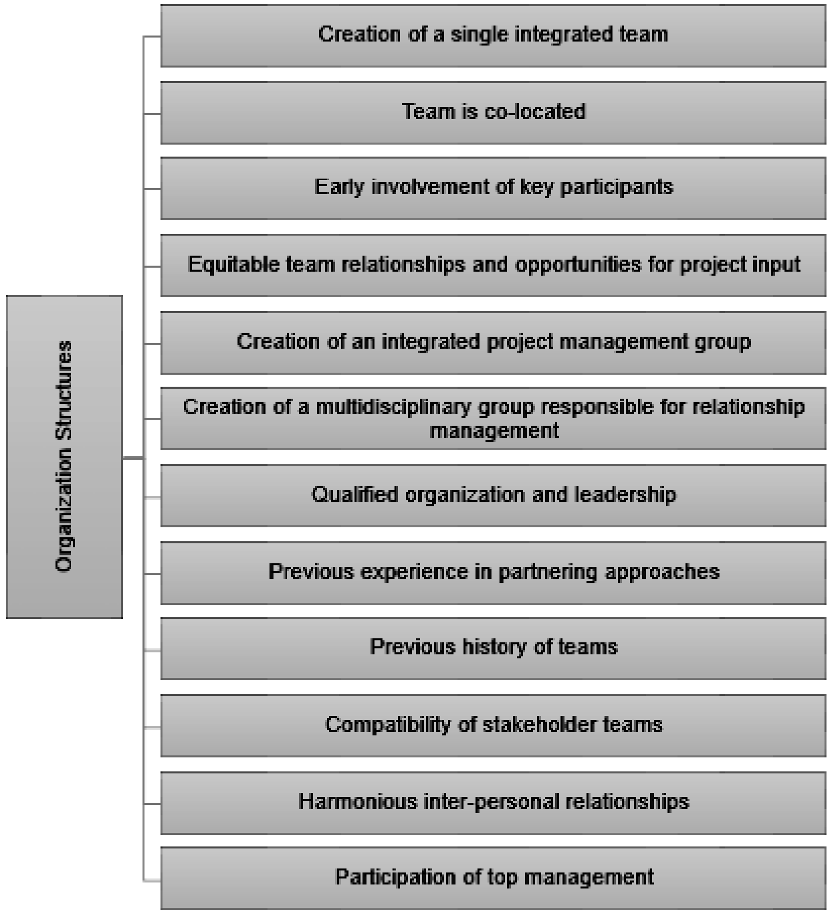

Figure 2: Factors under Organization Structures

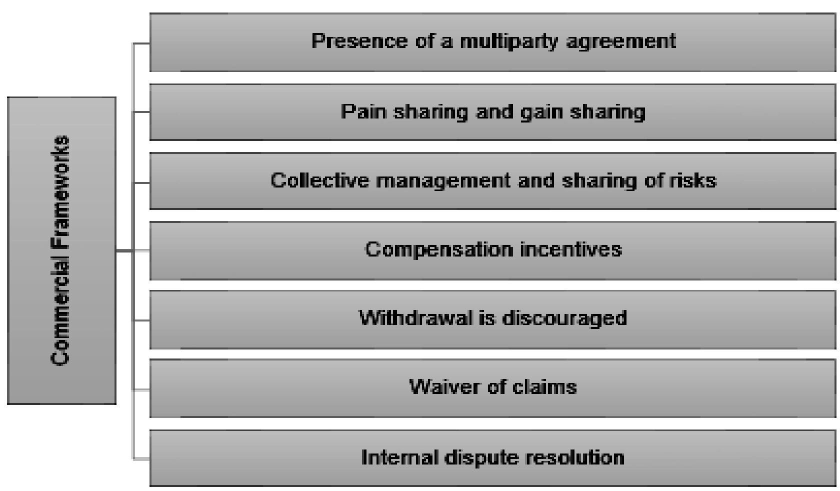

Figure 3: Factors under Commercial Frameworks

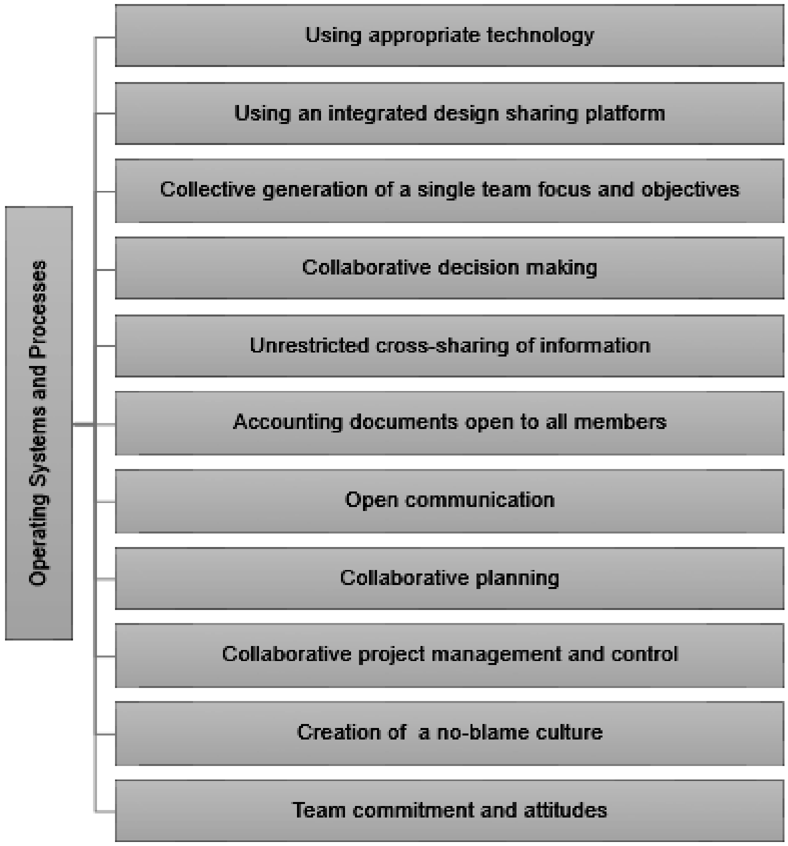

Figure 4: Factors under Operating Systems and Processes

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A COMPARISON OF COMPETITIVE DIALOGUE AND BEST VALUE PROCUREMENT

Paulos Abebe Wondimu[1], Ole Jonny Klakegg[2], Ola Lædre[3], and Glenn Ballard[4]

ABSTRACT

Competitive Dialogue (CD) and Best Value Procurement (BVP) are two different approaches to early contractor involvement (ECI) in public projects. However, it is not clear which approach is best suited for what kind of project situations, and which is better for implementing lean in public procurement. The purpose of this paper is to explore the similarities and differences of these approaches to develop recommendations for how to match approach with project situations. In addition to literature study, two large infrastructure projects were studied through 12 in-depth semi-structured interviews and review of documents. The findings from this study indicate that the two approaches have several similarities; e.g., both give a better result when they are used together with a design-build contract than design-bid-build contract, and they give clients possibilities to meet suppliers and clarify projects before contract signing. However, they also have a number of differences such as the number of competitors that develop a project and a supplier selection premises varies. The study concludes that BVP is a moreeffective procurement process than CD as regards procurement phase. However, CD gives more room for the clients to influence supplier solutions than BVP.

KEYWORDS

Best value procurement (BVP), competitive dialogue (CD), lean, early contractor involvement (ECI), public procurement.

INTRODUCTION

Main contractors have more experience than clients and designers in construction materials, methods, and local practice. Therefore, they can provide relevant information not only about generic constructability but also about resources availability and

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limitations in terms of cost, performance, access and site conditions. Construction knowledge and experience is an important element of lean construction. One of the ways to integrate construction knowledge and experience in early phases of a project is early contractor involvement (ECI) (Song et al. 2009).The main goals of ECIare project control, time gains, and innovation(Mosey 2009). ECI can eliminate waste of time, cost and effort that bedevils projects (Walker and Lloyd-Walker 2015). How clients design the procurement procedure decides how well organizations can be integrated and how well the competence may be utilized. The procurement procedure should create room for creative solutions and intensive exchange of ideas. Early start and an interweaving approach are importantin order to create an opportunity for the contractors to play an active role(Lenferink et al. 2012). There are different models of ECI depending on when the contractor gets involved in the project. CD and BVP are two interweaving approaches of ECI that European public owners can use. Both approachesallow interactions between a client and suppliers in early phases of projects and before contract signing (Storteboom et al. 2017; Wondimu et al. 2017).

There is a limited examination of lean thinking in public procurement (Schiele and McCue 2011).There is lack of research in the IGLC community in the area of public procurement, and there is no literature comparing BVP and CD. This paper contributes to addressing this issue byaddressing the following research questions.

- What are the similarity and differences between BVP and CD?
- Which approach is best suited for what kind of project situations?
- Which approach is better to implement lean in public sector projects?

This study has some limitations since the cases are limited to only two Norwegian public road projects.

METHOD

The research reported in this study includesliterature review and two case studies. The two cases were chosen because they are the first large infrastructure projects in Norway that have used the two approaches. The methodological approaches described by Yin (2014)was used during the case studies.

Literature review formed the basis for the theoretical background. The review of literature was undertaken using IGLC.net conference papers database in addition to the search engines Oria and Google Scholar. Oria is a Norwegian University library resource. Besides, citations chaining according to the principles laid out by Ellis (1993) was also used to find new literature.

The two cases were studied based on 12 in-depth semi-structured interviews with senior professionals from both client and contractor organization. Each interview was carried out face-to-face based on an interview guide and lasted between 60 minutes to 90 minutes. All interviewees were recorded and later transcribed.

A document study was carried out after the literature review and interviews. The document study included tender documents, tender evaluation protocols, and contracts. The purpose of the document study was to supplement the literature review and interviews and to achieve data triangulation. The data were hand-coded and analyzed while data were collecting and writing up the findings based on the description of Creswell (2013).

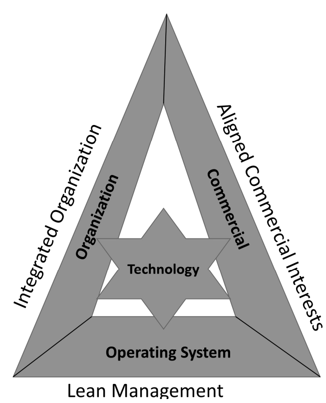
Table 1: Overview of cases and the respective interviewee's position

Client/Project name	Project Description (Budget €)	Proj. start-finish	Interviewee's position	ECI Approach
1) Nye veier/E18 Rugtvedt-Dørdal	16.5 km new four-lane highway (€200 mill)	2017 - 2019	Project director, Assistant project director, Contract and procurement director, Construction manager, Environmental advisor, & Construction discipline leader (6 from the client).	BVP
2) Statens Vegvesen/E6-Helgeland North	62 km new two-lane highway (€170 mill)	2015 - 2019	Construction manager, project manager and a representative from StatensVegvesenhead office (3 from the client) & project manager, quality manager and geotechnical engineer (3 from the contractors)	CD

THEORETICAL BACKGROUND

LEAN AND EARLY CONTRACTOR INVOLVEMENT (ECI)

Based on the Lean Construction Institute recommendation for projects to approach optimality, three elements are required. Those are an integrated organization, aligned commercial interest, and lean management. These elements are also called LCI triangle, see Figure 1. An integrated organization can be interpreted as one in which downstream industry actors participate in upstream activities, and vice-versa. The underlying principle for this side of the LCI triangle is that all relevant competence/knowledge are to be applied simultaneously to the generation, evaluation, and selection of product and process design alternatives. Thisis based on the view that different actors have relevant knowledge, and consequently must be engaged in generating and selecting from alternatives(Ballard 2012).



One of the main goals of ECI is time gains by conducting parallel or interweaving procedures rather than conducting them sequentially (Lenferink et al. 2012). Based on this goal, the authors of this paper consider ECI as one of the means to create an integrated organization and to approach project optimality. Furthermore, based on the authors' interpretation, both CD and BVP cover the first side of the LCI triangle since the purpose of the approaches is to involve contractors in the early phase.

Figure 1: LCI Triangle (Ballard 2012) (driven from Thomsen et al. (2009))

COMPETITIVE DIALOGUE (CD)

The CD procurement procedure was introduced in 2004 by the European Parliament for particularly complex contracts (European Commission 2006). This procurement procedure allows clients to discussrequirements with short listed suppliers before inviting final written tenders (Uttam and Le Lann Roos 2014). EU public procurement directive describes five circumstances in which the approach canbe used(European Parliament 2014).

It was introduced to provide an improved method for awarding complex public contracts (Arrowsmith and Treumer 2012). It is also intended to give public clients a flexible procurement procedure to enable a dialogue concerning all aspects of the contract with several competitors. The dialogue is an intervening stage between the tender announcement and the submission of final tenders. It is intended to help the client identify and define the means best suited to meeting its objectives. The awarding method in CD procedure is always most economically advantageous tender (MEAT) (Hoezen and Dorée 2008). MEAT (price-inclusive multi-criteria selection) is the weighted sum of various aspects of products or service that provides value to the project (Wondimu et al. 2016). Public owners can use CD to stimulate innovation through dialogue(Uttam and Le Lann Roos 2014). CD procedure has five phases; preparation, pre-qualification, dialogue, evaluation & selection, and execution, see Figure 2.

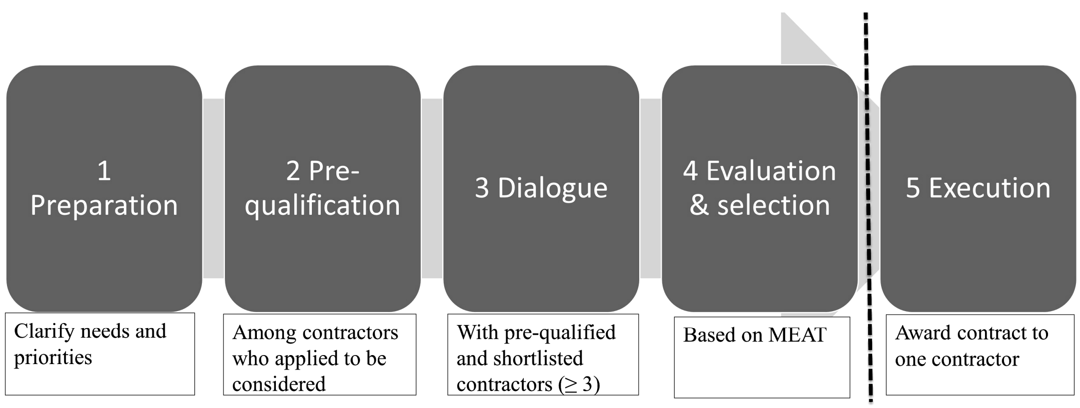


Figure 2: CD phases and majorclient activities

BEST VALUE PROCUREMENT (BVP)

Best Value Procurement (BVP) BVP is a procurement method that focuses on gaining the best value for the lowest costs (Snippert et al. 2015). A fundamental concept in BVP is the focus on selecting the supplier with the offer that is most advantageous to the client where price and other factors are considered (Elyamany 2010).There are different models of BVP (Perrenoud et al. 2017). This paper explores the BVP model that was introduced by Dean Kashiwagi in 1991 as bestvalue performance information procurement system (BV- PIPS). Regarding BVP there are no EU public procurement laws and regulations that regulate or prohibit from using the approach in public sector.

This BVP model concentrates on minimizing decision making of clients. One of the fundamental things of this BVP model is that the client should not try to be more expert than the real expert is. The client task is to get the right supplier, and they will deliver the best results. Minimizing the none expert (the client) management, direction, and control of expert suppliers are the philosophy behind BVP. In BVP both price and performance are considered during the selection instead of only price(Kashiwagi 2016).

BVP is an information-based procurement method that predicts theperformance of suppliers based on past performance information. Suppliers are ranked and then selected based on past performance, current capability, price, risk management and the quality of key personnel (Duren et al. 2015).

BVP method has four phases; pre-qualification, selection, clarification, and execution, see Figure 3.

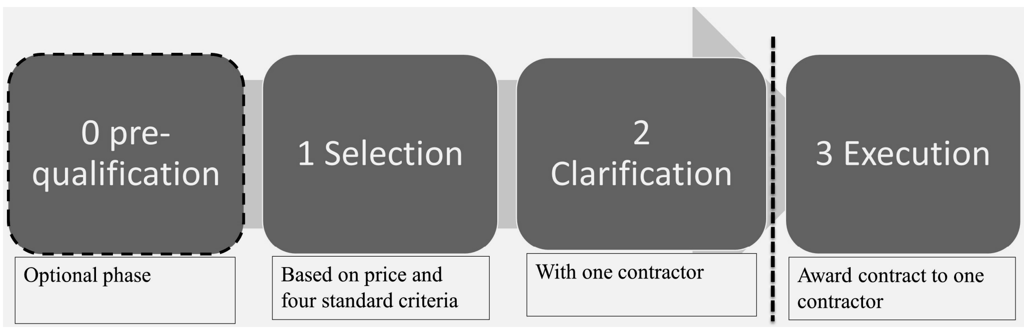


Figure 3: BVP phases and major client activities (developed based on Kashiwagi (2016))

FINDINGS AND DISCUSSION

COMPARISON OF CD AND BVP

This section explores the two approaches to determine the similarities and differences between them and to identify which approach suits for what kind of projects. The two case studies through interviews and document study helped to add to the knowledge gain through literature review and to understand how CD and BVP were interpreted in practice. Furthermore, the case studies contributed in determining the comparison factors and facilitate the analysis process.

The two approaches have similarities such as 1) can be used as an approach to implement ECI, 2) can be used under the EU legislation, 3) work best with a design-build contract than design-bid-build contract, and 4) allow interaction between a client and suppliers during the procurement phase before contract award such as during interview, dialogue and clarification. A summary of major differences between the two approaches is presented in Table 2 without recommending one of them over the other.

Table 2: Comparison between CD and BVP

No.	Comparison factors	CD	BVP
1	Timing of selection	Late selection	Early selection
2	Pre-qualification	Mandatory	Optional
3	Interaction	Dialogue	Clarification
4	No of competitors develop a project	≥ 3	1
5	Client's control on the detail of the supplier's solution during procurement	High control (The client knows best – the contractor is hired to do the job)	Low control (The contractor knows best – they are selected because of their expertise)
6	Client's role in the selection of solution	The client can filter the contractors' solutions in the dialogue phase	The contractor present their solution in the clarification phase
7	Client's resources need during the procurement	Demanding	Less demanding
8	Suppliers resources need during the procurement	All Shortlisted suppliers are required to develop solutions for the project, and it is demanding for all suppliers	Only one supplier develop a solution to a project, and it is demandingonly for one of the suppliers
9	Selection criteria	Technical and varies with project	Non-technical and standardized
10	Weightqualification/ price	10% to 40% / 90% to 60%	75 % / 25 %
11	suppliers compete and evaluated based on	Project-specific solutions and price	Four standard criteria and price
12	Evaluation method/scale	Not standardized	Standardized
13	Documents from the competitors to be evaluated by the client	Comprehensive documentation	Max 6 pages document
14	Historical origin	EU	USA
15	On what kind of projects can it be used?	EU public procurement directive describes five circumstances in which the approach canbe used	On all kinds of projects
16	Client access to suppliers' idea	The client gets access to several ideasat a time	The client gets access to only one idea
17	In what situation is the approach suitable	If a client wants to choose a supplier based on their solution for a specific project	If a client is looking for an expert that has done relevant things several times with high performance

The most interesting aspects oftable 2invite some comments:

The first comparison factor is the timing of the selection. In CD, the selection phase is after the dialogue phase. Whereas in BVP the clarification phase that is comparable with dialogue phase in CD is after the selection phase. The purpose of the selection phase in the two approaches differ. In BVP, the purpose is to shortlist andselect the best-qualified contractor to the clarification phase, whereas in CD, the purpose is to award the contract. Furthermore, even if the dialogue phase in CD and the clarification phase in BVP are comparableregarding the client meeting with suppliers before contract signing, they have a different purpose. The purpose of the clarification phase is a selected supplier explains the scope of the project to the client. That is to clarify what is included and not included in the scope of the project. Whereas the purpose of dialogue phase is to discussall aspects of a project with several pre-qualified and shortlisted suppliers to find, develop or select an optimal solution toa project. The difference means a lot to both clients and suppliers regarding how much resources both contracting parties use in the procurement phase.

In CD, pre-qualification is mandatory before the dialogue phase since the dialogue phase is demanding. In BVP pre-qualification is an optional phase since the whole BVP phases can function as pre-qualification. That means it is possible to use BVP together with open or restricted procurement procedure. Whereas CD should be used together with restricted procedure.

In CD, the interaction between the client and suppliers is dialogue with a purpose of developing an optimal solution for the project. In BVP, the interaction is that the best value supplier clarifies the scope of the project and present a detailed schedule. In CD during the dialogue phase, the suppliers and a client work together to develop an optimal solution for a project. In BVP the supplier that is selectedfor the clarification phase is considered as the expert. Therefore, the supplier is best positioned to clarify the scope.

The next comparison factor is the number of suppliers (competitors) that develop a solution for the project. In CD, at least three suppliers should develop solutions to make sure enough competition, and losers are paid some amount against their cost. This is reasonable since the selection of a supplier is based on their solution to a specific project, and since the selection phase is not over yet. However, in BVP only one supplier should develop a project since the selection phase is already over.

The client control during the procurement is the other comparison factor. In CD, a client selectssuppliers based on their solution to the project. That means the client should know details of the suppliers’ solutions during the procurement. Whereas, in BVP a client selectssuppliers based on their past performance. The philosophy behind BVP is to decrease a client’s decision-making, management, and control of the expert supplier. All these factors lead to less knowledge and control during the procurement.

The next comparison factor is the resource (time and money) spent by client and suppliers during procurement. In CD, several suppliers develop solutions for a project during the dialogue phase. The client should have a parallelconfidential dialogue with each supplier that is involved in this phase. At the same time, the client should give equal information and treat all suppliers equally to avoid giving acompetitive advantage to anyone. All these factors make CD demanding for the client and for all suppliers that are involved in the dialogue phase. In BVP, only one supplier develops a solution for a project during the clarification phase. This makes the procurement phase less demanding for the client and for suppliers that are not selected.

The next comparison factor is the selection criteria. BothCD and BVP use MEAT as a selection method. However, how MEAT is interpreteddiffers in the two approaches. In CD, the MEAT criteria are technical and vary from project to project. Whereas, in BVP the MEAT criteria are non-technical and are the same for all kind of projects. In BVP, the same five criteria (past performance metrics, ability to identify risk, additional value they can provide, capability of their key personnel (interview), and price) should be used in all kinds of projects even if the weighting could vary based on the project's needs.

The length of the documents the suppliers should submit varies in the two approaches. In CD, since the selection of a supplier is based on their solution to a project, they describe their solutions in detail in the form ofcomprehensive documentation. In BVP the suppliers can submit maximum six pages (two pages performance matrix, two pages client's project risk and two pages value adding plan).

European public procurement directives specify five situations when CD may be usedin a project. At least one of the circumstances should be fulfilledin order to use the method. However, regarding BVP there are no public procurement laws and regulations that regulate or prohibit from using the approach in public sector. As long as it is implemented within the existing basicpublic procurement laws and regulations, it is possible to implement the approach in all kinds of projects.

In CD, the client gets access to several suppliers' idea at the same time, the during individualdialogue phase. The selection in this approach is based on the best idea to the project. Therefore, CD gives the client to select an optimal and innovative solution for the project. In BVP, the client gets access to only one supplier plan to the project during the clarification phase. The selection in this approach is based on best past performance. Only one supplier (the first best value supplier) present their plan to the project during the clarification phase. The client asks questions and comment during this phase if they think their major concerns are not addressed adequately by the plan. If the client manages to document the scope presented by the supplier does not address their major requirements, the client can disqualify the supplier from the clarification phase. Then, they can invite the second best value supplier to the clarification phase to hear their plan.

In sum, one may conclude that CD suits when clients want to choose a supplier based on their solution for a specific project. BVP suits when a client is looking for an expert that has done relevant things several times with high performance.

CONCLUSIONS

This paper addressed three research questions.

1) What are the similarity and differences between BVP and CD?

The major similarity of BVP and CD is that public owners can use them to implement ECI. Since ECI is one of the important elements of Lean, BVP and CD can be used to implement lean in public sector. The other similarity is that they allow interaction between a client and suppliers before contract signing. Regarding their differences, the major ones are: In CD, several suppliers develop solutions for a project whereas only one in BVP. Furthermore, BVP is standardized and effective method compared to CD during the procurement phase.

2) Which approach suits for what kind of project situations?

The selection premises in BVP are based on the suppliers'past performances and ability to understand the current project requirement. Therefore, BVP suits when a client looks for a supplier that has done relevant things several times with high performance. The selection premises in CD arebased on the suppliers' documentation of their solution to a specific project. Therefore, CD suits when a client is willing to invest more in the procurement phase to increase the product value by competing several suppliers based on their solutions to the project.

3) Which approach is better to implement lean in public sector?

Both BVP and CD can be used to implement lean in public sector. BVP reduce waste and CD increase value. BVP is an effective procedure during the procurement phase,and it reduces waste in this phase. CD is relatively an expensive procedure during the procurement phase. However, it facilitates selecting and implementing project solutions that suit the project and the client needs. Therefore, CD increase project value with minor increase of cost during the procurement phase.

This paper contributes to IGLC community by explaining and comparing two methods that can be used by public owners to implement lean during procurement. Future study may explore the potential that the two approaches can from each other achieve both increases in value and reduce waste simultaneously.

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BEST VALUE PROCUREMENT (BVP) IN A MEGA INFRASTRUCTURE PROJECT

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ABSTRACT

The Norwegian Government recently established a new public company called New Roads with the aim to create more value for money within road investment. To meet government expectations, New Roads has started to use Best Value Procurement (BVP) in mega infrastructure projects. BVP emphasizes contractor selection and risk management from the beginning of the project to add value and reduce waste in all project phases. The purpose of this research is to explore the experience of client and vendor personnel with the implementation of BVP so recommendations can be given for future application. In addition to a literature review, one of the first BVP projects was studied through 11 in-depth semi-structured interviews with key informants. Both client and vendor applauded the approach. Three significant shared positive experiences with the method were found: better risk management, realistic performance expectations, and efficient procurement procedure. BVP is one of several approaches that can be used to award contracts based on qualification rather than price. In addition, the method brings risk management to the beginning of the project.

KEYWORDS

Best Value Procurement (BVP), Public Procurement, Infrastructure projects, Lean, ECI

INTRODUCTION

Infrastructure projects are growing in scale and complexity. Productivity problems in the construction industry are a global challenge (Pekuri et al. 2014). The Norwegian government sees the need for more effectiveimplementation strategies to increase value creation in infrastructure projects. The government claims that more efficient implementation strategies in infrastructure projects allow projects to be completed faster with lower project costs (Norwegian Ministry of Transport and Communications 2013). Toimplement the strategy, the government established a new public company called New Roads, a streamlined client organization.

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In order to build infrastructure projects more efficiently, New Roads involves contractors earlier and uses design-build contracts (DB). As one of the methods to include contractors, the company uses Best Value Procurement (BVP). BVP is a procurement- and management approach that aims to minimize inefficiency and waste of resources by contractinga vendor with a highlevel of expertise(Kashiwagi 2016).BVP is one of severalapproachesthat can be used to implement early contractor involvement (ECI)to increase value in public projects(Wondimu et al. 2016). BVP is one of the ways to award contracts based on qualification rather than only price (Storteboom et al. 2017). Collaborative approaches such as integrated project delivery (IPD), project alliancing, and project partnering have a similar focus (Lahdenperä 2012).

BVP was developed at Arizona State University by Dean Kashiwagi in 1992. The method has been modified and changed several times (Kashiwagi 2016). Best Value Approach and Best Value Performance Information Procurement System (BV PIPS) are names that also are used to describe this method. This paper uses the term BVP for consistency.

There is limited documentation related to BVP in the Norwegian construction industry. This paper explores the experiences of participants in a Norwegian infrastructure project and addresses the following research questions:

- How was Best Value Procurement implemented?
- What were the participants' experiences withusing Best Value Procurement?
- How can Best Value Procurement be improved for future use?

The research is limited to a single case and explores the experiences of the client and the winning vendor with the method. At the time this analysis was carried out, the case project had just started the execution phase. As a result, there search did not explore the approach during the execution phase.

RESEARCH METHOD

The research was carried out based on literature review and a single case study. The case was studied using eleven in-depth semi-structured interviews and a document study. A case study is suitable for research questions seeking to explain how or why asocial phenomenon works(Yin 2014).Therefore, the case study is an appropriate method to address the research questions. The studied case is presented in Table 1.

Table 1: Case presentation

Project Name	Description	Year	Cost (USD)
E6 Arnkvern – Moelv	24km road expansion	2017 – 2020	$ 287,000 000

A total of 11 key persons, 4 from the client and 7 from the winning vendor, were interviewed from the case project. The interviews were conducted through in-depth semi-structured interviews based on an interview guide. The interview guide was developed based on the research questions. All interviews were carried out face to face at the interviewee's offices. The interview took on average 60 to 90 minutes. Since it was a semi-structured interview, the informants were able to diverge from the theme and focus on what they found interesting. While the interviews followed a prepared guide, they were flexible enough to create an interesting discussion on the subject (Bryman and Bell 2015). During the interviews, field notes were takenand the interviewswere recorded. To achieve quality and credibility in the research, a summary of the interview was sent to the informants for reviewing. After the interviews, documents provided by interviewees were studied to achieve data triangulation (Yin 2014).The data were hand-coded and analyzed hand-in-hand with the data collection, and findings were written up based on the description of Creswell (2013).

THEORETICAL FRAMEWORK

LEAN WITHIN BVP

Lean is a way to design a production system to minimize waste and maximize value (Koskela et al. 2002). It is important to include lean elements in the contract in order to assure lean implementation (Toolanen et al. 2005). Advocates of lean construction promote early contractor involvement (ECI) to further reduce waste. ECI can be used in the construction sector to reduce waste by creating organizational integration in the early phase of a project(Wondimu et al. 2016).There are several approaches to implement ECI in the public sector(Wondimu et al. 2016). One of them is BVP. Kashiwagi (2016) describes BVP as a new procurement, risk management and project management approach.

Clients usually resist transparency, especially when it comes to revealing their budget for a project (Ballard 2008).When BVP is used as a procurement approach, the client seeks a transparent contract where as much of the project risk as posible is identified in advance. Transparency is created by providing dominant information during communication (Kashiwagi 2016).BVP has four phases as illustrated in Figure 1.

Figure 1: Four phasesof BVP

Preparation Phase

Rijt et al. (2016) label this phase as the preparation phase where the main goal is to prepare the client organization for implementing the BVP method. Kashiwagi (2016) describes BVP as a difficult shift in paradigm that replaces the client's decision-making, management, direction and control with the utilization of contracted expertise. The client must choose a sponsor in the organization who understands the BVP philosophy completely and choose a core team that will be trained in this new method (Sullivan 2010).

The central concern for the client is "what" is going to be achievedas a result of finishing the project. "How" becomes the vendor's responsibility (Rijt et al. 2016).

The final step in the preparation phase is compiling a core document describing the project objective and scope, weighting the selection criteria, and establishing the project budget ceiling. When the budget ceiling is known by the vendors, they can adjust their scope accordingly or decline to participate (Kashiwagi 2016). There is a risk that an incorrect budget ceiling may be set. Therefore, when working with the ceiling budget, vendors should be consulted to determine the budget (Rijt et al. 2016). According to Kashiwagi (2016), pre-qualification is optional in BVP, but it could be beneficial in markets with high vendor capacity. Pre-qualification limits the use of resources for the client and non-qualified vendors (Lædre 2009).

The literature on the preparation phase mainly focuses on preparing the client organization for the new approach.

Selection Phase

During the selection phase in BVP, the client should seek out the vendor with the highest level of expertise for the lowest cost. The client uses the following five selection criteria to select an expert vendor: Level of Expertise (LE), Risk Assessment (RA), Value Added (VA), price, and interview. The weighting of criteria can vary, but Kashiwagi (2016) and Rijt et al. (2016) state that priceshould be the least important factorcompared to qualifications because of the budget ceiling. In the selection phase, the client uses four filters: project capability (LE, RA and VA), interview, prioritization and dominance check before entering the next phase: clarification (Kashiwagi 2016). These four filters are explained in detail below.

During filter 1, each vendor must differentiate itself based on their company's expertise via the project capability submittals consisting of three 2-page documents. In the LE document, vendors differentiate themselves with non-technical dominant information that describes why they have the capabilities to fulfill the client requirements supported by previous performance data. The RA document is where the vendor identifies significant risks of the project that they do not have control over (client's risk), along with a plan for risk mitigation. The VA document includes proposals or recommendations that can add significant value to the project. The project capability is anonymous and will be rated by the evaluation committee before filter 2, interviews (Kashiwagi 2016).

Filter 2 is the interview of key personnel. This interviewshould be as short as possible, 20 minutes is sufficient (Kashiwagi 2016). It is comparable to a job interview where selected individuals are interviewed separately. Through dominant information, they should be able to explain their plan for project success (Rijt et al. 2016).

In filter 3, the client uses the rating criteria to prioritize the vendors. This is the first time the price is revealed to the committee. Based on the committee rating, the highest scoring vendor is addressed as the prioritized Best Value vendor (Rijt et al. 2016).

During filter 4 is a dominance check. Before entering the clarification phase, a dominance check is performed on the best value vendor to ensure that they are the best value for the lowest cost (Kashiwagi 2016). The dominance check investigates the accuracy of the ratings from the selection committee, verifying the information given by the prioritized vendor and determines whether the cost rules (if any) are met.Snippert (2014) states that information verification of the vendor before the clarification phase has great importance.

The BVP approach has a specific selection phase with five selection criteria. However, the method gives very little room for selection based on technical solutions.

Clarification Phase

When the prioritized BV vendor entersthe clarification phase, the objective is to clarify their offer. At this point, it is essential that the BV vendor explainwhat is included in their project scope and what is out of scope. By creating transparency in the offer, client expectations are likely to be more realistic. For the first time in the process, the vendor has to show technical competence by revealing his plans. This includes providing a detailed project schedule and milestone schedule, along with a plan for performance measurements through key performance indicators (Kashiwagi 2016).

The vendor presents the risk management plan (RMP) during the clarification phase. The RMP includes a list of identified risks, aplan for mitigating risk and an action plan if a listed risk occurs. The client owns the risk and is financially responsible for it, while the expert has no risk (Kashiwagi 2016). RMP and the weekly risk report (WRR) are included in the vendor's contract. Together they create transparency and remove the need for management and control by the client (Kashiwagi 2016). If the client accepts the vendor’s offer, the contractis signed after the clarification phase.

Execution Phase

After awarding the best value vendor that was selected as the expert during the selection phase and confirmed it in the clarification phase, execution begins. The risk management plan (RMP) becomes a dynamic document during the execution phase through the weekly risk report (WRR). The RMP and the WRR are the primary tools in the execution phase. They allow the client to perform quality assurance on the vendor (Kashiwagi 2011; Rijt et al. 2016). The vendor sends an updated WRR to the client every week to create transparency in the project. If the client’s organization has several BVP projects in their portfolio, a collection of all the WRRs form a Director’s Report (DR).In the DR, the client can easily get an overview of total project performance (Rijt et al. 2016).

FINDINGS AND DISCUSSION

Figure 2 shows the structure of the findings and discussion section. It is structured using the three research questions and organized underthe four phases in BVP.

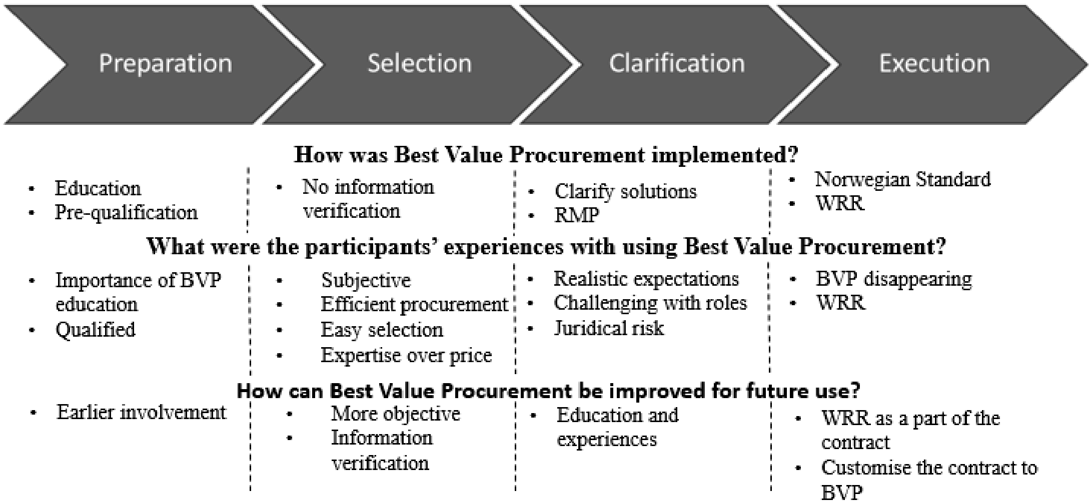

Figure 2: Findings as presented in the findings and discussion section

HOW BVP WAS IMPLEMENTED

In the **preparation phase,** the client used the Norwegian translation of the BVP book of Rijt et al. (2016) as a guideline. The client selected a sponsor and a core team according to the recommendations in this book. Not all of the participants in the client's core team were educated externally in the BVP approach. Unlike the client, the winning vendor trainedthe participants in the tender team externally. In addition, both the client and the vendor involved external BVP experts to support them during the preparation phase. By the end of the preparation phase, the client had developed a core document (request for proposal) with five project goals and a budget ceiling. Pre-qualification was also carried out, where by the client selected four vendors to participate in the tender competition.

During the **selection phase,** each of the four pre-qualified vendors submitted an envelope with two pages describing Level of Expertise (LE), two pages on Risk assessment (RA) and two pages on Value Added (VA). The client interviewed three persons from each vendor. These interviews were recorded and transcribed. The price was submitted in a second envelope to ensure a fair selection. Table 2 shows the client's weighting of the selection criteria.

Table 2: Selection criteria and weighting

Criteria:	**Level of expertise**	**Risk Assessment Plan**	**Value added**	**Price**	**Interview**
Weighting:	25%	15%	10%	25%	25%

After prioritizing the vendors, the client invited the highest scoring vendor to the **clarification phase** without dominance check or verification of the tendering information. During the clarification phase, there was a high level of interaction. The vendor presented the Risk Management Plan (RMP), Weekly Risk Report (WRR) and Key Performance Indicators (KPI) before clarifying planned technical solutions for the client. The contract was signed 6 months after the project was announced for tender. The contract was based on the Norwegian standard regulations for design and build contracts (NS 8407). Also, the client had a contract option for the maintenance of the road for the next 20 years. To sum up, the implementation of BVP was in line with the recommendations of Rijt et al. (2016).

At the time the data collection was completed, the project had been in the **execution phase** for only two and a half months. The interviewees' initial experience from the execution was that they had kept the WRR up to date and so far had managed to keep the BVP mindset.

EXPERIENCES WITH BVP

During the **preparation phase**, both client and vendor mentioned the importance of educating their teams in BVP since the approach demands a different mentality than traditionalmethods. A respondent from the client suggested that one of the reasons for choosing BVP in complex projects is that it steers the client to obtain a reliable and trustworthy vendor.

In BVP, qualifications are given more weight than price. This is appropriate when the client wants a qualified vendor. The client does not have to be concerned about the technical solutions during the preparation phasesince these will be explained during the clarification phase.

Both client and vendor expressed that they experienced the **selection phase** as transparent, so they did not worry about legal issues. All four interviewees from the client were part of the evaluation committee in the selection phase, and they all agreed that the prioritized vendor stood out from the competitors during the selection phase. Selection was based on the vendor's past preformance.The interview process was especially useful for the evaluation committee since it revealed which of the vendors best understood what the client needed.

Two of the client interviewees emphasized that the 6pagesin the first tender envelope made the selection phase more efficient. It forced the vendors to present only the most essential information. At the same time, the vendor was positive about being evaluated on expertise rather than lowest price. Still, they had to put a great deal of work into estimating the cost and providing the 6 tender pages.

The vendors' responses for how to meet the project goals described in the tender document were used for evaluation. It appeared that the project goals could be interpreted in several ways. As a result, the vendors' recommendations on how to meet these goals took very different directions, so it was difficult for the client to directly compare the recommendations. Because of this, the evaluation committee had to do subjective evaluations of these responses.

According to most of the respondents, the **clarification phase** was important for developing a good relationship between the two contracting parties. During this phase, the participants from the vendor and client are allowed to socialize. The client gets to know the vendor's personnel, theirtechnical solutions, and their work ethic before signing the contract. The risk management plan (RMP) was the primary focus throughout this phase, and the weekly risk reporting (WRR) began. As a result, both the client and the vendor found this phase useful.

Interviewees from both the client and vendor stated that the scope of the tender was clearly specified, and the client's experience was that the vendor led this phase. The parties experienced openness between them. For example, the vendor was transparent regarding quality differences in the road pavement. If they weregoing to maintain the road for the next 20 years, the quality would need to be high. If not, the quality might be low to save cost. This transparency enabled the client to adjust expectations before contract signing.

The challenging part of the clarification phase was to define the new roles for both the client and vendor personnel. In BVP, the vendor is the expert. Thus, the client should not direct, manage and control the vendor. This was challenging primarilyfor the client personnel since most of them come from traditional roles in the construction sector.

If the tender from the vendor doesn't meet the client needs, the vendor could be disqualified. So far, no vendors have been disqualifiedfor any Norwegian BVP projects. Therefore, the uncertainty is high regarding what the outcome of such a short coming would be. It is possible to identify BVP as an efficient procurement procedure for both the client and vendors since it is less resource-demanding than traditional procurement procedures, particularly because only one vendor goes on to the clarification phase and develops the project.

During this research, the case study project had just started the **execution phase**. It is therefore difficult to report the experiences with BVP in this phase. However, the vendor interviewees indicated that there is a tendency for the BVP philosophy to dissipate, even though they have maintained the WRR and tried to keep the BVP mindset.

This contract is based on the Norwegian standard regulations for design and build contracts (NS 8407), and BVP is not part of the contract.An example that vendor raised was about a client risk that they had been reporting for several weeks in the WRR along with a risk-reducing measure. Before the vendor was able to initiate this risk-reducing measure, the risk occurred. As a result, the risk affected project progress. When the vendor presented a claim for compensation since the risk had been reported in the WRR, the client's lawyer responded that the riskwas not reported in line with the contract (NS 8407). Therefore, the client was not fully responsible for the risk. However, this dispute was quickly resolved when the project manager of the vendor and the project manager of the client decided to meet and discuss the issue. From that point on, the vendor has carefully followed the contract to minimize the risk of a new dispute.

RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

Regarding the **preparation phase**, the interviewees from both the client and the vendor agreed that there is potential for value creation if the vendor is involved earlier than was the case here. More specifically, the vendor should be involvedbefore the zoning plan is decided. The zoning plan prevented the vendor from choosing an optimal road alignment and construction method. The contract allows the contractor to try to change the zoning plan, but that would require an uncertain political process in the local municipality. Therefore, the recommendation is to involve the vendor before the zoning plan has been finalized.

Based on the document study and observations, the **selection phase** seems to be more subjectively oriented than what is described in the literature. This is unfortunate, as it might lead to incorrect vendor selection. In the two pages describing Level of Expertise, the vendors should explain why they are capable of achieving the project goals in the best possible way. An example of a goal in the case project is “minimize disadvantages for all road traffic groups.” This phrasing leads to an interpretation of “disadvantages” by both the evaluation committee and the vendors’ tendering teams. When the written part of the selection phase is subjective, and the interviews will be subjective, then the whole selection becomes vulnerable. The authors recommend making this stage more objective by formulating the project goals in a clearlyobjective mannerand by stating in the tendering documents that the vendors can only submit objective claims.

The selection phase isprimarilybased on claims from the vendor. The vendor should support their claims by referring to previous performance. To ensure transparency in the process and to prevent vendors from submitting exaggerated past performance claims, it is crucial that the client verifies the information given by the vendor in the dominance check before entering the clarification phase.

The challenges in the **clarification phase** are related to the mentality of the vendor and client personnel. None of the interviewees complained about their roles. They accepted that the vendor is an expert and the client is a non-expert, but they said it was difficult to stay in those roles. More education and experience with the method will help the participants to understand and define their role better in the future. Since the method is new in Norway, it is important to transfer the experience between projects.

The primary tool in the **execution phase** is the WRR. Our findings indicate that the vendor changed their WRR practice for two reasons. First, WRR was not part of the contract. Second, the standard NS 8407 contract was not customized to fit another reporting system. Both the client and the vendor agreed that starting the risk management in the early phase had a positive effect. If the client wants to use the risk management plan from BVP in future projects, then the WRR should be part of the contract. Furthermore, the standard contract should be customized so that it suits the WRR reporting system.

CONCLUSION

Overall, the client and the vendor in the investigated project had a positive experience with BVP. As a result, they are enthusiastic for future use. However, this experience identified three major advantages of BVP over traditional procurement processes:

- Better risk management
- Realistic expectations of client’s and vendor’s performance
- Efficient procurement, with less waste.

The risk management approach for the case project was received with satisfaction from both parties. Vendor personnel expressed their expectation that they will use the same risk management with or without BVP in future projects. Realistic expectations in the clarification phase before contract signing create transparency and minimize the risk of conflicts. Further more, BVP is an efficient procurement procedure for both the client and vendors since it is less resource demanding than traditional procurement procedures.

Projects that are open for more than one solution benefit from ECI when using the vendor`s expertise in the early phase. During ECI implementation, awarding the vendor by qualifications rather than only price is beneficial. BVP is one of several approaches that can be used to award based on qualification rather than price. In addition, the approach brings risk management to the beginning of the project.

In the future, it is recommended that the experiences of the vendors that did not succeed in the selection phase be investigated. Future studies should also consider the effect of this procurement approach in the project execution phase. Furthermore, more case studies on future BVP should be carried put to compare the findings from this study.

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TRANSFORMATION FROM DESIGN-BID-BUILD TO DESIGN-BUILD CONTRACTS IN ROAD CONSTRUCTION

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ABSTRACT

This article was triggered by a public client opting to change contracting strategy on a pre-designed 4-lane motorway project from design-bid-build to design-build contract. The goal for the client is to build roads cheaper and faster with the greatest possible economic benefits for society.

In the article, we ask: Which changes associated with the transition from a design-bid-build to a design-build contract can be identified in the contractual relationship between the public developer, contractor and subcontractors? The article focuses on changes in relation to constructability, construction time and costs, and discusses the issues of quality and customer value.

The study is theoretically related to the principal-agent theory and transaction cost theory, where the threat of opportunistic behaviour is central. This is also seen through the lens of the Lean Construction triangle, which focuses on the need for harmonisation between commercial element in the contract, organisation and production.

We analyse the case in relation to three propositions:

- Design-build offers incentives that result in better constructability than design-bid-build contracts.
- Design-build results in lower production costs and faster construction than design-bid-build contracts.
- Quality and customer value come under pressure in design-build contracts.

The first proposition seems to be confirmed by the empirical analysis. Production cost is, however, not the same as the price for the client. It is more uncertainty related to the third proposition. An important finding is that the developer's change in strategy seems to

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result in a radical change in working conditions for the consulting design and engineering companies, as well as to a great degree for the head contractor. A strong relationship between the contractor and consulting engineers is especially important to ensure success in terms of execution, and we find indications that alliances have been formed between the parties.

KEYWORDS

Contract form, constructability, cost, progress, customer value.

INTRODUCTION

In this article, we focus on the consequences of changing a contract model from design-bid-build to design-build on construction efficiency. Several quantitative studies have been done on the variations between design-bid-build and design-build, and several of the findings indicate that design-build produces more rapid construction time (Whittington 2012, Park and Kwak, 2017). The choice between design-bid-build and design-build is very much a trade-off between the construction time versus the uncertainty surrounding the cost aspect in each specific project.

The case for this article has been taken from road construction in Norway, where all public road construction has previously – and quite traditionally - been governed by the Norwegian Public Roads Administration (SVV). Next, Nye Veier (NV) (translation: "New Roads") was created as a state-owned limited company established by the Norwegian government in 2016, having to enable more and faster construction of public roads with the available financial resources.

The article is only investigating the E18 Arendal – Tvedestrand road project, which is currently under construction[5]. The case comprises of two formerly connected stretches of road engineered by SVV as design-bid-build contracts, which are now combined as one design-build contract. The stretch of road in question is largely located on new terrain and encompasses a 23 km 4-lane motorway with several crossings on the route, including 27 bridges and more than 10 crossing points for wildlife. The contractual budget is approximately NOK 4 billion incl. VAT.

Based on contractual and structural change in responsibility and distribution of risk between central project participants, the overarching issue addressed in this article is: **Which changes can be identified in the transition from a fully engineered design-bid-build contract to a design-build contract?** We focus on changes in relation to constructability, construction time and costs in addition to discussing the issues of quality and customer value.

In the next sections, we first present the methodological choices made, thereafter the theoretical basis for analysing behavioural and contractual issues in business relationships. Subsequently, we propose a theoretical framework as the point of departure for our propositions. This is followed by an empirical analysis and conclusions made based on the propositions.

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METHOD

In this paper we are studying how the contract strategy has been switched from design-bid-build to design-build in one project. The unit of analysis is the change, as this type of alternation signifies that one set of incentives has been replaced by another set of incentives. Thus, our aim is to highlight what this means for the project's execution regarding the organization, the feasibility of construction, time, cost and quality. Since what we are dealing with here is a single project, the most obvious approach to choose is one form or another of the case study method. In this instance we first look to Sayer (1992) concerning theoretically informed case studies, then supplement this with Yin (2003), who distinguishes between analytical and statistical generalization in case studies. The term *analytical generalization* means that we conduct a test of our theory through engaging in discussion. The case study here focuses on questions associated with in-depth studies and questions in the form of 'why' and 'how'. We are in other words seeking explanations for our observations.

Next, we apply propositions to bridge theory and data. Each of these propositions is discussed in relation to our findings, where we see if the findings either disprove or confirm the propositions. In conclusion we return to the theory and evaluate whether or not it is fruitful for the study (abduction). The qualitative data are collected through conducting nine interviews, of which three are with the client, two with the main contractor (design management and production), two with project consultants (design management, BIM), one with the electro subcontractor and two with the construction subcontractor. Eldholm and Pedersen's master's thesis (2017) has supplemented this data collection.

THEORETICAL BASIS FOR ANALYSING BEHAVIOUR IN CONTRACTUAL RELATIONSHIPS

The major issue in the principal-agent theory is the contractual relationship between two or more parties, where one party, the agent, acts on behalf of another party, the principal (Jensen & Meckling, 1976). Different contractual mechanisms and incentives are used to govern the agent's behaviour and the possibility for opportunism (Eisenhardt, 1989). Misalignment of incentives and opportunistic behaviour are central issues in business relationships. Creating contracts with incentives that balance both risk and reward for both parties, may be a way to control the agent's behaviour in an appropriate direction for the principal. Contracts could include multiple dimensions of incentives, where the most effective balance, are of great importance in contract design (Kerkhove & Vanhoucke, 2015). However, a contract may only include the conditions that the principal is able to predict in advance, which in turn gives rise to an incomplete contract, and the agent room to act opportunistically after the contract is signed (Rindfleisch & Heide, 1997). The risk of opportunism is, to a large extent, the driving force behind contractual control mechanisms in business relationships (Williamson, 1985), and over decades vast amount of research has put these premises to the test.

In theory and practice, however, the mechanisms of governance and incentives to regulate inter-organizational behaviour do not find universal support. Several scholars have criticised the theoretical grounds for opportunistic behaviour in business relationships. In his vast examination of contracts, Macneil (1977) distinguishes between transactional and relational contracts, where the latter puts more emphasis on trust rather than monitoring mechanisms. Following this, Granovetter (1985) argues that buyers and sellers in the market do not make their decisions based on price alone; rather, their experiences over time lead to relationships founded on trust. Moreover, Müller (2009) claims it is restricting to portray contractual relationships as pure transactions, and people as primarily opportunistic. Likewise, other scholars are emphasising that trust is not only a cost-cutting device, but channels for knowledge creation and a basis for interactive learning which trigger technological development and economic growth (e.g. Lundvall, 1992; Kalsaas, 2011, 2013).

We will analyse the research question through the lenses of *governance mechanism sand incentives* between the client and contractor in a large construction project, coupled with the lean triangle perspective for efficient construction.

THEORETICAL ANALYSIS AND PROPOSITIONS

The Lean Construction triangle (Ballard, 2012; Howell, 2011)is an approach to understanding framework conditions for efficient construction in terms of time, cost and quality, as well as customer value. The idea is that there should be a harmonisation between the commercial, organizational and production perspectives. In this case, the commercial side of the model refers specifically to NV's contracting strategy and agreement form. The essence of an agreement form can be the distribution of risk and responsibilities between the parties, clarification of which responsibilities belong to the developer and the contractor respectively, which responsibilities are shared, and which deliverables must form the outcome. Klakegg (2017) divides the agreement form into contract form, risk distribution, conflict resolution mechanisms and settlement form. Design-bid-build and design-build contracts are thus examples of contract forms that specifically define the other aspects of the agreement form, both design-bid-build and design-build contracts can be said primarily to be transactional (see e.g. MacNeil 1977).

The organisational side of the LC-triangle covers how actors in the value chain cooperate, including the developer and users, the main contractor, architects and engineers in design, subcontractors and suppliers, as well as external agents and stakeholder groups. How the actors collaborate has a significant influence on the flow, efficiency and value creation of production (Matthews & Howell, 2005). Collaboration can be characterised by limited trust and opportunistic behaviour/sub optimisation on the one hand, while on the other enabled by a large degree of trust and goodwill to find solutions to unforeseen difficulties that arise. However, the threat of 'moral hazard' and sub optimisation between the parties can still occur along the way.

In line with the premises of principal agent theory, contractual incentives may provide both opportunities and delimitations to promote efficiency in production, including design. From this perspective we can consider incentives as an underlying force of direction (structure), but contextual circumstances may prevent impact of incentives from being observed in individual projects.If we examine many constructions projects, however, we can expect the structures of the agreement forms/contracts to come through.

Based on the arguments above, we draw the following propositions:

- Proposition 1: Design-build offers incentives that result in better constructability than design-bid-build contracts.
- Proposition 2: Design-build results in lower production costs and faster construction than design-bid-build contracts.
- Proposition 3: Quality and customer value come under pressure in design-build contracts.

From the first proposition we argue that when the design-build contractor is responsible for both design and construction, they have incentives to adapt the design to their expertise and production equipment. In the case of design-bid-build contracts, the client is responsible for the detailed design, and there can be a time gap between the design and construction phases.

As the various entrepreneurs are different with respect to equipment and working methods it is impossible to design solutions that are equally constructible for everyone. In traditional design bid build contracts, clients aim to design road projects that are just sufficient for tendering a competition to build. Once an entrepreneur has been selected, designers are hired to complete follow-up engineering as well as work out detailed design. Without proper incentives, advisers may want to do the least amount of work possible before the tender competition, as they would at this point be working in accordance with a fixed rate contract, while follow-up work is reimbursed in accordance with hourly rates. In this sense advisers have incentives during the construction phase that coincide with those of the entrepreneur: The entrepreneur can demand to be paid extra through presenting change requests due to poorly executed drawings or those lacking key elements, while advisers earn extra by the same mechanism. Thus, the incentive scheme that follows a design bid build contract may hinder the execution of a project without hidden agendas. We can further assume a completely different dynamic between the contractor and design consultancy firm when the design phase is controlled and paid for by the contractor who will then be responsible for construction.

In proposition 2 we assume that costs and time is closely connected to the issue of constructability. Good constructability can be expected to yield lower costs and quicker production for the contractor, if they are otherwise operationally efficient and external risks are manageable. These savings in time and cost for the contractor may be shared with the developer and yield lower total costs of the project. However, in traditional design-build contracts, the supplier also factors in risk at a premium rate (cost) for the client. The literature does not confirm that design-build contracts become cheaper for the client, see for example Park and Kwak (2017). On the other hand, the literature confirms that design-build is favourable for rapid completion (op. cit.).

In addition to the constructability argument, the contractor is responsible in design-build for the lead time from start-up to handover and has the opportunity to optimise design and production processes to ensure rapid progress. In design-build contracts, design and construction take place simultaneously, rather than sequentially as in design-bid-build contracts. This enables time crashing and may reduce the total completion time. In addition, we can expect less detailed design drawings if there is close interaction between the design and construction teams. Relatively long stretches of road in the same project provide the opportunity for many points of attack in the trace and utilisation of economies of scale for the contractor. Less rig cost adds to the time and cost benefits. For the contractor, this represents lowering the risks of fixed price contracts and progress delays.

In design-bid-build contracts, when the executing contractor is not responsible for the design documentation, there are good *'opportunities'* for the contractor to find defects in the specified documentation, which may open for moral hazard, confer the previous theory. When price is highly emphasised for awarding the contract relative to other performance measures, we can particularly expect tactical pricing in order to win the contract, strong incentives for variation orders, and pressure for shirking on quality. Under these circumstances the conditions for opportunistic behaviour are thriving. The general notion of conflict and low productivity (e.g. Klakegg, 2017) in the construction industry underlines this.

From the above line of arguments, it follows that the quality and customer value can be under pressure in design-build contracts with a fixed price. Design-bid-build contractors may be more favourable for ensuring customer value as the developer retains control over the design phase. But to capitalize on this contractual arrangement, the developer needs major monitoring and control procedures to follow up the implementation phase, while at the same time ensuring disincentives towards poorer constructability and higher total costs. A contracting process that ensures early involvement of contractors will work towards strengthening the relationship (Swärd, 2016) and increasing constructability, while reducing costs. This is because contractor's engineering knowledge can be utilized in the design, procurement and preparation of work documentation.

CONSTRUCTABILITY, COSTS, BUILD TIME AND QUALITY/CUSTOMER VALUE

PROPOSITION 1

The road works project was nearly done being designed as two design-bid-build enterprises when NV took over the project from the SVV. The respondents refer to several attempts to change the original project plans in order to not only make it constructible but also to eliminate unnecessary costs. For example, there was a level crossing where the line was raised by 14 meters, where the entrepreneur could reduce their soil-rock mass removal by 700,000 cubic meters, out of a total of 7 million cubic meters. In another example, the attempt to transform a tunnel into an intersection, which would have produced both lower construction costs as well as operating and maintenance costs, had to be abandoned. We are talking about changes that require zoning changes, where the municipality in which the initiative has started is the regulating authority. The head of the client's project organisation states that "*we didn't have a chance politically speaking, as so much negativity had been created even before the project got started*".

The project was met with such a great deal of resistance to the change involving creating an intersection instead of the tunnel that the entire initiative was stopped. There was resistance from the zoning and state sector authorities associated with outdoor recreation and wildlife, as well as several private interest groups. There was no time for long regulatory processes. The individual case that probably created the greatest amount of negativity was that the main contractor had not included street lights in their original bid. Omitting street lights created a great deal of negative coverage in both the local and national media and was in the end not approved by the VD. Several people started to think that NV was going to build quickly, cheaply and badly, according to the head of the client's project organisation. Further, changes had been made to the wildlife underpass tunnels, something that is referred to as a "huge challenge" since there are no national guidelines pertaining to this matter. Additionally, several other minor changes were made which deviated from the original project plan. One informant from the design-build contractor states that 'we are good at some things, we choose solutions that are great for us and that work in relation to our production apparatus.' By example, reference was made to the formwork systems the company has at its disposal, and that such systems are not available off the shelf. Consequently, bridges are designed that are suited to these formwork systems. The informant also argued that 'when SVV designed the facility as a design-bid-build contract, they designed many different types of bridges and portals without any real purpose.' The design manager works hard to standardise to enable the reuse of formwork systems. He strives for a system with few variables to avoid having to use new materials and equipment and added that 'we can't afford it'.

The picture painted by the design-build contractor is confirmed by informants from the design side. However, in hindsight the design manager believes that 'we were too open and creative in relation to the opportunities at the beginning. We started off by taking on too many battles/changes.' Examples of this included increased fillings and shorter bridges. Bridges are highly costly.

The data gathered demonstrates that there is a close cooperation in the project between the main contractor and the designers. The design work was carried out by a major Norwegian consultancy firm, and they have all disciplines under one roof, also electrical specialists. The design-build contractor's design manager and two design assistants are based in the same location as the designers, and almost daily contact is reported for the discussion of solutions and priorities.

Details are moreover provided about a radically different working situation for the designers in the case of a design-build contractor, and in terms of simultaneous design and construction. One statement was that "*we have been controlled by SVV for 40-50 years*". In the past, "*we would deliver a main deliverable in transportation projects once every 6 months*," but that "*now we supply work documentation up to 2-3 times per day at times.*" The findings also show that there are constant changes that need to be made to priorities based on the needs that arise on site, where geology and geotechnics are the major drivers of uncertainty for the project. The design-build contractor's design manager refers to coordination between the design and production sides, describing it as very important as "*production can suddenly say that we need to go into more detail on an area that we had envisaged.*" This is something that has led to a lot of frustration amongst designers who are suddenly informed that something they have worked hard on for a long period of time must be put on hold. Changes like this can occur because a job becomes more complex than expected and must be prioritised. One example was that the design-build contractor had underestimated the blasting process on one side of a bridge and had to change the direction of the work in order to buy time. According to the contractor's informant, willingness to change is very important in this approach to construction, cf. the following concerning the necessity for changes to attitude.

One change that results from this connection between design and construction is that the designers must deliver work documentation that is incomplete, which is something neither they nor the contractor is used to. This triggers a risk for the work documentation and 3D model being used for something it is not ready for. A system is used to manage degrees of maturity - the so-called model maturity index (MMI), which corresponds to Level of Development (LOD) system. The model can provide, for example, the work documentation for blasting/tracing the road, but not the basis for other road building tasks. The contractor describes this method as a 'top-down-method', which means that first they determine the blasting profile. In design-bid-build engineering, they would first strengthen the road using various types of layers before the blasting profile was determined. This change is an example of adapting to the head contractor's needs. Another point that emerges is that the contractor often does not require detailed designs for everything. The respondent from the contractor emphasises, in this regard, that for the road 'we need data to trace the road' while 'for construction of the road we have our own standardised solutions'.

Reference is made to the framework for design-build contracts which requires changes in attitude and that 'some still remain mostly occupied with finding design faults.' Engaging in self-criticism, the informant from the consultant states that they are often asked to recommend a solution from several options, and that "*on the consultancy side we find it easy to recommend the best solution, while the contractor is interested in something that is cheap and good enough*". The design-build contractor's design manager explains that communication with the designers has developed from being problematic to being "*much better*". Previously, we ended up with "*far too many questions from the experts*", and "*it may have been that our messages were not clear enough*". One challenge from the perspective of the design-build contractor is that "*the consultants work with their own tunnel vision and may not be aware of a number of other related issues*". Instead of preparing a complete solution that transpires not to be constructible, and having to start again, "*we try to correct the course while in progress prior to getting too far*". The informant adds that "*this is something we have to train at*". It is pointed out that to achieve this, it is very important to frequently involve the production apparatus. They provide input "*sometimes based solely on gut feeling, but it's often accurate*".

In comparison to design-bid-build contracts for roads, one design manager on the consultancy side claims on the basis of their own experiences that the SVV wanted good solutions, which are expensive, and that he - in his job –"*works to get the most work possible for my designers*". Furthermore, that "*this is completely the opposite to what happens in a design-build contract*". The informant makes the point that "*selling hours in design-build contracts is not the ruling factor,*" as "*time is too scarce*".

PROPOSITION 2

To manage the construction period in just 2 years and 9 months, "*you need a little bit of crazy*", according to the design-build contractor's design manager. He emphasised the need for "*very good progress monitoring*" and the ability to rapidly implement corrective measures in the event of deviations on critical tasks. It emerges from the interview with the design manager that excavation commenced one months after conclusion of the contract. A reflection from the same person is that "*it was too early - in the future we will need to have the plans ready before we begin to engineer*". The consultant company began design work on behalf of the risk owned by the contractor during the tendering stage. The head of the consultants emphasises that it is "*technically straightforward to build roads on virgin territory, but since the construction project has to take place in a short window of time, it becomes complex*". He adds that this is a "*way of clarifying solutions that we are not used to*". The head contractor attacked the complexity in relation to the scope and time by dividing the projects into smaller control areas.

The subcontractor for constructions (bridges) has received the underlying design and drawings too late and responded by simultaneously working on more bridges than planned in order to follow the project's schedule. At the time of the interview, 10 out of 26 bridges were being worked on. The informant pointed out the increased complexity involved with running 10 building sites at the same time. The informant had a feeling that they were only given priority within design after the road line had been taken care of.

A respondent from the head contractor places an emphasis on the importance of capturing *'everything'* in the contract, which requires experience. This is due to the fact that the price of the same job, based on his experience, increases during the process, largely on the basis of follow on costs for other disciplines, but the contractors "*are also hucksters"*. For example, it was claimed that "*squeezing an activity into a very brief period of time, with lots of people and equipment, sees resource utilisation fall from the 90-100% mark to 60%. There might be a lot happening, but it isn't efficient*". The contractor's design manager says that "*we are happy to be tough when it comes to purchasing - it's survival tactics. My tactic has been to avoid going for the lowest price, but to aim for those in the middle layer*". In the tendering phase, the head contractor allied itself with a regional concrete works contractor and an electrical contractor with its own design responsibility, in addition to the consultancy firm.

We have mentioned street lights. These were introduced in the work plan after the contract had been signed, and according to a respondent from the client, "*so we ended up paying more for street lights than what we would've done in a normal competitive situation*", and he made the point that "*the longer you wait, the most it costs*". The respondent explained this phenomenon as being a question of supply and demand, and that it is a "*relatively common occurrence in construction projects that additional work is something that entrepreneurs make a lot of money at*". The client respondents pointed out that they felt it was important that contractors earned money, and that anything else would produce a poorer profession over time.

An informant from the head contractor who is closely connected with production claimed that it is difficult to say if design-bid is cheaper or more expensive than design-bid-build, "*as the costs start running no matter what*". His perspective was to utilise 130 large, expensive machines in two shifts: "*We're very much on the ball, we don't have time to sit around, we have to produce*". Machinery costs is a central cost driver for the head contractor. Additionally, the respondent thinks that design-bid-build was easier to work with, because "*then the design work is finished*" and "*we can go directly to the client to find solutions to any problems that arise*".

PROPOSITION 3

Respondents from the contractor feel confident that they are in control of the quality and refer to the fact that "*trust in the project is very high*", and that the head contractor "*plays with very open cards*". A development has taken place in the project in the sense that the client had thought that they were not to be out on the building site hardly at all in order to have "*full control over what happens when and where*". They are referring in this regard to the fact that "*there is, in spite of everything else, a huge investment of 4 billion*" (NOK). The client's staff inspects both the entrepreneur's quality systems and performs direct daily checks, and an informant claims that their experience is that it is not enough to inspect indirectly, that despite everything there are 800 men employed by the head contractor who are working on the construction site, and who might have different approaches to assuring quality. The head of the client's project organisation states that "*I am very happy to have my inspectors*".

The execution of government road works projects in Norway is strictly regulated through among other things a system of handbooks that describe this execution in detail. A distinction is made between 'must' and 'should' requirements. Deviations from 'must requirements' are to be approved by the VD, while the regional SVV-organisations processes 'should requirements'. This implies that even if it is a design-build contract emphasizing functional description, it is also a system of quality assurance requirements that practitioners must base their projects on.

The data shows that experiences with the handbooks vary slightly. According to the head contractor's design manager, they have "*spent thousands of hours on understanding the handbooks, which are often inconsistent*". Furthermore, the informant states that "*if we are to aim to build cheaper and better, something has to be done about the regulations*".

Another aspect connected to progress and costs is, according to the informant from the head contractor, that NV requires a reporting regime in the project that is equivalent to what would be required on a design-bid-build contract.

CONCLUSION

The quality data show that great efforts have been made in the project through increasing construct ability and simplifying the project in a way that we can easily relate to the transfer to design-build. One obstacle to being able to move further in this direction is existing zoning plans and external forces working against changes. Moreover, we see from the data that road construction using a design-build contract provides a radically different working methodology in terms of implementation than is found in design-bid-build contracts. Thus far, the data shows that the close relationship between the design-build contractor and the designers appears to be very much central to success. All in all, proposition number 1 concerning constructability appear to be verified.

With respect to the aspect regarding rapid progress in proposition 2, we have found indications that most likely concur, including improved constructability from proposition 1, working in several parallel places, simultaneous engineering and construction conducted by the entrepreneur, utilisation of large scale advantages with regard to rigs and operations. There are moreover indications of good collaboration between the client organisation and head contractor, who are pulling in the same direction.

The indications regarding progress may also be connected with reduced costs in design and production. The design work must take place more quickly and seems to have with a less detailed design for certain work tasks. This indicates relatively less resources for design, and along with the other factors, design-build seems to produce lower production costs, given that the head contractor manages to optimise his demanding logistics with good flow and resource utilisation. Design-build also has a regime of change requests that can contribute to pulling costs upward for the client. On top of this, there is figuring out the risk costs. Altogether the data indicate lower production cost, but that is not equal to lower price for the client. A more secure analysis would require including more quantitative data.

In relation to proposition number 3 concerning the fact that design-build contracts put pressure on quality and customer value, we have less data to verify, but it has been confirmed to some extent. However, this primarily stems from theoretical grounds that strong focus on progress and costs may lead to reductions in quality. The data shows that there is a focus on construction to a good enough standard, rather than the best possible. It appears that the VD's handbooks are significant for ensuring a minimum standard, even if they can simultaneously be a source of irritation for practitioners.

The theory concerning incentives is confirmed in relation to expected changes in behaviour due to the transition from design-bid-build contracts to design-build contracts (proposition 1), which means we can assert that this is an appropriate theory for the analysis of such a phenomenon.

Further research on how contractual strategies may change incentives for collaboration and efficiency in construction is planned to include additional investigation of multiple partners in the construction value chain, through both quantitative and qualitative research approach.

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PROCESS-BASED COST MODELING FRAMEWORK AND CASE STUDY

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ABSTRACT

This paper provides a theoretical basis with reasons why traditional cost modeling methods are insufficient to support project delivery whereby product and process design are integrated and rapid cost feedback facilitates trade off analysis between multiple design alternatives. Traditional cost models do not sufficiently reflect cost changes due to changes in process design. This prompted our research into an alternative cost modeling method able to: (1) specify cost changes due to changes in product design, (2) specify cost changes due to changes in process design, and (3) provide rapid cost feedback to assist decision making during design/planning phases. This led to developing the Process-based Cost Modeling (PBCM) framework that is presented in this paper. The PBCM framework includes three phases: (1) collecting process and cost data, (2) mapping this data to Building Information Model (BIM) objects, and (3) providing cost feedback during design. The key contribution of this framework for modeling cost is that it takes into account product and process design features and can thus serve integrated project delivery teams while they explore production system design alternatives.

KEYWORDS

Process-based Cost Modeling, Cost Estimating, Target Value Design, Lean construction

INTRODUCTION

In current construction accounting practice, the cost of an installed component is the cost of materials plus the cost of all resources used to install that component (Means 2015). Traditional cost models such as regression models (Bledsoe 1992), parametric models (Skitmore and Marston 1999), and elemental estimating methods (Soutos and Lowe 2011) rely on historical data to model the cost of new designs. Historical cost databases provide some kind of average productivity and cost measured based on completed projects. The problem is that those projects may not have used methods to eliminate process waste or

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improve productivity, and their context may differ significantly. Consequently, using these productivity- and cost data, possibly coupled with outdated practices, tends to increase estimated durations, drive up estimated resource needs, and thus inflate estimated cost.

Researchers have criticized traditional cost models for their focus on resources rather than on processes. Wilson (1982) criticized these models' reliance on historical data to produce estimates of building or component cost without explicit consideration of their inherent variability in product design and installation processes. Bowen et al. (1987) argued that traditional cost models do not explain the systems they represent and suggested that realistic cost models must simulate the construction process and take into account the cost implications of the process used to construct buildings.

Li et al. (2003) and Bargstädt and Blickling (2004) modeled human resource activities to determine process durations and associated process costs during simulation of production processes. They estimate labor costs while playing the production process as a computer game by measuring resource consumption in the simulated processes. While this may yield more accurate estimates than those based on historic data, they require detailed process data that may be available only late in the construction documents phase. Moreover, it may be very time consuming and expensive to collect data and simulate construction processes. To facilitate estimators' judgment on cost implications of product customization, Staub-French and Fischer (2002) and Staub-French et al. (2003) proposed an activity-based cost model to help estimators customize a project's activities, resources, and resource productivity rates based on their preferences and the particular features in a given product model. This helps estimators more rationally adjust project activities and resource productivity rates but it does show estimators what the cost implications are of changes in process, such as transportation and site logistics, as the result of changes in product design.

CURRENT PRACTICE OF COST MODELING TO INFORM TARGET VALUE DESIGN (TVD)

Integrated Product-Process Design—as pursued on projects that use TVD—is a management practice that drives design to deliver customer value within project constraints (Ballard 2009). The TVD environment offers opportunities to project team members engaged in the design phase including: (1) Collocation and collaboration, (2) Set-Based Design exploring multiple design alternatives, (3) Frequent sharing of incomplete information, (4) Simultaneous design of product and process, (5) 3D Design/Modeling and digital prototyping, and (6) Trade contractor and supplier participating in design.

The TVD process results in identifying design alternatives, not only with different product cost and process cost, but also with different product features. As pointed out, traditional cost modeling methods are too granular to allow for trade-off analysis between alternatives of product- and process design especially as needed to support TVD. TVD teams need a cost modeling method able to: (1) quantify cost changes due to changes in product design (i.e., materials, shapes, or dimensions), (2) quantify cost changes due to changes in process design (i.e., sequencing, logistics, or construction), and (3) give rapid cost feedback to assist in decision making. Figure 1 presents the cost modeling process during Design Development on a project that uses TVD (Nguyen 2010).

Cost estimating practice applied during Design Development has not taken full advantage of opportunities provided when project teams pursue integrated product- and process design, such as those working in a TVD setting. Though project managers and detailers may be collocated, trade contractors' cost estimators may still work remotely in their own company office and have little access to information revealed in coordination meetings, logistics planning, and production planning. As a result, they may make assumptions on information already available, and estimate cost based on those. Such assumptions lead to 'contingency' built into the estimate to account for uncertainty. However, such contingencies could be eliminated if estimators were aware of discussions held during coordination meetings. Having cost estimators participate in key coordination meetings would make their estimate less padded with contingency and more accurately reflecting the current facts. Moreover, when evaluating design alternatives, the coordination team could benefit from immediate cost advice given by cost estimators.

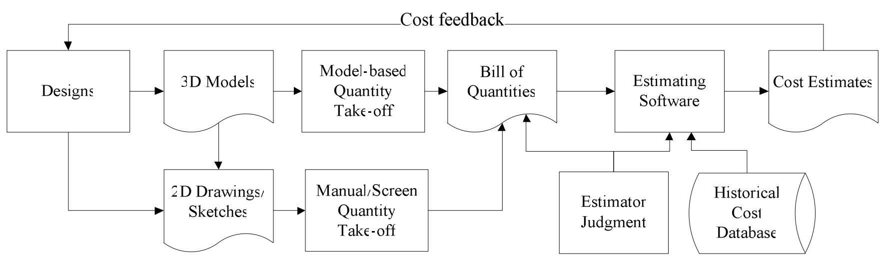


Figure 1: Cost modeling process during Design Development phase

Current cost estimating practice during Design Development has not taken full advantage of BIM. Though BIM has become a norm on many projects, cost estimators still perform quantity take-offs using 2D drawings extracted out of 3D models. By doing so, the design gets represented by multiple drawings (e.g., plans and elevations) thereby increasing the likelihood of an estimator missing or double counting individual design elements. In addition, quantity take-off on 2D drawings is time-consuming (Nguyen and Martin 2011). That time could be reduced by taking advantage of BIM, so as to free the estimator's time to perform more value adding activities such as helping their team with providing cost advice and value engineering. With the current estimating practice, upon completion of a bill of quantities (BOQ) especially in a large-scale project, a design may have changed, so that the BOQ and thus the cost estimate is out of date and possibly rendered useless.

OVERVIEW OF PBCM FRAMEWORK

The Process-based Cost Modeling (PBCM) framework presented in this paper is not intended to replace traditional cost models. Because the latter do not provide clear process information of the estimated items, PBCM is intended to supplement them by making process information explicit to designers, cost planners, and other team members.

By linking a product model to cost data, PBCM may provide rapid cost feedback to design and lessen the time required to assemble cost updates to inform TVD.

The purpose of PBCM is to support the selection of a design alternative during Design Development. Accordingly, the model needs to give a relative cost and this can be useful even when it is approximate. To do this, the cost model should be capable of making both process-related cost and product-related cost explicit to designers when they are analyzing design alternatives. Process-related cost may include cost of material handling and transportation, site logistics, and site installation depending on the scope being considered.

This cost model is best applied in projects where key players from upstream to downstream of the project (such as the owner, architect, engineers, GC, trade contractors, suppliers) are members of the design team. It also can be used in more traditional project delivery systems with integrated approaches such as Design Build (DB), Construction Manager at Risk, and Multi-Prime with DB, where both the GC and trade contractors can be involved early in the design process. A design-assist approach used in combination with these project delivery systems may further facilitate the participation of trade contractors in design (Gil et al. 2001). Since such early involvement is limited when using Design-Bid-Build (DBB) as the project delivery model, a PBCM has few opportunities for effective application in DBB. While the owner in a DBB contract (especially a public sector owner) may engage contractors early in design, in order to avoid conflict of interest in bidding, they will usually exclude them from the bid list. Although those contractors may provide insightful process- and cost advice to designers and help estimate product- and process cost, those estimates may not be all that useful since the contractors later selected to do the work may use different means and methods for construction. Figure 2 presents key process steps of PBCM including three phases: (1) Capturing process cost data, (2) Attaching cost data to an object family, and (3) Creating cost feedback to a design team.

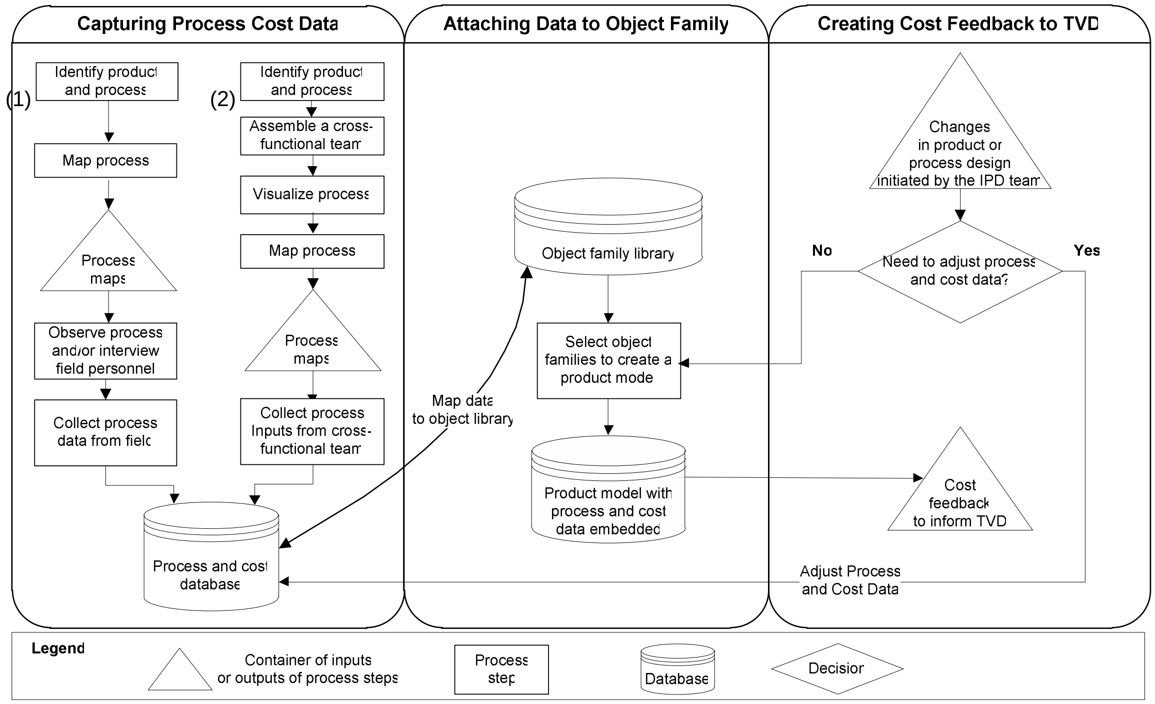


Figure 2: PBCM framework

Capturing Process- and Cost Data

Process- and cost data may be collected based on one of two scenarios: (1) products that have standard process designs and (2) products that require new process designs.

With standard products or systems (e.g., products Made-to-Stock (MTS) or Assembled to Order (ATO) (Tommelein et al. 2009)), it is possible for contractors to develop standard processes for installation and collect process data over time. In contrast, with products or systems with more unique designs, it may be more difficult if not impossible for contractors to develop standard processes for installation. The use of one-off Engineered to Order (ETO) and Fabricated to Order (FTO) products tends to lead to variation in the duration of installation activities that vary significantly in process design or require new process design. Detail steps for collecting process data for products that require new process design are proposed as follows:

Step 1: Identify product and process: Select products or systems that have a high installation cost, pose a challenge to site logistics, require tight coordination between specialists, or contain process uncertainty.

Step 2: Assemble a cross-functional team The cross-functional team should include the representatives of the designer or the engineer, the GC, the fabricator or the supplier of the product or system, and the trade contractors who perform site installation work.

Step 3: Present process visualization of installation alternatives to the cross-functional team. The objectives of process visualization are to: (1) graphically display construction processes to the team, (2) facilitate the coordination between designers, GC, suppliers, and trade contractors to integrate product- and process design, and (3) help the team develop a common understanding of work conditions.

Step 4: Map the process. 4.a. Define process boundary; 4.b. Identify process steps for each specialty and specify hand-offs between specialties; 4.c. Map the process and alternatives.

For each design alternative, the cross-functional team provides data and knowledge to map out fabrication, logistics, and installation processes using process mapping. Process maps serve as a platform for the team to provide input data such as activities, sequencing alternatives, estimated duration of each step, estimated number of man-hours to complete each step, equipment, inventory space needs, constraints and coordination requirements from each party.

Step 5: Capture process data by getting input from the cross-functional team. The GC, designers, trade contractors, suppliers, and cost estimators provide data on each activity in the process map such as distance from fabrication shop to construction site, truck capacity, design quantities, crew composition, activity duration, and estimated unit cost for each cost driver. Process cost is calculated using process data and established rates for labor, equipment, and materials.

Step 6: Feed process- and cost data into a database, calculate cost of each activity, and allocate activity cost to each unit of product.

CASE STUDY

A case study presents the application of PBCM to evaluate the installation alternative of a Viscous Damping Wall (VDW) (Nguyen et al. 2009, Newell et al. 2011) system used in the Van Ness Campus project (VNC). A VDW consists of an inner steel plate connected to an upper floor girder, a steel tank connected to a lower floor girder, and a viscous fluid in the tank. The inner steel plate hangs in the viscous fluid. In case of an earthquake it will move and through friction dissipate energy into the fluid. It is used to reduce seismic accelerations and wind induced vibration in a structure. Although widely used in Japan, VNC is the first project in the United States to use a VDW system.

The VDW challenged logistics and field installation for many reasons: (1) delivery and installation of VDWs required coordination of multiple project participants, (2) members of the project delivery team had no previous experience in fabricating, transporting, and installing the VDW system, (3) as a seismic control device installed in between upper- and lower girders, the sequence of installing the VDW system affected the sequence of installing the whole structural steel system, (4) VNC construction site was in downtown San Francisco, surrounded with busy streets, and with very limited storage area on site, (5) the large size and heavy weight of each VDW unit added risks to the installation process. In order to optimize the integration of product- and process design, the integrated project delivery team wanted to explore different schemes and solutions for VDW installation.

The team established close collaboration between the estimator, the Virtual Design and Construction (VDC) staff, the designer, and trade contractors. This collaboration helped the estimator to understand how the 3D model is built, the data contained in the model, and limitations of the model-based quantity takeoff. At the same time, it helped the VDC staff and the designer to understand estimating needs and formats so that they can specify names and assemblies of model objects for estimating purposes. Under the guidance of the estimator, the trade contractors provided process related information and specified impacts to fabrication/field installation due to changes in product features.

With trade contractors on board during Design Development, the team created process maps that cover design, fabrication, packaging, transportation, and installation of important systems or components. With their field experience, trade contractors provided estimates of process data and estimated cost for their work scope. In this case study, the researcher provided 3D simulations of construction process to help the team focus discussion on constructability, logistics, make ready work, activity duration, crew composition, and types of equipment. The researcher helped facilitate the application of PBCM process and performed semi-structured interviews with structural steel team representatives and the VDW trade partner to evaluate the effectiveness of the PBCM method in evaluating design alternatives (Nguyen 2010). Figure 3 depicts a sample in which different types of data, collected from the process mapping session, are input to a database.

Attaching Process Cost Data to Object Family

Figure 4 illustrates the linking of three different family types of the VDW to process- and cost data pertaining to four alternatives of installation. The product model contains object families created by the architect, the engineer, or the trade contractor. The database contains product and cost data collected for the project. Each object family type, e.g., the VDW size 7'x9', is linked to process- and cost data of its four installation alternatives including (1) pre-bolting, (2) inserting, (3) sequencing, and (4) pre-bolting with kitting.

Providing Cost Feedback to TVD

When designers consider a change in product (i.e., product family type) or process (i.e., method of installation), they may swap a current product family in the product model with another one in the model's product library and select an alternative of installation to see the impact on final cost. If the team sees the need for modifying process- and cost data, they can access the database to make adjustments. For example, team members may adjust crew composition, activity durations, transportation distance, etc. according to conditions of the current project. Since process- and cost data are linked to the object family, the team will be instantly provided with related changes in both product cost and process cost. The linking of data between product model and process cost model acts as an integrated product/process/cost model that can provide quick cost feedback to designers.

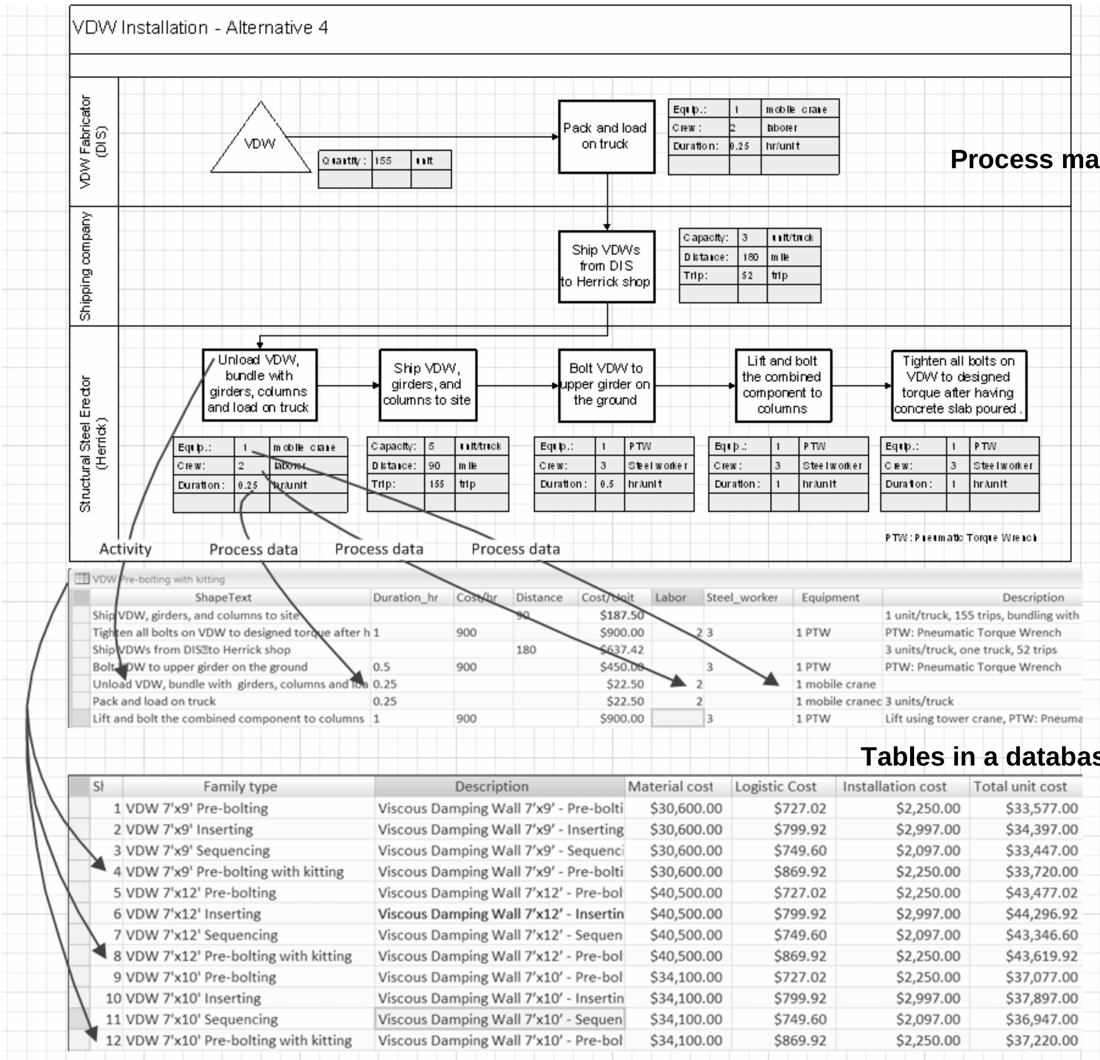


Figure 3: Data input from process map to database

This cost data can be included in a quantity schedule within a BIM authoring software (e.g., Autodesk Revit) to provide cost feedback to the design team in the course of selecting product or process alternatives. Data such as VWD counts can be extracted from the model to calculate a total cost (Figure 5).

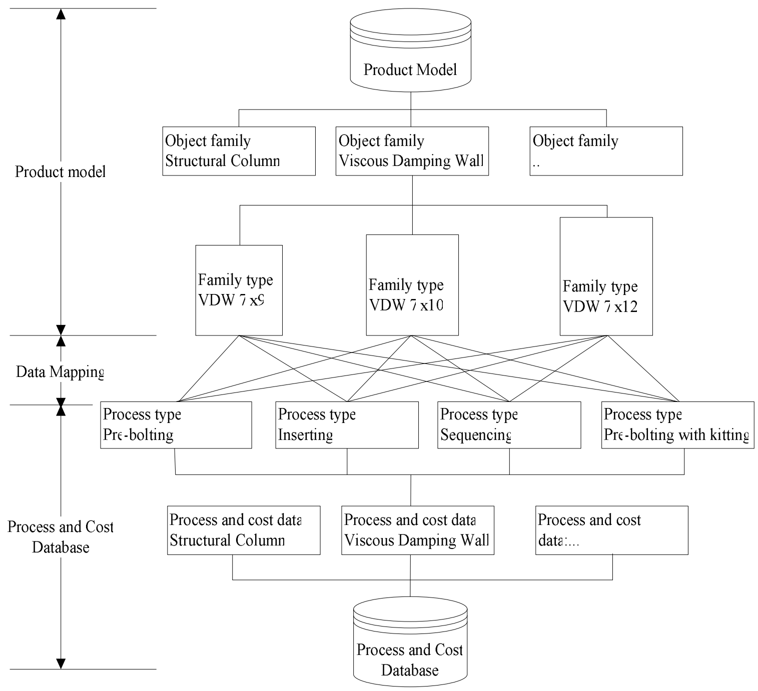


Figure 4: Linking object family types of a product model to process cost data

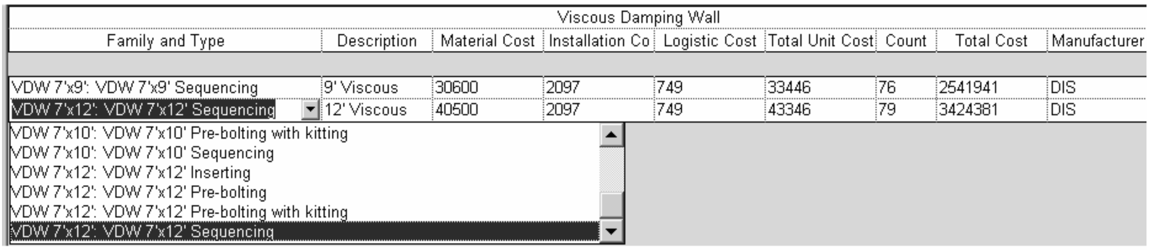
Viscous Damping Wall								
Family and Type	Description	Material Cost	Installation Co	Logistic Cost	Total Unit Cost	Count	Total Cost	Manufacturer
VDW 7'x9': VDW 7'x9' Pre-bolting with k	9' Viscous	30600	2250	869	33719	76	2562713	DIS
VDW 7'x12': VDW 7'x12' Pre-bolting wit	12' Viscous	40500	2250	869	43619	79	3445973	DIS

Figure 5: Cost feedback for 'Pre-bolting with kitting' installation alternative

Figure 5 depicts a VDW schedule view in Autodesk Revit: two VDW family types are used in this design including 76 units of VDW 7'x9' and 79 units of VDW 7'x12'. The selected method of installation is 'Pre-bolting with kitting'. Given the selected family types, the method of installation, and the quantities of VDW extracted from the design model, the total estimated cost for this design alternative is $2,562,713 + $3,445,973 = $6,008,686.

Figure 6 illustrates a team considering alternative means for installing the VDW. A team member may replace the object family type 'Pre-bolting with kitting' with 'Sequencing', 'Inserting', or 'Pre-bolting' installation method to see how cost will be effected. Values in related fields such as material cost, installation cost, or total cost, etc. will change to reflect the choice of installation method. When the quantity and the type of VDW get changed during design, this information will be immediately updated in the model, and a new total cost is calculated automatically.

With this method, estimators can connect any type of data contained in the process- and cost database to a BIM object. This method provides a link between a model element and its related cost and process data. This link enables designers to have immediate product and process cost feedback during design. The method is most useful in informing the decision-making process when it contains cost and process information provided by the trade contractors who will actually implement the work.



Viscous Damping Wall

Family and Type	Description	Material Cost	Installation Co	Logistic Cost	Total Unit Cost	Count	Total Cost	Manufacturer
VDW 7'x9': VDW 7'x9' Sequencing	9' Viscous	30600	2097	749	33446	76	2541941	DIS
VDW 7'x12': VDW 7'x12' Sequencing	12' Viscous	40500	2097	749	43346	79	3424381	DIS

VDW 7'x10': VDW 7'x10' Pre-bolting with kitting
VDW 7'x10': VDW 7'x10' Sequencing
VDW 7'x12': VDW 7'x12' Inserting
VDW 7'x12': VDW 7'x12' Pre-bolting
VDW 7'x12': VDW 7'x12' Pre-bolting with kitting
VDW 7'x12': VDW 7'x12' Sequencing

Figure 6: Cost feedback for 'Sequencing' installation alternative

CONCLUSIONS

This paper reviews limitations of traditional cost modeling methods and explores how an integrated product-process-based cost modeling method may be established and applied to facilitate Target Value Design (TVD). It formulated directions for developing the PBCM framework. Findings from the literature review and observations of the current state of cost modeling during the Design Development phase in the TVD environment revealed (1) the lack of an effective cost modeling method to inform TVD during Design Development and (2) the lack of a framework to take advantage of BIM in estimating product- and process cost. This paper delivered a proof of concept for a PBCM framework and validated it through application on a case study using action research. PBCM has more advantages in supporting TVD than traditional cost estimating methods have.

In addition, process-based cost estimating used in connection with BIM can provide more useful data to compare design solutions than traditional cost models do. Process cost data that comes out of the PBCM can be entered to BIM as properties of an assembly or a system, so that designers will instantly have cost feedback on how total cost is affected by their changes in product design or process design. By linking cost data to a product model (BIM), a PBCM provides rapid cost feedback to designers and lessens the time required to assemble cost updates that are to inform those involved in TVD. By integrating process- and product cost data with BIM, an integrated product/process/cost model helps to streamline the design process and reduce rework in the design/estimate/re-design iteration. In addition, the implementation of the PBCM method helps the IPD team to maintain a knowledge database of product design, process design, and their costs for future projects.

Further case studies should be conducted on different types of products or systems to test and to further refine steps to be included in the implementation of PBCM. A project team can validate a PBCM using feedback of actual costs to review and adjust the process- and cost data as well as to adjust PBCM for estimating costs of future projects. Further research is required to study the mechanism of adjusting PBCM based on feedback from the actual cost data.

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EVALUATION OF A CASE STUDY TO DESIGN A BIM-BASED CYCLE PLANNING CONCEPT

Paul Häringer[1] and André Borrmann[2]

ABSTRACT

Cycle Planning, or Takt Time Planning, is a key method to reduce the variability between different activities within the execution of a construction. A construction section such as a floor consists of multiple work zones, which should have continuous flow and similar cycle times to efficiently coordinate needed resources. However, for concrete structures it is often difficult to find suitable sizes of casting segments and their grouping to work zones. Nowadays, scheduling experts usually use their practical experience to find an intuitive solution for Cycle Planning, which might be sub-optimal. The objective of our research is thus to develop a semiautomatic method to generate optimal work zones for a cycle. The proposed solution is a BIM-based Cycle Planning concept for the cast in-situ construction method of walls. This paper lays the foundation for our concept and evaluates different designs of Cycle Planning layouts to ensure the practical relevance of the generated work zones. We provide an approach to the semiautomatic method: after splitting all wall objects into smaller sections, an optimization algorithm aggregates wall sections into casting segments and casting segments into work zones.

KEYWORDS

BIM, Cycle Planning, Takt Time Planning, Simulation, Local Breakdown Structure.

1 INTRODUCTION

Cycle Planning (CP) is a method to efficiently construct concrete structures cast in-situ. The preferred way to achieve a continuous flow is to schedule multiple casting segments and cycles throughout the floor of a building. The number and size of casting segments have a significant impact on the success of CP (Kenley and Seppänen 2010). CP is often unique to each building and time-consuming. The result is heavily dependent on the available practical experience. Building Information Modeling (BIM) is suitable for getting accurate quantity take-offs and makes it possible to speed up the planning process (Borrmann et al. 2015; MacLeamy 2004). Therefore, BIM helps to include the

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construction process further into the design phase so that CP could start already during the design process. BIM provides a very useful digital basis for creating the required breakdown structures like splitting wall objects into smaller wall sections and using their individual attributes. The next step after the generation of casting segments and their aggregation into suitable work zones is the optimal selection of formwork. In a Building Information Model, casting segments are available as objects or as an aggregation of multiple objects. Such objects and BIM processes in general can be used for automating formwork layouts (Singh et al. 2017). Maximum reuse of formwork in consecutive work zones reduces the amount of waste. Such work zones should be of similar size, shape, and work amount (American Concrete Institute Committee 347 2014). There are methods to optimize formwork in terms of reuse and minimum rental cost between already existing work zones, e.g. (Biruk and Jaskowski 2017). The research represented in this paper lays the foundation for filling the gap between the use of a general Building Information Model and automatic design of formwork layouts.

In the first part of this paper, we describe different layouts of CP. We show how three experts from three different companies, hereinafter called designers, designed a layout of CP for the same project and construction section with identical boundary conditions. Two of them work for formwork companies and one was the foreman responsible for the real construction project. According to the evaluation of these different layouts, we want to illustrate our approach – a BIM-Based Cycle Planning concept. The objective is to develop a semiautomatic method to generate optimal work zones for a cycle. We implemented a software prototype to prove the validity of the main elements of the developed concept. However, this paper does not validate the whole concept as we are still working on developing the concept further.

2 CASE STUDY OF CYCLE PLANNING

The initial step to reach our objective is to understand the Cycle Planning method. In order to understand it, we use a case study, which provides information about the process steps and individual rule interpretations. This is helpful for finding hard and soft constraints to generate a layout of CP more automatically.

2.1 DESCRIPTION AND STRUCTURE OF THE CASE STUDY

The selected case study is a construction section of a residential building. The building covers a surface area of about 750 m² over five levels and it is one of a group of buildings. Each level consists of eight apartments, two staircases, and an elevator shaft. The material of the shell construction is reinforced concrete. The construction company created the wall on site with the cast in-situ construction method. Based on the original plans, we created a Building Information Model. The designers were provided with the model and time schedule. The operating construction company used panel formwork as it is practicable for this type of building with a simple and linear geometry (Hoffmann et al. 2012).

In summary, these are the components and boundary conditions provided to the designers:

- The Building Information Model with geometrical and material information.

- The time schedule of 10 working days / 14 days with weekends with the time duration (time limit) for the construction section.
- The limitation to use only panel formwork and one tower crane.

We received different results of each of designers (Figure 1).

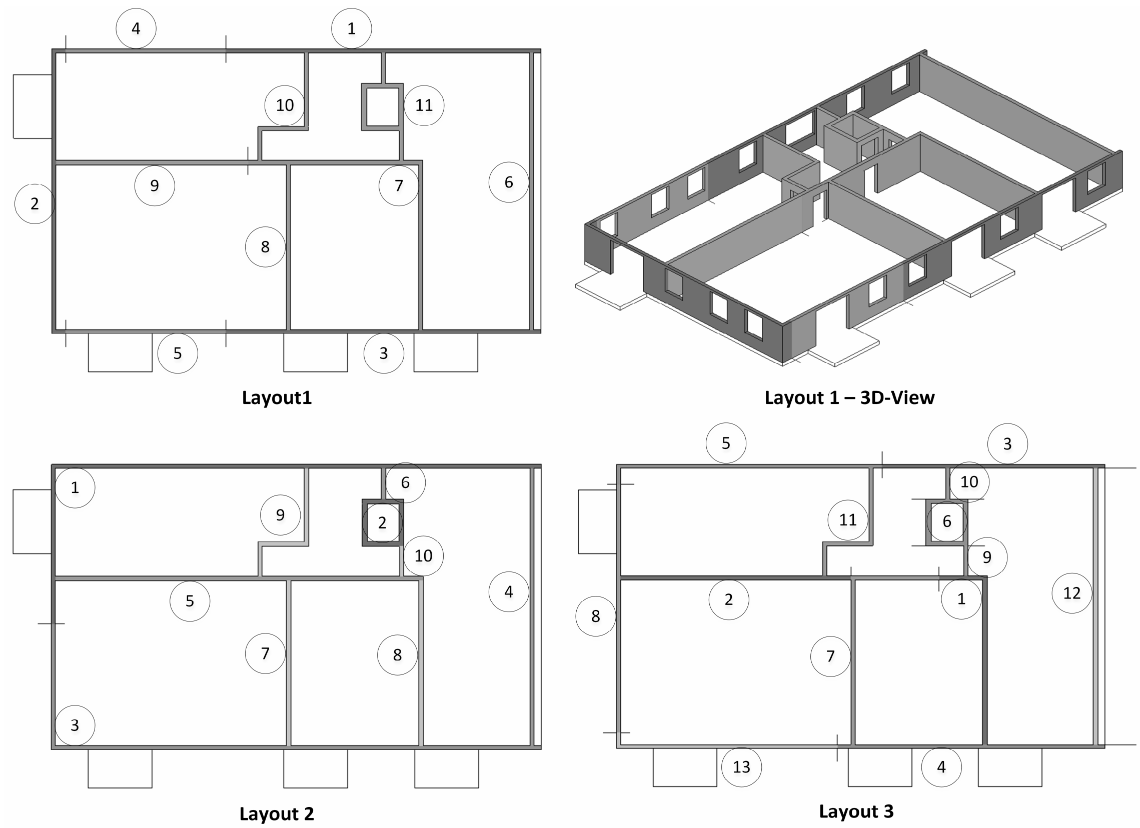

Figure 1: Visualization of the different layouts provided by the designers related to their work zones and associated casting segments numbered 1 to 11 (Layout 1), 1 to 10 (Layout 2) and 1 to 13 (Layout 3).

Each number represents a casting segment. A group of identically colored casting segments forms a work zone. Therefore, a work zone represents all the elements that are going to be built at the same time on site. At least two joints separate a casting segment. Because the design of the provided Building Information Model did not consider casting segments, we had to split already modeled walls manually for each received layout.

We received different data formats for the layouts from the designers. One designer used a 2D-printout of the construction section and different colored pencils. The other two designers used digital tools. One of them used the software Revit and DokaCAD, while the other used solely PeriCAD.

2.2 DATA EVALUATION

Before analyzing the layouts and their relation to the predetermined time schedule, we have to consider the technical characteristics and constraints. This is the initial step to find hard and soft constraints to generate a layout of CP more automatically. Table 1 lists the quantities of the properties Length [m], Volume [m³] and Gross Side Area [m²] for each casting segment.

Table 1: Comparison of the different layouts from Figure 1 related to their grouping into work zones (color) and properties of each casting segment (number). W stands for window and D stands for door opening.

	Layout1					**Layout 2**					**Layout 3**				
Segment	Length [m]	Volume [m³]	Gross Side Area [m²]	Openings		Length [m]	Volume [m³]	Gross Side Area [m²]	Openings		Length [m]	Volume [m³]	Gross Side Area [m²]	Openings	
				W	D				W	D				W	D
1	16.35	6.67	43.66	4	0	33.42	12.79	89.27	8	1	11.03	6.48	29.44	0	0
2	15.76	5.85	42.26	3	1	8.24	4.92	22.00	0	1	11.96	6.55	31.93	0	1
3	16.35	4.94	43.65	3	2	31.66	10.56	84.53	6	3	11.58	4.56	30.91	3	0
4	8.31	3.12	22.19	3	0	14.36	8.44	38.34	0	0	13.90	4.07	37.12	2	2
5	8.31	2.76	22.19	1	1	19.04	10.23	50.82	0	2	14.64	6.06	39.10	4	0
6	14.36	8.44	38.34	0	0	1.60	0.94	4.26	0	0	8.24	4.92	22.00	0	1
7	17.60	9.86	49.15	0	2	8.55	5.02	22.82	0	0	13.14	7.24	35.08	0	1
8	8.55	5.02	22.82	0	0	8.55	5.02	22.82	0	0	12.90	4.26	34.26	3	1
9	9.98	5.86	26.65	0	0	8.01	4.23	21.38	0	1	1.55	0.44	4.14	0	1
10	8.01	4.24	21.38	0	1	1.55	0.44	4.14	0	1	1.60	0.94	4.26	0	0
11	11.39	6.31	27.95	0	2						8.01	4.23	21.37	0	1
12											14.36	8.44	38.34	0	0
13											12.06	4.32	32.19	2	1
Total:	135	63	360	14	9	135	63	360	14	9	135	63	360	14	9

Every row in Table 1 represents a casting segment. The numbers of the casting segments refer to the numbers shown in Figure 1. The casting segments with the same color within a layout belong to the same work zone. A vertical line separates the work zones. Additionally, Table 1 contains the number of openings for windows (W) and doors (D) for each casting segment. This quantity is crucial because every opening influences the possible size of casting segments. On the one hand, more openings lead to increased time for setting and stripping the formwork, because of box-outs on sheathings. On the other hand, the casting volume is decreased and thus the time needed for reinforcing and pouring is shorter because fewer rebar elements are required.

None of the layouts had joints at openings. The reason is that joints through openings behave like a cantilever. It is like a beam, which is anchored at one end to a support. A structural engineer usually does not consider this for walls during the structural analysis. If there is a cantilever during the execution process on site, then the engineers must consider this, because it changes the internal forces (Fingerloos, Hegger and Zilch, 2012). This is an additional challenge during the design process. Therefore, the rule of not placing joints at openings is considered as a hard constraint.

By contrast, the following rules are soft constraints. One method to avoid cracks due to shrinking is to provide adequate construction joints (Woodson, 2012). With respect to limiting the length of casting segments, a rule from one designer is to limit the length to around 12 meters, which is shown on Layout 3 in Table 1. The maximum length in Layout 3 has casting segment 5 with 14.64 m. Such a length limitation is also observable in the layout pattern for Cycle Planning (Institut für Zeitwirtschaft und Betriebsberatung Bau, 2013). In corners and especially at building edges, walls often need additional reinforcement stirrups (Fingerloos et al. 2012). Joints in corners increase the time and the effort of rebar bracing with stirrups. Another disadvantage of joints in corners, especially in the corner of a building, is the reduced space for the bulkhead formwork. The designer's idea is to overlap such corners through a length expansion of a casting segment. The application of this rule can be seen for casting segments 1 (Layout 1), 2 and 3 (Layout 2) and 8 (Layout 3) in Figure 1. A suitable solution for rebar bracing in T-type corners is the use of rebar connection systems.

The essential rules we can derive from the layouts are:

- No joints through openings.
- Limit the length of casting segments.
- Avoid joints in corners, especially in L-type corners in building corners.

2.3 Different Layouts relating to Takt Time

According to Frandson (Frandson et al. July 2013) *"Takt-time is the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)"*. In our case, the product is a finished work zone (a piece of wall) and we need all products finished within 14 days. As mentioned, we have 10 working days and with an assumption of 8.5 working hours per day, we get a total working time of 85 working hours. For Layout 1 with three working zones, we get a takt time of 28.33 hours/product. Both Layouts 2 and 3 have four working zones, so for them, we get a takt time of 21.25 hours/product.

In order to calculate the time for each activity, we used the denoted quantities from the Building Information Model (Table 1) and multiplied them by performance factors. We estimated the amount of rebar using a percentage of the casting volume and calculated the needed time for the reinforcement activity (Hofstadler 2007). Since formwork elements are used over and over in different work zones, box-outs on sheathings will change their position over time. We took this into account by considering such changes as well as openings with constant time durations taken from (Institut für Zeitwirtschaft und Betriebsberatung Bau 2013).

Often the construction companies have their own values for the performance factors with an approximate target number of workers they need to meet the activity time. Because we did not get all the detailed data from every designer, we decided to use values that were close to the designer's data as well as to the data denoted in guidelines (Institut für Zeitwirtschaft und Betriebsberatung Bau 2013).

Table 2 illustrates our calculated duration times for the activities setting, reinforcing, concreting and stripping, respectively.

Table 2: Calculated duration times of each activity and cycle time (Sum Work Zone) for the work zones as well as their mean absolute derivation related to the takt time.

	Layout 1			**Layout 1**				**Layout 1**			
Activity	**Work Zone 1**	**Work Zone 2**	**Work Zone 3**	**Work Zone 1**	**Work Zone 2**	**Work Zone 3**	**Work-Zone 4**	**Work Zone 1**	**Work Zone 2**	**Work Zone 3**	**Work Zone 4**
Setting	9.81	9.09	6.67	8.34	6.53	6.01	4.67	6.17	7.36	7.18	4.72
Reinforcing	9.25	12.82	11.36	9.39	5.60	10.39	7.79	9.32	7.98	9.06	6.76
Concreting	5.92	5.13	3.70	5.00	4.00	3.20	2.53	3.40	4.41	4.20	2.60
Stripping	2.62	3.63	3.21	2.66	1.58	2.94	2.21	2.64	2.26	2.57	1.91
Sum Work Zone:	27.61	30.66	24.95	25.38	17.71	22.54	17.20	21.53	22.00	23.01	16.00
Takt time:		28.33			21.25				21.25		
Derivation:	0.72	2.33	3.38	4.13	3.54	1.29	4.05	0.28	0.75	1.76	5.25
Total Derivation:		6.43			13.01				8.04		

For the real construction project, our calculations were based on the same trade groupings and number of trade workers. Trade 1 - carpenters, with 4 workers for the activities setting, stripping and concreting. Trade 2 - steel fixer, with 3 workers for the activity reinforcing. If the duration for setting and reinforcing are the same, the waiting time between the two trades is reduced significantly. Because of openings and the additional time for out-boxes, activities setting and reinforcing take about the same amount of time in Work Zone 1 - Layout 1 as well as in Layout 2. One possible way of balancing the setting and reinforcement activities is changing the aggregation of smaller wall objects into suitable sizes of casting segments. This we can do automatically in our concept.

The layout with the minimal mean absolute derivation and therefore the best layout is Layout 1 with 6.43 hours. Layout 3 is second with 8.04 and Layout 2 is third with 13.01 hours. In addition to minimizing derivations between cycle and takt time as well as between different duration times of activities, especially the limitation of the maximum length of casting segments and the reuse of formwork are further crucial criteria.

3 BIM-BASED CYCLE PLANNING CONCEPT

According to the analyzed and evaluated case study, we defined constraints to develop a first approach of an algorithm to split objects automatically. The main research question is, is there a way to semi automatically create a Cycle Planning layout, which could be more optimal in terms of continuous flow and cycle time?

Combining such objects into casting segments and work zones is an optimization problem. Therefore, a metaheuristic optimization algorithm can help to create a more optimal solution (Bianchi et al. 2009). Our first approach is to use simulated annealing in combination with a discrete event simulation.

3.1 CONCEPT OVERVIEW AND DESCRIPTION

Based on the case study, we designed a BIM-based Cycle Planning concept (Figure 2).

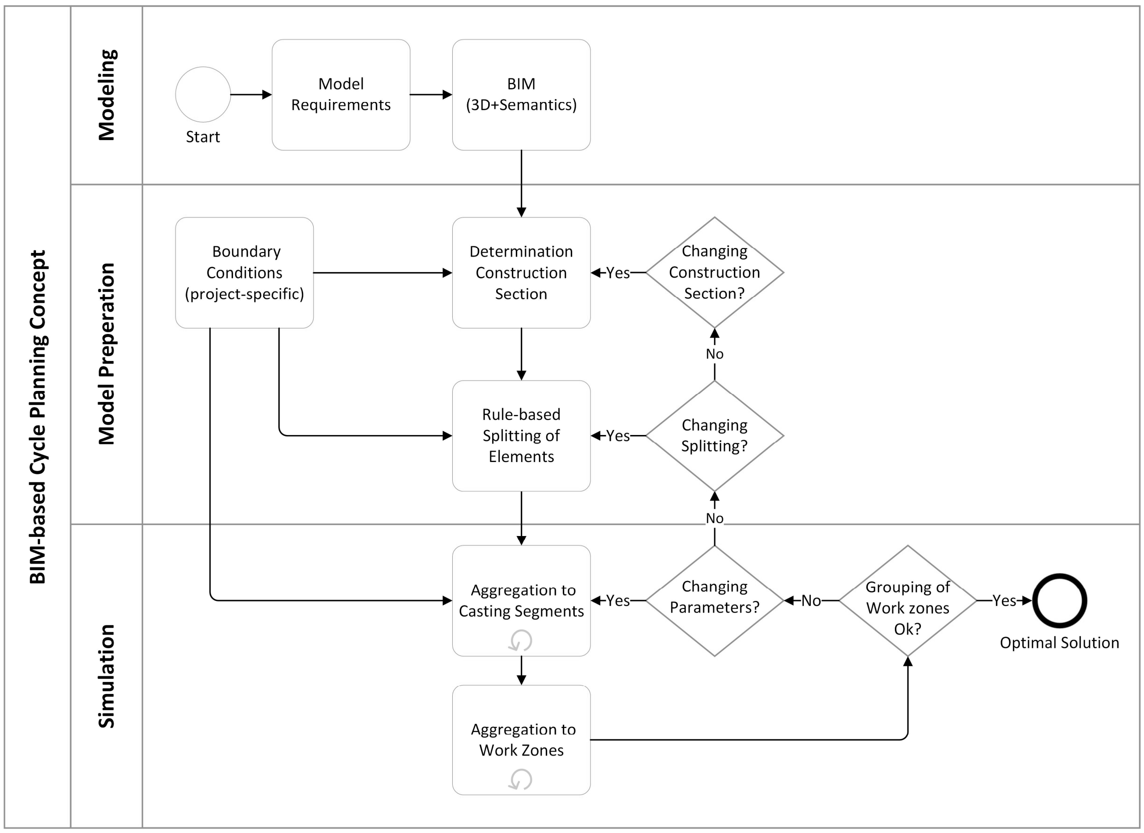

Figure 2: Design of our BIM-based Cycle Planning Concept

The basement in our concept is a Building Information Model. For the project-specific boundary conditions, the next step is to determine suitable construction sections following by a rule-based splitting of objects, which should be semiautomatic. This approach is illustrated in Figure 3 and is based on the binary tree data structure (Garnier and Taylor 2010).

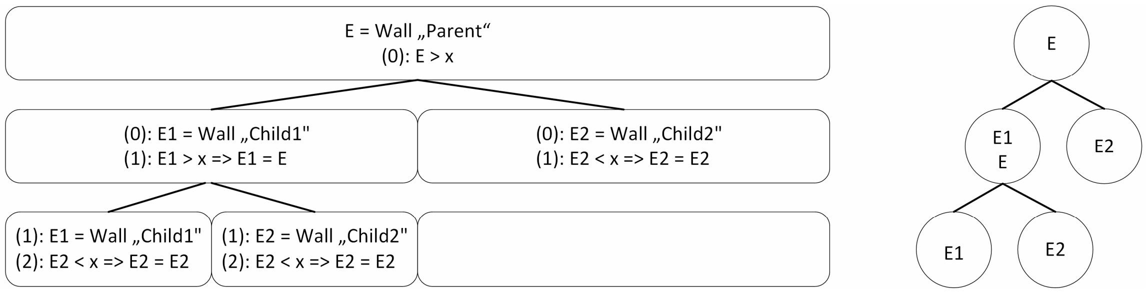

Figure 3: Binary tree approach for a semiautomatic rule-based splitting of objects

An object in a BIM is unique, so splitting one object into multiple objects creates at least two new objects. The root object represents the parent (E) and the two new generated objects are the children (E1 and E2). The variable x defines, for example, the user input for the maximum length of an object. In the first cycle (0), the algorithm checks whether E is longer than x. If this term is true, then the children E1 and E2 replace E. The second cycle (1) repeats this step with E1 and E2. E2 is shorter than x, so E2 stays E2. E1 is longer than x, so E1 becomes a root object E. This is repeated until all objects are shorter than x, which happens in the next cycle (2).

For the simulation and optimization, we separate the process into two steps. The first step is the aggregation into casting segments and consists of setting one side of the formwork, putting in the required reinforcement, and then setting the formwork on the opposite side. The second step is the aggregation into work zones and consists of concreting and stripping the formwork. For the first step, we implemented a prototype with the software Plant Simulation by Siemens PLM Software. During the implementation, we had support from PPI-Informatik, which is a German company that uses Plant Simulation to simulate and optimize material flow in the process industry.

3.2 AGGREGATION TO CASTING SEGMENTS

Our objective function to find an optimal solution for the size of casting segments is a combination of construction time and number of joints. The method we use for the optimization is simulated annealing (Kirkpatrick et al. 1983). With the use of the topological relationships between objects, we know which objects lay side by side and we can aggregate adjoint objects into casting segments.

We prepared a small simulation scenario with six wall objects. The wall objects had different durations for the activities setting and reinforcing. The objective was to find an optimal solution for the size and amount of casting segments. One trade did the setting and the other the reinforcement, so that these activities could be done in parallel. Figure 4 and Figure 5 show different results of two simulation runs with different settings for the objective function.

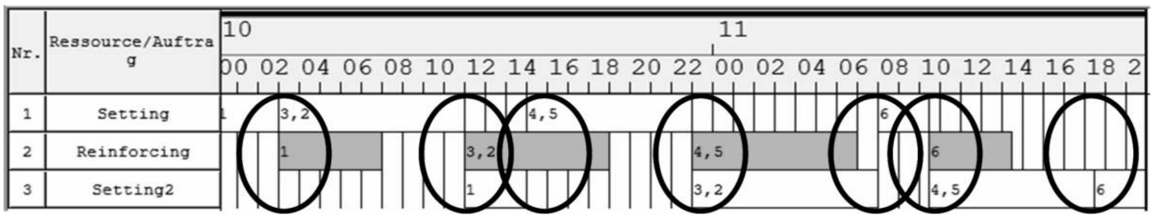

Figure 4: Simulation with a higher objective of minimal construction time

The axis of ordinate shows the activities reinforcing (no. 2) and setting, which is divided into nos. 1 and 3. The axis of abscissae shows the timeline. The bars inside the Gantt chart represent the casting segments. The listed numbers inside show which wall objects belong to the same casting segment.

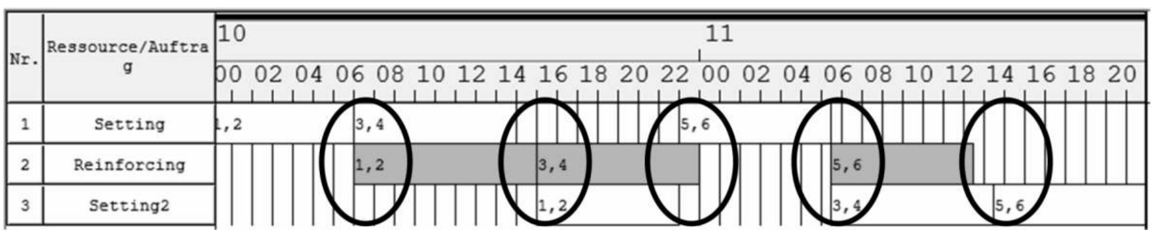

Figure 5: Simulation with a balanced objective between minimal construction time and variability between the activities

The result with a higher objective of minimum construction time aggregates wall object 2 with 3 and 4 with 5. The result with a balanced objective between minimum construction time and less variability between activities aggregates wall object 1 with 2, 3 with 4 and 5 with 6. Because of dependencies and waiting times between the activities and trades, the first simulation result is one hour faster than the second. However, the second result has less variability and fewer intersections between the activities, which shows the different number of ovals in Figure 4 and Figure 5. At such intersections, there is a combined effect of dependence and variation. Managing such an intersection is essential to deliver projects in the shortest amount of time (Gregory A. Howell 1999). Reducing the number of intersections means less managing, so it increases the likelihood of delivering a project in a shorter amount of time. Therefore, the second result could be faster than the first.

4 CONCLUSION AND OUTLOOK

This paper aims to analyze and evaluate different Cycle Planning layouts of a case study to design a BIM-based Cycle Planning concept. A Building Information Model is the basis for extracting required information easily and consistently. Even for the same wall objects of a construction section, a Cycle Planning layout can look differently. There are many possibilities and it is not easy to find an optimal solution. The results related to the takt time show that work zones have more or less variable cycle times, so there is a need to find better solutions. The represented concept can help to generate Cycle Planning layouts more automatically. Our implemented prototype is the first step in generating suitable sizes of casting segments automatically and considering the variability between activities. The simulation results show that a simulation with a balanced objective between minimum construction time and variability between the activities could be more reliable than a simulation with a focus only on minimum construction time.

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WINNING THE BID – A STEP-WISE APPROACH USING BIM TO REDUCE UNCERTAINTY IN CONSTRUCTION BIDDING

Aslesen, S.[1], Kristensen, E.[2], Schanche, H.[3] and Heen, P. I.[4]

ABSTRACT

This paper explains how to win a construction bid at the right costs. It suggests a structured, step-wise approach where at each step data analyses are carried out based on earlier bids, which are combined with assessments from an active risk management system, to come up with reliable estimates. To make sure all significant cost elements in the project are understood, linked together and communicated effectively, a building information model (BIM) is applied and worked on every step of the way from a preliminary, rough estimation to a final, complete bid.

The paper derives from an ongoing development project to improve the bidding process in a Norwegian construction company. It intends to solve the following problem: *How can we reduce the uncertainty in the bids we offer?*

The paper introduces a new way to organize the bidding process, including certain principles, to reduce uncertainty already in the project development, and attempts to increase our knowledge of the construction bidding process. The literature review is focused on theories of relevance to address the uncertainties inherent in construction bidding. The paper concludes that a project bid will always be burdened with uncertainty. Whereas traditional bidding theory gives support to the behaviour of economic agents who do the pricing to maximise profit, we find it relevant to introduce the concept of bounded rationality to explain why construction bidding is not a straightforward matter and how uncertainty management is fundamental to come up with the right costs.

KEYWORDS

Uncertainty management, bidding process, BIM.

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INTRODUCTION

The construction industry business is about to win the bid, and to execute the project. But how do we know which are the right projects? During the bidding process, when the project is still in its developing, there is an element of uncertainty which can be particularly high. Uncertainty, however, comes with an upside, too, and not only a downside. Almost no matter the level of detailing at an early stage, there are normally several ways to solve a project. In construction bidding, uncertainty is about taking advantage of these opportunities as well as including risks in the calculation.

This paper reports from an ongoing development project in a construction company, to improve their bidding process. The business unit is part of a major Norwegian construction company. It has a yearly turnover of around 3,3 billion NOK (415 million USD), and where just below 2 per cent or 50 million NOK (6,6 million USD) a year is invested in bidding work. Each year about 30 bids are prepared by the unit. The percentage of projects gained or won vary significantly amongst different markets, although with a total average of between 40 and 50 per cent of the bids being realized each year. Our concern is partly related to the share of projects won, which we think is too low considered the efforts made to win each project, and partly related to the substantial variation between markets in acquired projects. We suspect that the variability in projects won is particularly owed to a lack of standardized procedures in the bidding process.

Bidding, although requiring a highly qualified effort, is fundamentally about making assumptions. In the construction industry, these assumptions are typically based on multiple criteria and various trade-offs, which in turn are transformed into cost estimates. Uncertainty management can be performed to foresee if the project can be influenced by incidents which may have a positive or negative outcome on the results. Even though the project is not yet initiated, one may work to optimize it according to its potential risks and opportunities. In the paper, we describe a step-wise approach to develop a project bid at the right costs. By applying this approach, we expect to speed up our bidding process at the same time as the bids we offer have a higher return rate than today as well as a lower level of uncertainty.

THEORY

Competitive bidding has been studied for more than 50 years. One of the early, notable contributions to the field is by Friedman (1956) on competitive bidding strategy. It involves maximising the expected profit from a single tender where each competitor submits a closed bid by selecting a mark-up on cost that maximises expected value of the profit – which is the product of the mark-up and the probability of winning the contract (Runeson and Skitmore 1999). The problem, according to Friedman, lies in determining the probability of winning as a function of the mark-up (op.cit). Friedman’s competitive bidding strategy has later been reinterpreted by Gates (1967) from a single bid strategy into a general, profit maximising pricing model. An essential characteristic of the model presented by Gates (1967) is a mark-up that is constant, over time and in practice, from tender to tender (Runeson and Skitmore 1999). It excludes the possibilities of systematic changes in the mark-up to calculate the probabilities of success at different mark-ups (op.cit.).

Construction bidding is the procedure of submitting a proposal by contractors to carry out a described construction project (Zhu 2008). A construction bidding process normally consists of several contractors competing to perform a job by submitting a sealed proposal until a certain date previously defined by the client (Ribeiro et al. 2013). The usual format of this process is based on the rule that – all other things being equal – the contract will be awarded to the competitor which submits the lowest bid (Cheung et al. 2008). Note that, although increasingly more contracts are being awarded according to factors other than price, awarding contracts to the lowest bidder is still far from having been phased out (Seydel and Oslon 2000). Finding the right price is moreover not a very straightforward matter. The construction industry faces strong levels of price competitiveness (Chao and Liu 2007). The competitive pressures may lead contractors to lower their profit margins to produce a more competitive bid (op.cit). A contractor might also cut the margins for other reasons, such as positioning in a specific market, maintaining long-term client relationships, developing strategically important competence in-house and so on. Whatever reasons it does not rule out the strategic importance of establishing some sort of link between the mark-up level and the probability of winning the bid.

How, then, to determine whether the price is right? In an article by Runeson and Skitmore (1999) the competitive bidding theory is criticized for being inappropriate to describe the construction bidding situation. This is done on two grounds; first, that to maximize the expected value of every single bid may work well for a game of poker or when betting on horses, but the problem in construction tendering is to maximize the return to a given productive capacity. There is almost always a choice of contracts to bid for, and winning a contract means that part of the firm's resources is locked up so that the firm is unable to compete for potentially more profitable contracts. Second, that the theory is based on a failing logic the way it assumes any observed differences in tenders must be unsystematic and due to inaccuracies in the cost estimates. How can it be, then, that ever so often all estimators get it wrong by about the same magnitude and in the same direction and at the same time? This rhetorical question leads the authors to conclude that bidding implies a behaviour that is far removed from the assumption of rationality that is central to most aspects of economic reasoning.

Where does this leave us in terms of finding the right price? It seems that a profit-maximising bidding strategy as a prescribed practice is ill-founded, which may also explain why there is little evidence of its adoption in practice (Runeson and Skitmore 1999). However, if not driven by utility maximisation, then what? Several studies suggest that decisions regarding the definition of the mark-up level are mainly supported using subjective judgment, gut feeling and heuristics (Hartono and Yap 2011). Although this is apparently what happens in many circumstances, we believe that the notion of bounded rationality as coined by Nobel Prize winner Herbert Simon in *Models of Man* (1957) is more usable to understand agents' actions. According to Simon, people are boundedly rational the way they experience limits in formulating and solving complex problems and processing information (op.cit). This does not necessarily mean that people behave irrationally, for instance in their struggle to come up with the right price. In an article by Beckert (1996) on the uncertainty embedded in economic actions it is suggested that people are intentionally rational, but that the existence of uncertainty prevents people from knowing what is best for them to do. Uncertainty is here understood as the character of situations in which agents cannot anticipate the outcome of a decision and cannot assign probabilities to the outcome (op.cit).

If we apply this concept of uncertainty to the bidding process, it is reasonable to question the very existence of such a thing as an optimal price or bid. Partly, because information is often limited, not wholly accurate and missing, and partly because of our insufficient mental capability to make sense and process the information. Rather than searching for the optimal price, finding ways to reduce the uncertainty in the bids we offer may seem like a more appropriate approach to structure the bidding process. At the firm level, the main bidding procedure for a construction company can be separated into two stages: 1) the bid/no bid decision and 2) the mark-up decision (Zhu 2008). The incorporation of uncertainty into these major decisions will necessarily imply a process for generating alternatives, and procedures for estimating them – at the same time accepting the limits of human cognitive capacity for discovering alternatives (Simon 1987). Besides, past bidding information can work as a guideline for future bids. While the accuracy of cost estimates can, by definition, only be assessed in relation to actual costs, it may show useful to apply the real empirical data a contractor compiles concerning earlier bidding competitions where a specific mark-up level is included in the bid proposals. If not to predict the future, then simply to organize past bidding information in a way that is meaningful to current bid decisions (Crowley 2000).

From the Lean Construction domain, Target Value Design (TVD) as a method for setting project targets and steering design and construction toward them can be relevant. TVD is particularly designed for the project delivery process and involves engaging deeply with the client to establish the target value (Tommelein and Ballard 2016). While the bidding process takes place before the project is realized it may often include close collaboration with the client, which is typically the case in private work construction. Besides, even though the client is not involved in the bidding process per se, there are normally several guidelines expressed suggestively by the client in his or her inquiry. A central part of the bidding process, as such, is about to use the client's needs to spur innovation in both product and process design – to reduce costs. To support this innovation process, using Choosing-By-Advantages (CBA) and virtual first-run studies (VFRS) can be highly adequate. CBA is a method for sound decision making which is often used when multiple variables need to be considered to make an informed decision, and where an advantage is a difference between the attributes of two or more alternatives (Suhr 1999). First-run studies is another principle attached to the Lean Construction concept, including trial execution of an operation as a test of capability to meet safety, quality, time and cost targets (Tommelein and Ballard 2016). Traditionally, these studies are done ahead of the scheduled first start of an operation. In the bidding process, they may instead take form of virtual prototyping using BIM, to visualize and estimate alternatives, clarify uncertainties, and make decisions.

A STEP-WISE APPROACH TO WIN THE BID

The step-wise approach to construction bidding presented in figure 1 below is explained in further details in the subsequent sections.

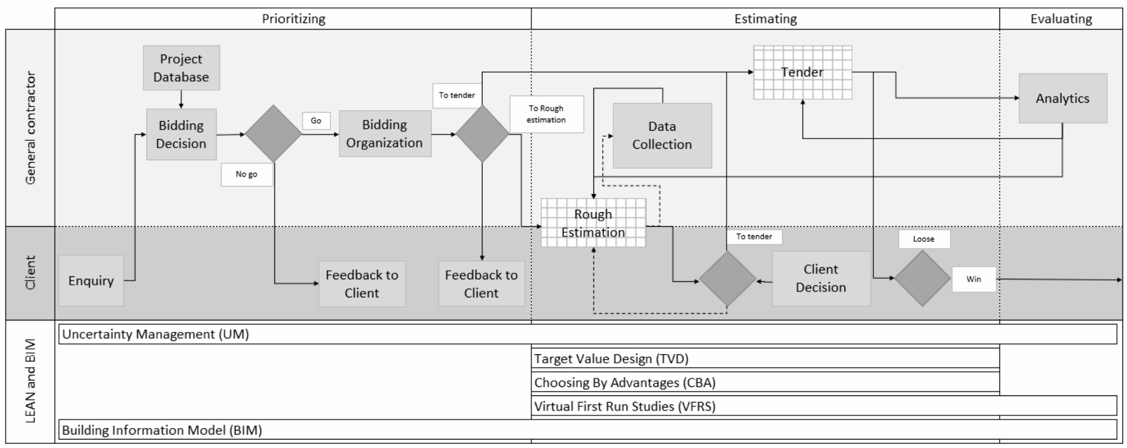

Figure 1 A step-wise approach to construction bidding

TWO STEPS TO BID – ONE STEP TO LEARN

We suggest the bidding process to be divided in three steps. The division into steps is done to define its main activities, as well as to rapid the process up by pulling it towards a decision point at the end of each step. By this, we hope to make for a more concentrated effort in the bidding work.

The first step we call "prioritizing", where projects are to be chosen based on the unit's business strategy. It goes back to the point that there is almost always a choice of contracts to bid for, and that working to win a contract means that part of our resources is locked up so that we are unable to or less capable of competing for potentially more profitable contracts. Main decision criteria to go further to bidding can be; 1) a reasonable chance to win, 2) good prospects for making a decent profit, 3) strengthen positioning in a market of significant importance, and that we 4) develop in-house competencies. In the work to identify major opportunities and risks, we want to use the active risk management system to apply information from earlier bids. The system describes and quantifies the cost consequences of various uncertainties. The quantification is done by triple estimating the probable outcome of uncertainties, where we operate with worst case, most likely case and best-case scenarios. The system also contains "thick" information about the actions taken to optimize the upsides and reduce the downsides of every uncertainty identified on the project level. The information will be supplemented by an overview of tenders and inquiries in different markets, to evaluate possible gains and losses by choosing to go further to develop a bid.

The second step we have called “estimating”. It is to be released from a decision to prioritize the project. The estimating can be done either directly as a detailed calculation of the various posts included in the project, or it may start as a rough estimation to come up with a preliminary guesstimate for a client to decide whether to go further with the project or not. The rough estimation will be developed from a list of geometric factors based on earlier bids, which are to be merged with cost components from our calculation program. It should be visualized in a BIM model, where the model can be used to communicate, analyse and evaluate different solutions with the client. The detailed calculation is a more comprehensive business. It includes estimating costs for the in-house production and for the rigging and management of the construction site, besides adding incoming bids from subcontractors and suppliers to the calculus. As part of the estimating, we consider opportunities and risks – be they technical, commercial, contractual or progress related – to be measured and actions to be formulated to reduce the uncertainties. In the end, the bid will be submitted after a final review where the price, together with the project content and design, is locked.

The third and last step we have called “learning”, which is to take place after the bid is submitted. It will be based on the ambition to continually learn and improve from what we do. To learn from the process, we will follow up closely with the client to clarify confusions and issues that need further explanation. Furthermore, we will invite the bidding team to do an evaluation of the bidding process. The evaluation will be supplemented by information from the competition, such as regarding assignment criteria and the ranking of bidders, feedback from the client and so on, which are to be utilized as part of considering which projects to prioritize next.

ROUGH ESTIMATION USING TARGET VALUE DESIGN

The unique nature of a construction project poses challenges to accurate estimation. At the same time, there is a relatively high degree of repeatability in some of the products we deliver. Particularly so, in resident housing projects. For a real estate developer who invests in a piece of land, the decision to do so is likely spurred by fiscal motives. Before buying the land, certain enquiries are usually needed about the product to be localized there. Some of these enquiries will typically include a contractor’s opinion. In the following, we describe the process of developing a rough estimation as a response to these enquiries, where using target value design (TVD) – including choosing-by-advantages (CBA) and virtual first-run studies (VFRS) – can provide this process with the kind of structure it lacks according to today’s practice.

Target value design in the early stage of developing a construction project is unusual since it will be performed before a budget is set. Nonetheless, in our experience the client may still have a relatively clear idea of what he or she is willing and able to spend to achieve the project (allowable cost). At the same time, spending no more than necessary can help to spur innovation in a way that contribute to reduce the actual costs in the project. When a client meets with a contractor on an early basis, he or she normally has a scope and some constraints on money, time and otherwise which set limits to what can be achieved through the project. As part of the rough estimation process, we wish to inquire a specification by the client to narrow down the alternatives. Using TVD, cost is applied as input instead of an output in the early design stage. Indeed, sometimes a client may already have met with an architect and even bring to the table some early sketches of what he or she wants, while in other instances the client does only have a rough idea. No matter the level of detailing, we think it might be useful to introduce CBA at this point to support the client in making sound decisions, by limiting the set of alternatives to select from.

When we have gained a relatively clear idea of the factors, criteria and attributes of the alternatives that the client has, we want to perform first-run studies to help the client decide which of the alternatives is the most valuable to him or her by evaluating their geometric, quality and not least cost related consequences in virtual mock ups. The client will in this way be able to walk through the virtual models to decide the best option to fit his or her requirements, he or she may choose to change the scope to get more value from the project, to reduce the scope or even kill the project. An essential benefit from our perspective is that we will spend more time to become familiar with the project, which in turn may lower the risks and their related cost implications.

APPLYING BIM TO REDUCE UNCERTAINTY IN THE BIDDING WORK

Adopting BIM to the bidding process we suspect may greatly improve the understanding of the project at an early stage as well as contributing to the effectiveness of the process itself. A building information model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories, and project schedule (Azhar 2011). As part of the bidding work, a BIM model can be used for cost estimation and quantity take-offs. The model can also be applied to visualize the timeline for the construction work as well as to detect potential conflicts, interferences and collisions. A BIM model may thus allow us to collaborate more accurately and efficiently in the bidding process, which in turn can work to reduce the uncertainty of the bid.

When every project (and bid) has a BIM model with its own calculation attached, we risk possessing many sets of data with differing cost information on the same or similar objects. Data clustering, or the division of a set of objects into groups of similar objects, will therefore be important to standardize the information. The task of data clustering is to divide a set of data into sub sets containing similar data (Veenhuis and Köppen 2006). When this is properly done, we hope to be able to model the behaviour of specific objects in various virtual environments without modelling each single object explicitly. For instance, when developing a rough estimation of a point house where the client wants to maximize noise considerations. Then, we want to be able to include in the calculation factors like the amount of saleable square meters, west facing balconies and so on. Applying CBA at this point will help us decide the advantages and importance of each of the alternatives, evaluate the cost data and identify the most workable alternative.

Data clustering, or data swarm clustering, is inspired from nature resembling the aggregation of animals, i.e. flock of birds, schools of fish and so on, where to maintain the structure of the swarm each swarm-mate behaves according to certain rules such as keep close to your neighbours or avoid collisions (Veenhuis and Köppen 2006). Applying BIM to the bidding work, the implementation of discrete rules is likewise important to be able to properly evaluate the cost and design consequences of different choices in virtual mock-ups using First-Run Studies. For instance, when the client plans a housing project with a garage for all the residents, where he or she wants to consider the cost and design consequences of placing it below or above ground. Then there needs to be certain rules established, in example as to where to place the costs of the ground floor so that prices are comparable before the benchmarking is done. If rules are not established, we risk (still) to be highly dependent of the tacit knowledge of the single calculator about how to calculate these costs.

DISCUSSION: WINNING EVERY TIME – A VIABLE STRATEGY?

The nature of competitive bidding is like a game where you win from time to time, and loose every so often. However, each bidding process starts with the ambition to succeed. Thus far, winning every time may say to be a viable strategy in construction bidding. At the same time, a general contractor is often bounded by factors which are likely to affect his or her behaviour in ways that influence the price – and thereby also the propensity to win so that winning every time is only viable to a certain point. In the following, we suggest grouping these factors in three major categories; *the winner's curse*, *the capacity challenges* and *the competitive edge*, where we discuss how to handle their related uncertainties by using our step-wise approach to construction bidding.

The winner's curse

The winner's curse involves the tendency for the winner in a low-bid-wins auction to be the one who underestimates his or her costs the most (Seydel and Olson 2001). Indeed, while underestimation can be the result of a calculated risk for reasons we will get back to in the next sections, we will here discuss it as something unwanted. The problem may start already in the prioritizing. Unless you have carefully considered your winning strategy, the risk of overexertion can be ubiquitous. The victory may thus be with an ugly taste. Bidding too low, and winning, is a quite common phenomenon in competitive bidding. By introducing the step-wise approach, involving analyses of uncertainties, decision points and learnings from earlier projects and bids, we hope to reduce the possibility of ending up by the winner's curse. But because of the clients' inclination to choose the lowest bid, this may also prevent us from winning the bid – while simultaneously it increases the possibility for someone else to end up by the winner's curse. A more fundamental way to avoid ending up by the winner's curse could be to decide a fixed mark-up, and never go below a certain profit margin when projects are being calculated. No matter what, it does not prevent the risk of underestimation as a malfunction, in example when costly factors are undervalued in the calculation. For a general contractor to distinguish between simple and complex elements can be a recurring challenge, with the subsequent pricing of simple things as too expensive and complex things as too low-priced. By applying BIM to the estimation of costs we expect to promote a more complete understanding of the project in the bidding team, so that errors and the subsequent mispricing will be a limited problem.

The capacity challenges

A general contractor calculates projects to get jobs. The jobs vary in size. What is more, they tend to come in an unregular fashion. This is the basis for the capacity challenges. Whether due to under- or overcapacity, the problem may have differing consequences on the price. When a general contractor is in need for work, he or she may lower the profit margins to produce a more competitive bid. This is a situation where one might end up by the winner's curse, but where there is a calculated risk behind the bidding behaviour. The contractor's reasoning for lowering the mark-up, apart from the obvious need for work, can also include less risk taking due to more in-house production as opposed to extensive use of hired labour. Under-capacity, on the other hand, can work to raise the mark-up in the bid. Not necessarily because of the apparent advantageous situation of having a full order book, since in the construction industry this is normally a very temporary state of being. Rather, it is the decision to bid still, for instance to maintain a strong position in a market, where due to the lack of productive capacity in-house one is forced to base the bid on a massive hiring of personnel. A step-wise approach to develop a bid does not rule out these capacity challenges. However, a thorough evaluation of the capacity situation should be included in the prioritizing and estimating of jobs, to make the right choice whether to go further to bidding and to decide the right level of the mark-up based on the risks involved.

The competitive edge

If the focus was solely on winning, then a rational strategy for a general contractor – at least on a short-term basis – would be to concentrate all the efforts in one or a very few markets where he or she holds a strong position because here the propensity to win every bid would be high. Being a general contractor, however, involves keeping the ability to meet the demands of various markets. This is because in a longer-term perspective markets fluctuate, and they may do so in an unsynchronized manner. The competitive edge for a general contractor lies thus in a combination of capabilities. The situation can be compared with the ambition to become a decent tennis player. The game of tennis is a very complicated business, much because it requires a set of skills to win. You may cultivate certain skills such as your serves and, indeed, come a long way, but to become a complete tennis player you must be able to handle numerous circumstances since you never know exactly where the next ball will come. For a general contractor, competencies are worked up through projects – much like a tennis player's skills are developed by playing the game. In terms of prioritizing bids, one may want to lower a bid and accept a reduced profit on a short-term project basis (winner's curse), if the longer-run strategy is market penetration or to strengthen the position in specific markets. Especially so, when a lower profit in some segments can be compensated by a higher income in other segments. Extremely important here (as in every instance) would be to communicate to those who will execute the project, the conditions behind the project calculation.

CONCLUSION

In this paper we have explained how to win a bid at the right costs. We propose a step-wise approach supported by BIM, to reduce uncertainty in construction bidding. Since we are in the middle of testing and developing further some of the ideas, we are not yet able to conclude about the workability of the approach. Particularly so, when it comes to target value design and its belonging processes related to structured decision-making (CBA) and virtual mock-ups (VFRS). Their implementation will represent a significant effort in the case company to standardize the bidding process. In the paper we have also discussed how construction bidding is not a straightforward matter. The inclination to maximize the outcome, as emphasized in competitive bidding theory, is here contradicted by an alternative view where considerations such as the need for work, market penetration, and in-house competencies lead us to conclude that the general contractor is boundedly rational in his or her bidding behaviour.

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ENABLING LEAN DESIGN WITH MANAGEMENT OF MODEL MATURITY

Andreas Nøklebye[1], Fredrik Svalestuen[2], Roar Fosse[3], and Ola Lædre[4]

ABSTRACT

Traditional construction management has struggled with an ad hoc approach to design, increasing the number of negative iterations and sacrificing potential value. Building Information Modelling (BIM) has been driving information management in design, but its use has yet to be described in a way which makes it compatible with planning tools such as Last Planner™. Level of Development (LOD) could allow for this by attributing maturity to the BIM-model, yet previous studies of LOD implementation have shown potential for improvement. This paper researches current approaches, experiences and requirements for using maturity-based management in design.

A study of two large projects with maturity-based management using interviews and an analysis of measurements was conducted in addition to a literature scoping study.

The paper formulates five aspects of BIM-based workflows which needs to be addressed in order to manage their development. In addition, the study reveals how use of maturity-based management can provide a foundation for managing BIM-based workflows according to lean principles.

Finally, the paper concludes with practical recommendations for enabling lean design with management of model maturity, such as how to specify maturity levels or how to disaggregate the model into disciplinary sections.

KEYWORDS

Lean design, BIM, LOD, Set-Based Design (SBD), Last Planner

INTRODUCTION

Whereas production has a clear set of sequentially dependant, pre-defined tasks, design is better described as a set of interdependent, reciprocal iterations (Knotten et al. 2014). Because of this, the design workflow is much harder to manage, often resulting in an ad hoc approach (Carlos T. Formoso and Liedtke 1998; Knotten et al. 2017).

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With the evolution of information technologies over the last decades, several new tools have become available to designers, most notably Building Information Modelling (BIM). Although they have provided an effective way for integrating product information into the design process, especially when used together with Integrated Concurrent Engineering (ICE), these new tools are still being managed with a traditional mindset (Leite et al. 2011).

By planning and executing work according to lean principles, the Last Planner™ system has yielded significant returns when applied in the production phase of AEC-projects. As such, similar improvements in the design phase could be attained by applying Last Planner™ to BIM-based workflows. However, BIM-based development lacks an orderly process, effectively making it incompatible with such planning tools.

The concept of Level of Development (LOD) was introduced as a means to formalize the development of a BIM-model (BIMForum 2017), and could be used as a way of attributing a work process to the BIM, making it compatible with Last Planner™. LOD has been approached in several ways (Abou-Ibrahim and Hamzeh 2016; Leite et al. 2011; McPhee 2013), yet lack of consistent understanding and utilization of LOD are common in projects (Hooper 2015), and no documentation regarding LOD as an enabler for Last Planner™ in BIM-based workflows could be found by the authors during the process of writing this paper. The research questions for the study were as follows:

1) What are current approaches to maturity-based management?
2) What are the experiences from maturity-based management?
3) What are the requirements for successful maturity-based management?

Five key aspects of BIM-based workflows were formulated from lean theory. These aspects were later examined in two large pilot projects using maturity-based management in order to present practical requirements for implementation and use.

METHOD

A literature scoping study was conducted to map existing literature on the topic. More than 130 of the most relevant scientific works were assessed from sources such as IGLC, Scopus and Compendex. In addition, general interviews were conducted with four professionals proficient in BIM and LOD in order to achieve a greater understanding of the field.

Two pilot projects using maturity-based management conducted by two of the largest Norwegian design build contractors (Skanska Norway and Veidekke Entreprenør AS) were studied using interviews with case practitioners ranging from managers to designers, in addition to a document study. All interviewees had prior experiences using Last Planner™ and ICE. All interviews were recorded and transcribed. Said transcripts were later verified by interview participants as representative of their views. Cases include Tiedemannsbyen, an apartment complex of five, six-storey buildings (Skanska, approx. $54M, ~14 designers), and E6: Arnkvern-Moelv, a 24km long Class A road project, part of the international E-road network (Veidekke, approx. $260M, 30+ designers).

BACKGROUND

LEAN IMPLEMENTATION OF TOOLS

Lean systems utilize standardization and continuous improvement in order to improve their practices (Moore 2007). By doing so, systems are enabled to dynamically adjust towards their lowest point of entropy, avoiding needless creation of waste in implementation efforts.

LAST PLANNER™ AND BIM IN DESIGN

There exist several definitions of BIM, depending on whether one is addressing it as a model, a tool or a platform (Fosse et al. 2017). For the purposes of this paper, BIM is best described as a computerized foundation for an integrated collaborative design process (Jacob and Varghese 2012). This computer model consists of a sum of geometrical objects, each associated with certain disciplines. Development of the model is expressed through a series of iterations of said objects and their relationship relative to each other (Knotten et al. 2014), which eventually results in a digital representation of the final building.

The Last Planner™ system enables lean management by applying pull-based planning of tasks, thus reducing waste (Ballard 2000a). Some studies have proven the potential for applying Last Planner™ in building design (Fosse and Ballard 2016; Hamzeh et al. 2009), although only in limited applications. The challenge in doing so has been attributed to the differences in workflow between design and production (Grytting et al. 2017). To implement Last Planner™, one must thus be able to describe the iterative nature of design, assign responsibilities and relate these processes to a clear project development structure.

One of the primary differentiators of design and production is the fact that iterations in design can be both positive and negative (Ballard 2000b). As such, managing building design according to lean principles becomes a matter of reducing negative iterations while keeping the positive ones. The Toyota design approach (Set-Based Design) starts with mapping available design space and functional requirements for an object, then using input from different disciplines to narrow down the number of available concepts, converging towards a final design (Sobek et al. 1999). By determining the boundaries within which work will be conducted, workflow iterations are more likely to be positive, and thus value-creating for the project. Another benefit of this approach is the ability to systematically share incomplete information, a feature vital to the design process (Busby 2001).

LOD

Level of Development (LOD) is a measure of the reliability of the information associated with a specific object within the BIM, expressed as a series of levels (BIMForum 2017).

The application of LOD in construction design becomes apparent when viewing it in relation to Set-Based Design. The different levels of LOD expresses the gradual development of the BIM, specifiyng points of interest related to the increasing reliability of designs. This effectively describes the development of the model as a set of milestones relating to its attributes, which is a neccesity for using Last Planner™, seeing as the progressively developing work packages in design are hard to associate to its binary attitude towards task completion. In doing so, planners are enabled to pull certain generations of designs only when needed, thus reducing the risk of rework.

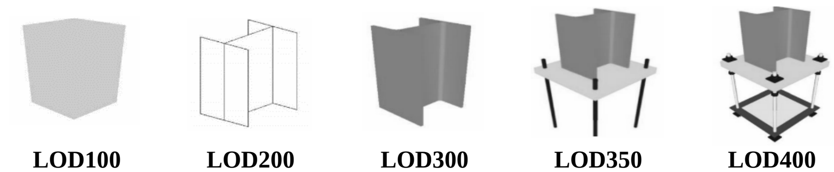

Figure 1: Visual illustration of LOD-levels for a column (BIMForum 2017)

Table 1: Example of generic LOD-levels (BIMForum 2017)

Levels	Description
LOD100	Graphical representation in the model as a symbol or a generic object.
LOD200	Graphical representation in the model as a generic object with approximate quantities, size, shape, location and orientation.
LOD300	Graphical representation in the model as a specific object with quantities, size, shape, location and orientation.
LOD350	Graphical representation in the model as a specific object with quantities, size, shape, location, orientation and interfaces with other building systems.
LOD400	Graphical representation in the model as a specific object with quantities, size, shape, location and orientation with detailing, fabrication, assembly, and installation information.
LOD500	A field verified representation in regards to information and geometry.

Although possible to do on a per-object-level, it is often more practical to manage LOD-levels on a section basis when dealing with larger projects, combining multiple objects within the same room, floor, or similar to define larger sections of the BIM. The relative size of these sections ultimately determines the degree of specificity LOD will be managed in the project. In keeping with theory, the specificity should be managed in a way such that designers and other stakeholders are enabled to understand design development as two distinct processes. Firstly, the process of developing a specific section from idea towards production ready design, and secondly, the process of interactions and inter-dependencies between sections as they develop, influencing the design space and functional requirements of each other as they do so. In addition, effective concurrent communication can only be established once the model state is accurately communicated to designers. Surmising these aspects, theory dictates maturity-based design-approaches as presented in Table 2.

Table 2: Theoretical approaches to aspects of BIM-based workflows

Aspect	Approaches from theory
Specification of maturity levels	Requirements for an object achieving a certain maturity should be related to make-ready of future tasks. Being unrelated to the volume of detail, levels should specify the necessary information for model progression towards value creation.
Degree of model disaggregation	The disaggregation of the BIM into sections should be done in such a way that the amount of information within one section remains comprehensible for all designers, and so that all project participants are enabled to understand the overall development of sections.
Communication of model maturity	The method of communicating the maturity levels of the different parts of the model should enable designers to know the fitness of the information they are working with, without being needlessly complicated to manage.
Planning and control of workflow	Planning tools for visualizing and optimizing flow of work during design, such as Last Planner, should be used. LOD deliveries should be incorporated into plans.
Responsibility for assigning maturity	In keeping with principles from Last Planner, having the designers declare the maturity of their own work increases their ownership to tasks and responsibilities.

CURRENT APPROACHES

TIEDEMANNSBYEN

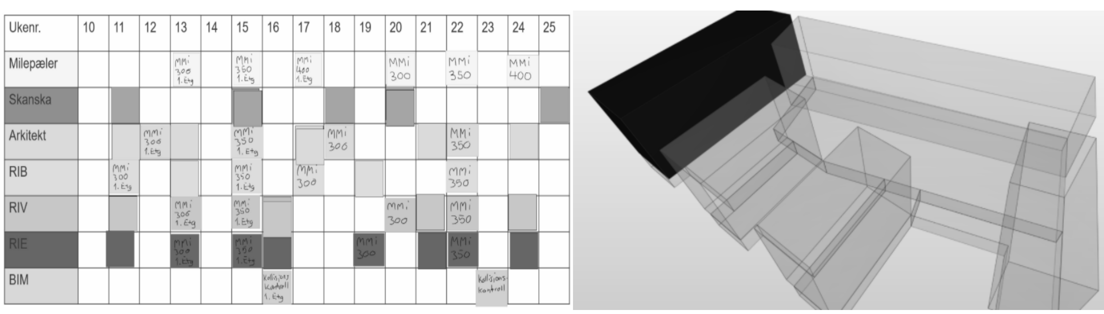

Figure 2: Model sections (left) and MMI-milestones in Last Planner (right)

Implementation of model maturity was done according to Skanska Norway's guidelines for using MMI (Model Maturity Index, which in practice uses the same maturity levels as LOD with simplified descriptions and the inclusion of a "MMI250"-level"). The model was separated into ten sections, one for every basement and building in the complex (Figure 2). Maturity was assigned to all geometry managed by each discipline within each section. The design team was coordinated in ICE-sessions utilizing Last Planner™ for planning and control. Milestones for different sections achieving MMI was represented by post-it notes in Last Planner (Figure 2). Management opted not to develop a specific tool for communicating the development of model maturity, relying on designers being up to date regarding model maturity from the weekly ICE-sessions.

Maturity deliveries for the 300-, and 350-level were controlled by BIM-coordinators. Maturity levels were tied to specific tasks that designers were required to accomplish. In addition, weekly charting of the number of collisions detected in the model was used as an indicator of progress, both externally and for the design team.

E6: ARNKVERN-MOELV

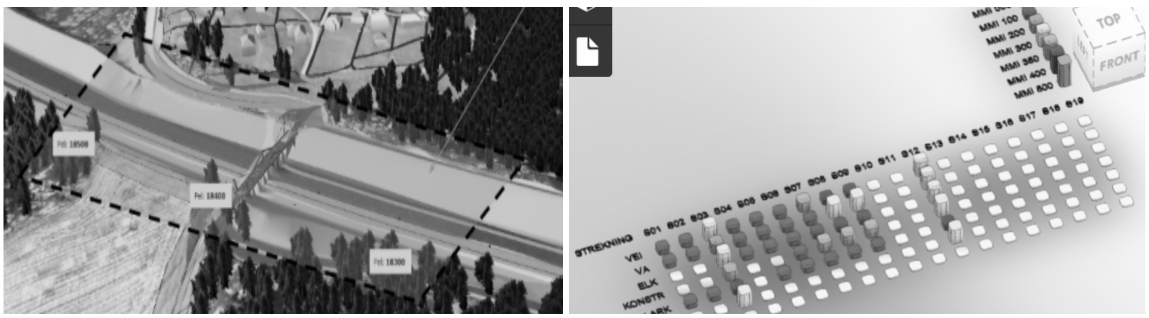

Figure 3: Example of section (left) and Visualization of MMI-levels, sections on x-axis, disciplines on y-axis (right)

Arnkvern-Moelv was conducted with a similar approach to Tiedemannsbyen, using similar maturity levels for large sections (Figure 3) in addition to ICE-meetings and Last Planner™. Differences include use of a 3D-chart for visualizing development of model maturity (Figure 3) and the absence of collision-control metrics to indicate progress. The exclusion of these metrics was not made because it was impossible to do, but rather the fact that it would not benefit the design process. This is a result of the project being a road, which generally is less constricted by small geometrical tolerances and intersections than building projects. MMI-levels were based on functional requirements for design deliveries, and often tied to specific tasks. Level requirements were adjusted per discipline in order to more accurately reflect individual functional requirements of different deliveries.

EXPERIENCES FROM CURRENT APPROACHES

RESULTS COMPARED TO TRADITIONAL APPROACHES

Practitioners from both cases cited the following differences in design work compared to traditional practice:

- **Increased understanding of the current state of the BIM model:** Designers reported having an easier time understanding the extent to which they could rely on the information they were working with.
- **Increased understanding of needs and responsibilities:** Designers reported having a better understanding of what they were supposed to deliver, as well as providing clear guidance to other designers regarding what information they needed.

- **Increased sharing of incomplete information:** As opposed to traditional means of withholding incomplete designs from other disciplines, designers were now enabled to systematically share qualified incomplete information.
- **Increased ability for project participants to express project development:** In contrast to traditional practice (having designers make subjective approximations of design development to external stakeholders), project progress was now quantifiable and easily understood by everyone.

The tracking of the number of model clashes for Tiedemannsbyen illustrates cultural inertia in adoption of new technologies. Performance was initially sub-par, the team missing all relevant deadlines for the first of the five buildings (Figure 4).

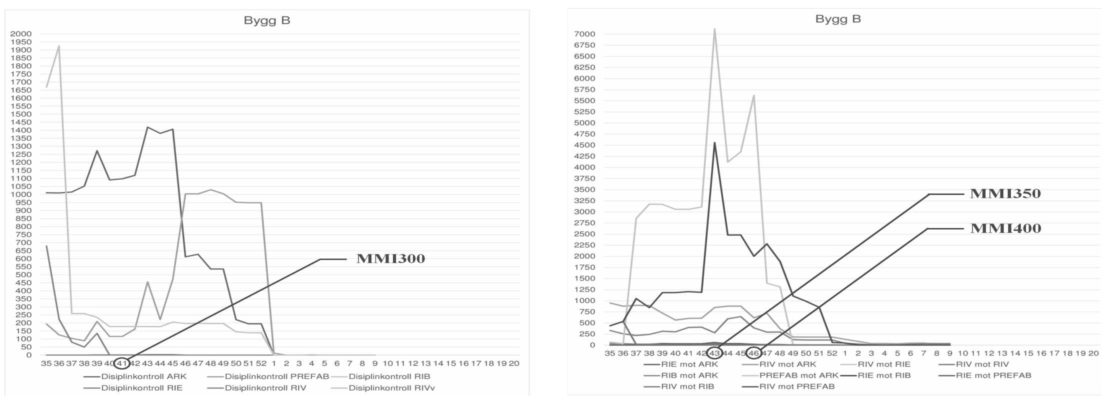

Figure 4: Weekly charting of the number of clashes within "Building B", disciplinary (left) and interdisciplinary (right), Tiedemannsbyen.

Although the team was unable to meet its deadlines for the first section, efficiency and reliability in meeting deadlines grew as the designers were increasingly exposed to the framework. Four months later, during the design of the third building, the model matured sufficiently to enable the same team to meet their deadlines (Figure 5).

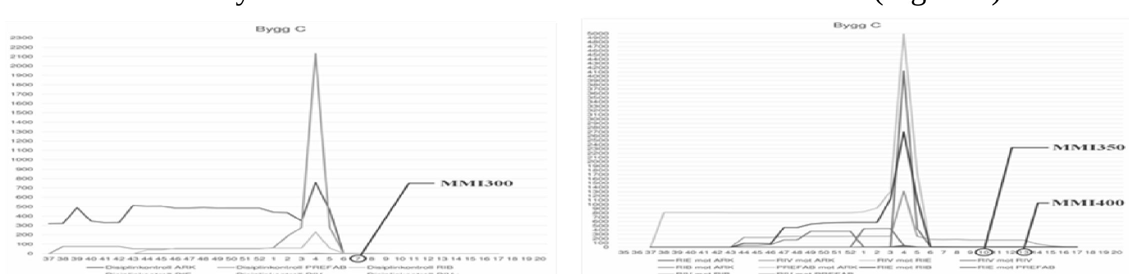

Figure 5: Weekly charting of the number of clashes within "Building C", disciplinary (left) and interdisciplinary (right), Tiedemannsbyen.

Although in some cases showing a slight tendency to inversely correlate to the number of tasks, Percent Plan Complete (PPC) remained around 80% for the entire project, while the number of tasks completed per week increased by 69% from the average number of tasks completed in weeks 36-1 to the averages recorded in weeks 2-10 (Figure 6).

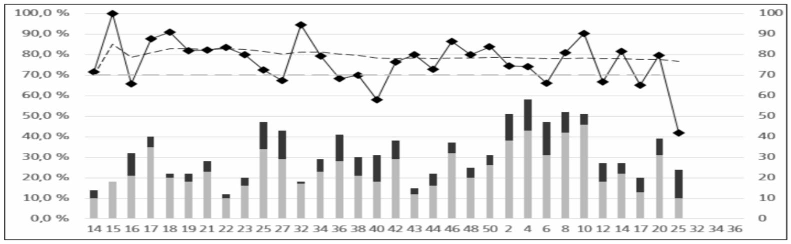

Figure 6: Tracking of PPC (linegraph) and number of tasks (bars), Tiedemannsbyen

It should be noted that Figures 4 and 5 reflect the total number of clashes in the BIM, including several cases of objects clashing with no relevance to constructability. However, this automated weekly chart generation requires little effort and is used to track trends rather than absolute number of clashes. More thorough clash reviews were performed specifically at MMI300 and 350 both by each discipline and by the project's design manager. Although some improvements are to be expected by designers throughout a design project, the trends in the graphs reveal a significant shift in practice, especially when considered relative to the increase in the total number of tasks completed per week.

REFLECTION ON IMPLEMENTATION APPROACHES

The following positive observations regarding implementation were made:

- **Voluntary adoption by designers:** As a sign of successful implementation, designers resolved to use the system rather than reverting to traditional practices.
- **Management of maturity for large sections rather than individual objects was regarded as a factor for success:** While remaining small enough for designers to comprehend the amount of information within each section, the larger sections made it easier for all project participants to understand the overarching flow of the project. Management of maturity on a per-object level would render this unfeasible.
- **Simple visual aids greatly benefited designers:** Graphing collisions per week as in Tiedemannsbyen or charting maturity in 3D as in E6: Arnkvern-Moelv exemplified relatively minor undertakings which greatly improved communication of model state, increasing the transparency of project flow for all participants.
- **Case-specific adjustments were regarded as a factor for success:** While keeping a certain level of standardization of the system, flexibility in including or excluding functionality based on unique project circumstances made implementation easier.

On the other hand, the following areas of improvement were discovered:

- **Lack of clarity in MMI-level specifications:** Designers cited somewhat ambiguous specifications for MMI-levels, which at times required subjective interpretations from the designers as to what they were supposed to deliver.
- **Lack of software guidelines:** Several minor issues hindering communication due to lack of clear guidelines for software use were reported. Designers were in some

cases working with different datums and units, in addition to being unable to load different files due to server-side errors or faults related to naming conventions.

- **Third party evaluation of model maturity required:** Designer did on some occasions deliver models which was not mature enough to warrant a new MMI-level. The inclusion of a BIM-coordinator evaluating deliveries proved necessary.
- **Cultural inertia:** As with any efforts to implement new methods, one of the greatest obstacles to success was the inability or reluctance of some designers to change their existing practices.

REQUIREMENTS FOR SUCCESSFUL MANAGEMENT

Positive results in implementation in both cases can largely be attributed to an approach of establishing a simple foundation for standardization and continuous improvement. The solutions to the first three aspects in each case illustrates this, where efforts have been made only to implement what is necessary for adjusting designers to a new way of working. After all, the tasks designers were responsible for carrying out were the same as before, the only difference being the process-related context now associated to the tasks. The importance of this approach is made further evident in the observation that cultural inertia was deemed to be one of the biggest obstacles for successful implementation. The results also highlight the fact that the software is in no way finalized or fool-proof, requiring management to pre-emptively address common pitfalls. This observation may serve as a reminder that design management is still an exercise in managing people, despite technological innovations.

The maturity-level specifications were discovered to have the most potential for improvement, being relatively simple in its current state. Although room for improvement was discovered, theory cannot go further than to suggest that these levels should reflect the functional requirements necessary for pull actuation of future tasks, recognizing that more detailed specifications of levels would differ with discipline and type of project.

The management approach of separating models into larger sections and managing these sections by discipline, rather than trying to manage individual objects, was determined to be a factor underpinning success in both cases, serving as a better way of explaining the overall model development from concept to final design.

Although both projects illustrated a necessity for standardization of practice, having some flexibility in management approaches was also deemed necessary. The solution to this issue given in the cases was to standardize functionality, yet provide the ability for management to choose which functionality to implement on a case by case basis.

CONCLUSION

Findings illustrate that there is a theoretical case to be made for maturity-based management as an enabler for using Last Planner™ in BIM workflows, and that experiences from case studies seem to support this notion. In practical terms, projects utilizing maturity-based management indicates a greater ability to communicate model state and progress as well as designer needs and responsibilities, resulting in the design process being more transparent and manageable. Successes in adoption can be attributed to a practice of utilizing standardization and continuous improvement while still allowing for a certain degree of flexibility in project implementations.

Based on theory and experiences from case studies, recommendations for using maturity-based management of BIM workflows are as listed in Table 3.

Table 3: Management recommendations based on theory and case experiences

Aspect	Recommendations
Specification of maturity levels	Maturity-levels are based on the future functional needs, formulated as specific tasks. Tasks are specified for each level, per respective discipline.
Degree of model disaggregation	Segregation of model into sections as large as possible without making the amount of information for each discipline within each section incomprehensible for designers (Examples: Figures 2&3).
Communication of model maturity	Visualization of maturity per discipline, per section in a chart, possibly excel (Examples: Figure 3).
Planning and control of workflow	Last Planner™ and ICE. Milestones for maturity-levels are attributed to post-it notes used as deliveries in collaborative planning.
Responsibility for assigning maturity	Designers should feel ownership to the maturity of their tasks, although an independent evaluation of maturity may prove necessary until level-requirements has been sufficiently standardized to avoid misunderstandings.

It should be noted that a vital point of success for implementation in both cases has been the simplicity in their approach, as well as successful, project-specific choices made by management. Having historically been approached as an object-level attribute, one could make the case that failed LOD implementations in the past have been a result of pushing needless functionality instead of pulling technologies from project needs. After all, the positive yields documented in this study does not come from a radical change in practice, but rather a simple approach of associating existing work and tools to project development.

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CAN BIM FURNISH LEAN BENEFITS - AN INDIAN CASE STUDY

Nilay Singhal[1], Ritu Ahuja[2]

ABSTRACT

Building Information Modelling (BIM) is recognized as an enabler for proficient accomplishment of projects in construction industry at different levels. Various benefits have been achieved globally through BIM implementations including enhanced visualization, collaboration between stakeholders throughout the project life cycle, time and cost savings, value engineering, change management and many others. Harnessing the BIM capabilities efficiently to gain maximum benefits on the projects can be a major milestone for the Indian built environment sector. For this study, BIM has been identified as an effective process for achieving various lean benefits for construction projects in India.

The project envision BIM as a catalyst for improving the current scenario of Indian construction sector. The paper is based on exploration case based research methodology wherein, both literature review and semi-structured interview have been done. Relationship between BIM and lean by studying the use of various BIM capabilities on construction projects from initiation stage till operations and maintenance stage has been established. Lean benefits corresponding to each BIM capability has been reported upon validating in discussions with the industry experts and literature review.

KEYWORDS

BIM, Collaboration, lean construction, Indian Construction sector, Value.

INTRODUCTION

Indian construction sector is well known for its fragmented nature yet it is economically as viable as other sectors (More et al. 2016). From the past research, it is evident that construction impacts environmental, economic and social aspects of built environment (Rahman et al. 2013). Therefore, it becomes imperative for the stakeholders in this field to exercise effective pre-construction, construction, operations and maintenance strategies

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and their subsequent implementations. Sustained growth in Indian economy has called for faster and quality construction practices by overcoming impediments—outdated technology, lack of training, poor planning, fragmentation, etc. Hence efforts are being made to yield quality products and services, benefits and assured return on investment (More et al. 2016). Lean construction is based on the underlying concepts and principles of the Toyota Production System (TPS) that focuses on waste minimization, enhanced delivery of value added product and services to customers, and continuous improvement (Sacks et al. 2009). BIM as defined by the National Building Information Modelling Standards (NBIMS) committee of USA is a digital depiction of physical and functional features of any infrastructural facility (Chougule and Konnur 2015). BIM also known as Virtual Design and Construction (VDC) has been reported to be in its experimentation stage in India (Sawhney 2014). Lean has helped in maximizing profits in Japanese manufacturing units. Thus, amalgamation of BIM and lean can bring surplus benefits to the construction industry (Bolpagni et al. 2017). There exists a synergy between lean and BIM (Sacks et al. 2009). BIM capabilities can be interpreted as potential characteristics resulting in functions or specific tasks that can be performed to accrue lean benefits on construction projects. This paper discusses the lean benefits of implementation of BIM on construction projects in India and reports a robust framework for case studies of the same.

LITERATURE REVIEW

Literature review acts as a foundation for this paper for which previous publications have been used to develop a BIM-Lean framework for case studies depicting BIM capabilities, their subsequent lean benefits. It has been reported that independently developed lean construction practices can be effectively leveraged by implementing BIM (Gerber et al. 2010). According to a UK based case study for design and construction of prison system, lean was the first deciding step on their path to BIM implementation (McGraw Hill Construction 2014). BIM directly contributes to lean goals by improving predictability, collaboration, discipline, learning and implementation (Koskela 2014). Reasons for such a close relationship between BIM and lean can be attributed to following BIM capabilities and lean benefits as identified through an extensive literature review in sections below—

BIM CAPABILITIES

BIM provides a common platform for stakeholders to work in a collaborative environment (Rokooei 2015). BIM helps in capturing reality, minimizing wastes and rework, conflict resolution, work sequencing, automation and customization (Ball 2014), value generation and improved workflow (Mollasalehi et al. 2016). Visualization of the proposed facility early in the design phase helps in realising what the proposed facility will look like upon completion (Mollasalehi et al. 2016). BIM simplifies quantity extraction, preparation of Bill of Quantities (BOQs) and accurate cost estimates (Raphael and Priyanka 2014). BIM capabilities such as Clash detection, 4D Scheduling, construction sequencing, collaboration and communication have been utilised extensively in previous projects (Sacks et al. 2009). Design coordination, Energy and performance analysis, digitised walkthroughs, Generation of "as-built" models help in value addition

(Muthumanickam et al. 2012). Integrated Site Planning, Change Management, Structural Analysis, BIM for Supply Chain Management (Ahuja et al. 2017), Code reviews, Fabrication/shop drawings, Forensic analysis, (Azhar et al. 2008) can be achieved to accelerate the project realization. Past researches have demonstrated that organizations are reluctant to adopt such innovative technological solutions due to scepticism (Premkumar and Roberts 1999). Identification and evaluation of risks and challenges at an earlier stage improves the effectiveness of technological advances (Chien et al. 2014). Availability of technical expertise will encourage BIM adoption (Ahuja et al. 2016). Favourable attitude towards BIM, availability of BIM based softwares on trial basis and consistent beliefs and values for BIM adoption catalyses the implementation of BIM in Indian scenario (Ahuja et al. 2018). At the same time BIM implementation faces challenges because of lack of standardization and complexity in processes (Ahuja et al. 2018). Capabilities of BIM facilitate the collaborative management of Construction and Demolition Wastes (CDW) (Akinade et al. 2018). However, at the same time it must be realized even though there a single model on which entire team of specialists works, yet there is loss of tribal knowledge because specialists are either shifted to new projects or they migrate to other firms (Barista, 2014). Such a turnover may lead to indirect form of waste in construction on account of loss of knowledge, skills and expertise. It is of utmost importance that the project management team should realize the benefits of BIM capabilities (Rokooei 2015) and disadvantages of disguised turnover of expert manpower (Barista, 2014).

LEAN BENEFITS

Increasing the customer satisfaction, flexibility, application of best working practises to gain competitive advantage over rivals propels lean adoption (Salonitis and Tsinopoulos 2016). Lean promotes continuous improvement at work places by creating an environment of mutual trust, respect and harmony (Banna 2017). It minimizes wastes, i.e. activities that do not add value to client’s demands (Skhmot 2017). Overproduction, delays/ waiting, over processing, unnecessary motion, inventory costs, knowledge scatter, wishful thinking and under realization of skills are identified as wastes (Larman and Vodde 2009). Lean processes help to improve worker’s safety and increase staff productivity by enhancing communication and collaboration within project teams (Karakhan et al. 2016). A survey conducted by McGraw Hill Construction reports lean practitioners achieved greater customer satisfaction and higher construction quality as key lean benefits (McGraw Hill Construction 2013). As per Construction Lean Improvement Programme (CLIP), organizations that adopted lean under its guidance achieved improved communication, team dynamics and waste minimizations which also saves money and effort (CIRIA 2003). Primary objective is to identify value addition from customer point of view and consider the interrelatedness and interdependence between the stages any project (Bade and Haas 2015). Proactive involvement of project team members and healthy competition leads to reduced project schedule (Riddell 2017). An interesting study regarding the BIM implementation and lean benefits resulted in formulation of a matrix which has been termed as BIM-Lean framework for case studies in this paper.

RESEARCH METHODOLOGY

Two projects were identified for conducting this study which helped in countering the following queries:

- What capabilities of BIM have been implemented on two of the construction projects in India?
- What potential lean benefits can be accrued by implementing BIM?
- What lean benefits have actually been accrued in the selected case studies?

In order to answer the above questions, an exploration based case study approach was adopted. (Yin) defined case study as an empirical investigation that examines an existing phenomenon within its real-life context especially when the boundaries between phenomenon and context are not distinctly obvious; and which uses either single or multiple sources of evidences. For this paper two case studies based on exploration of real life event are used to depict relationship between BIM and lean in order to specifically report various lean benefits which were obtained by effective implementation of different BIM capabilities. Following procedure as shown in Figure 1 has been adopted for the paper—

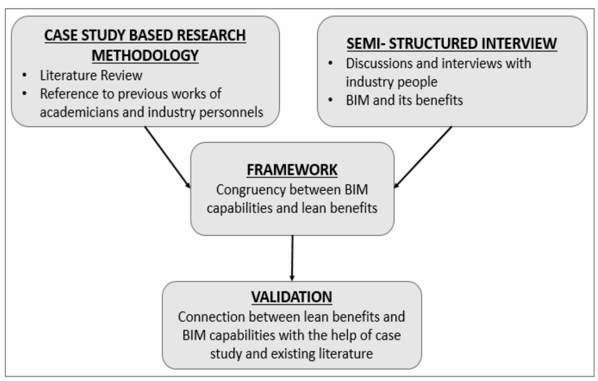

Figure 1: Research Methodology Flowchart

- Literature Review: As exploration based case study demands prior fieldwork and data collection to lay a concrete foundation for the study (Zainal 2007). Different BIM capabilities that are being utilized globally have been explored via existing literature and previous works of academicians and industry experts. Similarly, the lean benefits based on the principles of lean philosophy have also been identified.
- Framework: Based on extensive literature review and subsequent study and analysis, semi structured interviews with industry experts were conducted to identify what BIM capabilities have already been used and are being used in the selected Indian case study projects. There was specific interview and discussion with respect to each BIM capability with the expert working on that particular functionality of BIM. Subsequently, different lean benefits complementary to the accrued BIM capabilities were discussed with the experts via semi-structured interviews and reported in the form of a framework.

- Validation: The framework so developed upon the basis of literature review and semi-structured interviews was subsequently validated by the industry experts. There were series of detailed discussions held with the experts. Based on which analysis as to what, when and how each lean benefit was achieved while implementing or after having implemented a particular BIM capability. The experts are having an experience of more than fifteen years working in the construction and modelling industry and have been working on 5 dimensional BIM based projects both in India and abroad.

CASE STUDY PROJECTS

PROJECT 1

A commercial retail centre with a gross built up area of 35000 m^2 is being built in one of the cities of India. Client and General contractor mutually agreed for BIM based project implementation. A BIM consultant was thus hired BIM. Execution Plan (BEP) which is a contractual document that delineates roles and responsibilities of team members (Aungst 2017) and specifies guidelines for BIM implementation was prepared. Training sessions were organized by the BIM consultant to train the team on BIM based technologies for the project. Meetings and discussions were periodically conducted.

Preconstruction Phase:

Architectural, Structural, Mechanical, Electrical, Plumbing, Furniture and Fixture (MEPFF) drawings were prepared initially using 2D CAD in compliance with Level 1 (McPartland 2017) BIM implementation. Conceptual models were prepared using 3D CAD. Architects team developed Revit models with a maturity level of LOD 300 from Good for Construction (GFC) drawings and Enscape plug-in was then used with Revit to develop a Virtual reality (VR) model. MEPFF models were developed with maturity level of 400. Models were shared on a Common Data Environment (CDE) to enable real time discussions and coordination between team members. This improved transparency, information sharing, motivation, reduced rework and reduced duplicity of efforts. Walkthroughs helped in detecting clashes of services with the architectural and structural components to prevent time and cost overruns during execution stage. Material quantities were extracted directly from the Revit model and exported to excel file to prepare Bill of Quantities (BOQs). Construction schedule prepared on Microsoft Project (MSP) was imported on Navisworks Manage which was synchronized with previously imported Revit model to perform real time simulations for construction sequencing. Project Management Consultants (PMC) and contractors worked together to finalize the total duration of the project with the help of simulations.

Construction Phase:

Model was meticulously updated with the help of GFC drawings. Contractors at the site simultaneously updated the budget and schedule on the basis of progress to facilitate the development of pour schedules. Walkthroughs enabled planning and positioning logistics - materials, equipment, labour at site to improve safety and avoid irrelevant motions and work activities for increasing productivity at site. Construction Operation Building Information Exchange (COBie) data was updated on a excel file to build data for facility management.

Operations and Maintenance stage:

COBie and Revit models replaced the as-built drawings with rich and real time information. This information will be useful in maintaining and keeping the facility up and running with enhanced safety and minimized lifecycle costing.

The connections between BIM capabilities and various lean benefits reported has been presented in Table 1 below wherein, (•) means that the particular lean benefit was obtained to the corresponding BIM capability and (•) means that the particular lean benefit was not obtained to the corresponding BIM capability.

Table 1: BIM-Lean framework for Project 1

STAGE	BIM Capabilities	Worker safety	Increased staff productivity	Improved communication	Reduced project schedule	Reduced lifecycle cost	Continuous improvement	Better risk management	Waste minimization	High quality construction	Improved team dynamics	Greater Customer satisfaction
PRE-CONSTRUCTION (Project 1 and 2)	Design coordination	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Visualisation/ walkthrough	✓	✓	✓	×	×	✓	✓	✓	✓	✓	✓
	Quantity take-off	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	4D Construction Sequencing and Scheduling	✓	✓	✓	✓	×	✓	✓	✓	✓	✓	✓
CONSTRUCTION (Project 1)	4D construction sequencing and tracking	✓	✓	✓	×	×	✓	✓	✓	✓	✓	✓
	Cost Tracking	×	×	✓	×	✓	✓	✓	✓	×	×	✓
	Safety Management	✓	✓	✓	×	×	✓	✓	✓	✓	✓	✓
	Collaboration and coordination	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OPERATIONS and MAINTENANCE (Project 1)	As- built drawings and models	×	×	✓	×	×	✓	✓	✓	×	×	✓
	Facility management	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓

The BIM capabilities and lean benefits listed in the table are based on findings from the literature review. However, the interrelationship between the two as depicted above has been thoroughly investigated and validated by discussions with industry experts.

PROJECT 2

A renowned Indian Public Sector Undertaking (PSU) has proposed the construction of— 2 halls (500m^2) in the existing building, Bungalow (494.12 m^2), Guest house (1052.11 m^2) and a multipurpose hall (556.7 m^2) at its Northern region headquarter in Lucknow, India estimated close to INR 232 cr. A leading engineering and architectural firm situated in Noida, India has been awarded contract for design development and construction. Based on the project brief they presented to the client their intent for implementing BIM supported by their own BIM success stories in previous projects. The team impressed with the capabilities and advantages of BIM agreed for implementing it in the pre-construction stage.

Pre-Construction Stage:

A local architectural consultant in Lucknow was hired by the awardee to facilitate information exchange. The local architect created a CAD based conceptual design based on project brief which was subsequently revised and updated by the leading contractor for primary approval by the client. After approval REVIT based model was prepared which was used to estimate quantity, prepare BOQ and cost estimate, detect clashes, prepare site logistics plan, compliance with local and Indian standard codes. Client received a real time view of the proposed facility which encouraged active participation from their side. There was a reduction in efforts as any changes suggested by client was simultaneously updated on model which greatly enhanced information reliability and developed client's trust and interest in BIM. Construction schedule, work sequencing was formulated to facilitate risk minimization and increase quality at minimized cost in a safer work environment during project's lifecycle. Influenced by BIM capabilities and benefits client team is planning to implement the same in execution stage. The BIM capabilities adopted and the benefits reported at the preconstruction phase of this project are also similar to Project 1 preconstruction phase.

DISCUSION AND CONCLUSION

Preliminary findings for Project 1 and Project 2 are reported in the BIM-lean framework in Table 1. The lean benefits facilitated by BIM implementation has been discussed and compared with global literature. BIM synergises the entire project team working on the project. They can coordinate simultaneously while designing building elements- slabs, columns, beams, stairs, walls, fittings and fixtures, etc. of the same model and any changes made by one party are visible to the other to obtain holistic view of the facility and effective project documentation. Project team can leverage their skills, experience and expertise to devise risk management strategies while nourishing the design development with optimised resources to maximize value addition, customer satisfaction. A very important aspect of design coordination is clash detection. Previous studies also report that BIM enables visualisation of the building elements-MEP, architectural, structural to avoid any physical hindrance by one component to another (Dave et al. 2013). This saves time, money, material and human effort, because if clashes occur during execution, it will delay the work and leads to wastages. Project team members and client get a better understanding of the design. Walkthroughs helped the client to connect dots in design development. Thus lean benefits such as Worker safety, enhanced staff productivity, communication, waste minimization, customer satisfaction, improved team dynamics, construction quality and better risk management were achieved. This is in congruence with the case on Shanghai Tower in China that formally declared a total material savings of thirty two percent using Revit and Navisworks Manage by visualizing clashes and accelerated progress (Autodesk, 2012). During design development of its basement seven clashes were identified and during construction there were no clashes at all. 4D construction sequencing and scheduling implemented in the above projects is a combination of a BIM model and project schedule which enables visual analysis and simulations to prepare risk management strategies (Dawood et al. 2002). It also helps in preparing a site management plan. 4D model can be used to guide procurement of resources and positioning of equipments and temporary structures at site. BIM models facilitated automated quantity take offs. When we use BIM models we need not to measure each and every detail by entering commands as we used to do so while using AutoCAD, instead BIM authoring softwares such as REVIT provides the advantage to generate automated schedule of quantities from the parametric data of the model elements. In case there are any changes made in the properties of elements, the same gets easily updated in the revised schedule which allows savings in time and human efforts apart from assuring accuracy. Client gets quick access to cost estimates to help him finalise the project's scope. As per the case study by (Franco et al. 2015), during calculation of total quantity of dry wall using traditional CAD practise and BIM based model, BIM resulted in total savings of two percent on Drywall panels as it also considered the openings for doors and windows. BIM reduced total cost by fifteen percent. This incentivised increased confidence in documentations, collaboration, coordination, accuracy and productivity.

Storage and maintenance of 2D as-built drawings is a tedious task also it becomes difficult for the new members to understand the design in absence of the team that worked on it. Using BIM as-built models containing detailed information and history of changes regarding each element can be prepared. BIM is an enabler which helps to eradicate basic causes of waste generation— improper and unexpected design changes, poor procurement and control, planning, inefficiencies in material handling, residues of raw materials, and rework (Cheng et al. 2015). This is exactly in line with the collaborative approach between BIM benefits and Lean principles of construction.

UNESCO declared world heritage site Opera House, Sydney is managed using Industry Foundation Class (IFC) format for interoperability of BIM files. It has reported following advantages— contacting the concerned department in case of element failure, retrieve history of elemental revisions, maintenance, visualisations, simulations, security, improved customer service (CRC Construction Innovation 2007).

Findings in this paper are compatible with the previous works and evidences. BIM tends to yield lean benefits, increased confidence in project team and improved work flow. Societal demand, organizational acceptability, technical complexities are key factors to the implementation of BIM (Tulenheimo 2015). No prominent success stories of BIM are available with respect to the Indian context (Sawhney 2014). The same is evident in a model by (Ahuja et al. 2016) wherein entire project is categorized at macro-level, organizational team at meso level and its members at the micro level which places BIM adoption between micro and meso level. This suggests that BIM is majorly used in pre-construction stage for designing purposes which is in congruence with the project 2 as mentioned in this paper. Even though the project consultants are willing to implement

BIM yet, clients are quite reluctant to implement the same because of long lead time for scale implementation, lack of awareness and high training costs (Ahuja et al. 2018). One of the case study participant expressed the necessity for governmental initiatives to encourage and facilitate BIM adoption in India. India needs to develop expertise in BIM implementation and invest wisely for better Return on Investment as reported in the past projects.

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LEVERAGING ADVANCED VDC METHODS AND REALITY CAPTURE TO INCREASE THE PREDICTABILITY FOR PREFABRICATION

Zach Murphy[1], Durga Saripally[2], Sahil Dhakla[3], Rudy Trujillo[4], Eric Luttmann[5] and Aiswarya Sreekumar[6]

ABSTRACT

Construction processes happen in partially controlled environment; resulting in prefabricated components being vulnerable to variances resulting from deviation in quality of work put in place. However, wider adoption of VDC methods and advances in Reality Capture technology has opened up avenues for adopting prefabrication in construction projects by enhancing predictability using two methodologies. First, the use of advanced VDC methods to create highly detailed and coordinated models. Second, incorporating deviations in installed/existing building components using as-built 3D models created from laser scans of the construction site.

This paper focuses on case studies of commercial projects in the USA that have prefabricated interior wall partitions, resulting in higher productivity and quality. Further, it would outline the processes and workflows used by a global team, located in the USA and India; concluding with quantitative and qualitative benefits observed on these projects.

KEYWORDS

Lean Construction, Prefabrication, Reality Capture, VDC, digital fabrication, assembly

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INTRODUCTION

Construction projects are nonstandard, unique, single-order and single production products (Arditi and Gunaydin 1997). Unlike manufacturing and other productions, which have fixed site and similar production conditions, construction production sites always display non-standard site conditions and installations. Consequently, due to non-repeating activities, lack of clarity and non-uniform standards, variations occur in the quality of work in-place. In current practices, the subsequent trade activities adjust and absorb variations. This limits the scope of prefabrication in construction projects. When construction defects are detected later during prefabricated trade installation, they can have cost implication in the form of rework on site and delays.(Vishal et al. 2015) This causes quality concerns when prefabricated elements must be assembled in place on site.

However, wider and deeper implementation of VDC methods allows to leverage the technology to prefabricate different building elements. This work attempts to showcase an approach for detecting and enhancing predictability for variances and accommodation for tolerances on site. This approach can help to capture such deviations early in the construction process for subsequent prefabricated element installations. This is needed since such defects eat into the overall savings made by general contractors and small trade contractors. This could be because of the rework on prefabricated elements which are unforeseen prior to shipping and installation, due to on site variances caused by defects.(Arditi and Gunaydin 1997)

Previous studies of BIM and Lean have explained BIM enabled automated work package creation, resource levelling, value planning, prefabrication, and benefits of coordination through the use of BIM.(Gerber et al. 2010), RFI associated with interface between architecture and structure of a BIM model (Filho et al. 2016), real time supply chain management using VDC and Lean (Cho and Fischer 2010), etc. This paper builds on the findings of the above-mentioned research. In addition, it also delves in the benefits of using Reality Capture techniques in construction projects. Use of reality capture as feedback for prefabricated wall panels is based on the lean theory of continuous improvement. It allows for feedback from site for accurate design of prefabricated elements. The identification and avoidance of risk for prefabricated wall panels during the construction lifecycle is possible by using advanced VDC methods and reality capture. This approach has not been captured in previous studies.

At present there is limited active construction quality predictability approaches being leveraged for prefabrication. The quality of work put in place on the site is subject to a larger tolerance than most activities that are machine controlled. Current surveying and quality checks are not effective. They only provide data at specific location and time to represent work in place. Such data are interpreted manually and are not integrated electronically into project design model and prefabrication spooling information set. However, in digital fabrication, robotic welders use laser for accurate placement– straight from MWF model. Robot welds at +/- 1/8” tolerance for placements taking accurate data from model.

BACKGROUND RESEARCH

OVERVIEW OF THE APPROACH

The study identifies the problems which lead to waste during construction relating to the prefabricated elements -

- waiting: for preparation of element which doesn't have enough clearance, or needs to be provided opening/beam pocket etc. in the prefabricated panel or for chipping of nearby structural element
- defect: in vicinity of location of installation of prefabricated element

And demonstrates solutions using case study to implement lean philosophy with the help of advanced VDC methods and Reality capture. The different approaches are practically implemented in the cases mentioned here, at different stages of the project.

The context of this study is defined by 2 case projects based in the USA, carried out by company P(general contractor) having extensively defined usage of BIM services under the standard services contract with company V, based in India. Project G is a tenant improvement effort for a commercial development in high-tech business park located in Bay Area, USA. Project M is tenant improvement effort for a pharmaceutical research laboratory building in Bay Area, USA. Company D is drywall contractor for both projects.

Finally, the study focuses to evaluate the optimization possible by following these approaches. Personal interviews have been conducted with personnel from project team representing company P & company D. The series of questionnaire administered helped to validate the approach conceptualized through the course of the projects demonstrated here via case studies.

PREFABRICATED PANEL MANUFACTURING - COMPANY D WORKFLOW

Construction of interior walls using light-gauge metal-stud framed walls requires coordination with multiple trades. Construction of metal stud walls happens in three phases that are interspersed by activities of other trades—layout of top track, installation of stud framing, and gypsum board sheathing & finishing. Company D manufactures wall panels, complete with framing for MEP openings, using computer numerical control (CNC) machine based on 3D models developed by company V. The Revit-based 3D models incorporate site constructability considerations and are also coordinated with other building systems (Figure 1). In addition to the elements required for coordination, the model also incorporates location of punches and welds to inform the CNC machine.

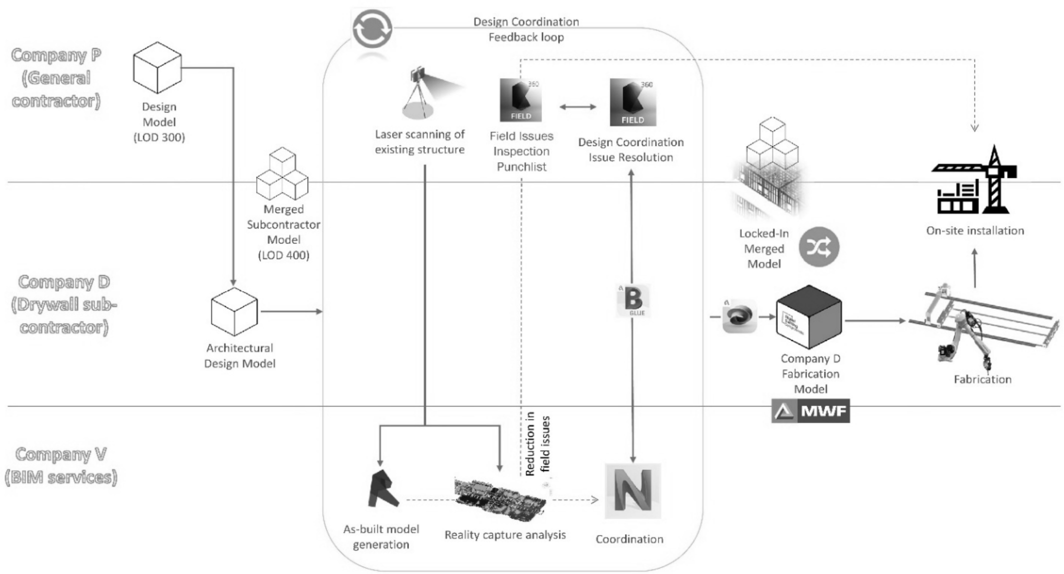

Figure 1: Design coordination feedback loop workflow

VDC METHODS TO ENHANCE PREDICTABILITY

MODELLING FOR FABRICATION

Currently, the design of prefabricated wall panels is done by using the 2D buildout plans & architectural 3D design model as reference. The 2D buildout plans highlight the location of wall panels. However, the 3D model allows to check for constructability & model integrity.

Firstly, a stripped architectural model is generated. Company V creates a basic architectural model in Revit, using 2D design drawings, that contains walls, doors, windows and other relevant elements. The walls are then broken into smaller parts that represent individual wall panels. Using a Revit based plugin, the framing is generated as per design and construction guidelines.

INCREASING PREDICTABILITY - BIM COORDINATION

The drywall framing model is checked for clashes with other systems like HVAC ducting, plumbing and fire protection lines in a federated model. Once the layout of all the systems is finalized after resolution of all clashes, the signed-off models are used to adjust the framing of openings in the drywall model.

This is different from the traditional construction process where MEP openings are framed on site on basis of MEP already installed. It also requires that installation of all systems happen as per the sign-off model. The pre-planning results in a cost savings, better flow of work and faster installation.

ENHANCING PREDICTABILITY - REALITY CAPTURE

Recent development in prefabricated wall panel design process is to bring the feedback for site conditions by using reality capture. The laser scanning of the facility which is under construction allows the possibility of analysing the variation in building components which could be affecting the clearances for the installation of prefabricated elements.

These variations occur due to deviations which evolve while the construction happens on site. For instance, the deviation in floor flatness during the concrete casting. Using traditional VDC method, the height of wall panel which is to be fabricated can be found out by using design model. Whereas, due to deviation of site conditions from design conditions generally, the available clearance height could be varying. Magnitude of this variation depends on the quality check and compliance followed while construction is executed. These variations can be considered by using the construction site point cloud data as reference while generating the 3D model for wall panel prefabrication.

The 3D model generated using this approach considers the on-site variations and helps the prefabrication team to generate accurate height wall panels. The "accurate to site condition" wall panel output is generated from 3D model and used as input for prefabrication in CNC machine. This process removes the possibility of rework and material wastage which occur when the wall panels would not fit in place during installation due to variation in available clearance on-site.

The point cloud data captures site conditions with up to 3mm accuracy. This allows analysis of the relevant components present on-site which pose risk for installation of prefabricated elements. This risk could be either material wastage or rework to fix the wall panel or the component which clashes with it.

ENHANCING PREDICTABILITY – ADVANCED VISUALIZATION AND PLANNING

Advanced visualisation and planning creates benefits for the project in terms of time and cost saving by avoiding unnecessary on-site installation and coordination efforts for different services. The services can be checked for routing and constructability issues before actual installation on site.

The virtual design construction provides a platform for collaborating in the 3D model environment, the different systems which are to be built or are already present on site before construction. The analysis of the 3D model for various purposes such as coordination, constructability check, model integrity check etc. provides enhanced predictability for components which must be engineered to order.(Tillmann et al. 2015)

Using digital fabrication, the involvement of robots and 3D model provides better predictability and quality assurance. Predictability is enhanced due to usage of 3D visual models and lesser manual intervention.

CASE STUDIES

The drywall subcontractor, company D, executed wall panel fit-out job for project G & project M. Drywall installation effort for Project G was carried out precedent to project M.

There were few coordination and constructability issues faced by team during project G. Such as, some panels could not be installed on-site since they were not coordinated with the accurate as-built core & shell structure. Also, panels were not coordinated with MEP trades from sequencing standpoint. This lack of sequencing communication led to delay in panel installation. This was because, the MEP trade subcontractor had to remove their elements while drywall subcontractor waited. At few locations, MEP trades could not remove runs and multiple wall panels were re-fabricated with modification or were adjusted manually on-site while doing installation effort.

In project G, structural model based on record drawing did not accurately reflect the site conditions. To update the structural and fire protection pipes model as per as-built conditions, a detailed QC was done using point cloud data as reference. The deviations were captured in the modified as-built model. This accurate as-built model was then used for coordination of all subsequent trades.

Company P site team was provided with a heat map (Figure 2) showing the 2D graphic representation of the variation in floor height. The floor slope analysis was done before arriving at site, so that the team could plan for fixing potential issues which would affect the wall panel installation. The upfront effort streamlined panel installation. Further, no effort was spent onsite in changing the panels to site conditions. The team identified areas where floor is to be chipped/grouted or filled for creating levelled surface. A dedicated team worked on surface preparation using heat map before wall panel fixing team started panel installation effort. This allows to streamline the process of installation of prefabricated dry wall panels, avoiding rework and material wastage.

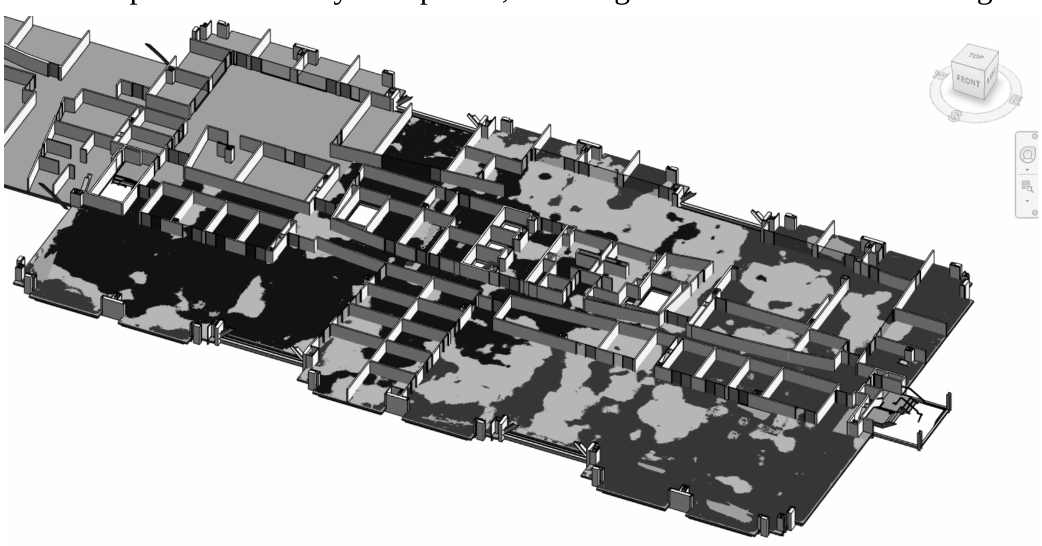

Figure 2: Heat map generated from point cloud data referenced on the wall panel design model

Also, a floor 3D model was developed in Revit from point cloud data, which reflected actual site conditions. The floor model with 1/8th in. accuracy was created using automated process to pick the available point cloud data. This 3D as-built floor model was clash-coordinated with the wall panel 3D model in Autodesk Navisworks to identify places having insufficient clearance causing potential issue of material wastage or rework on site. The clash report was generated to identify major clashes, using which adjustment were done in wall panel design model and notified to team working on site for installation effort. (Figure 3)

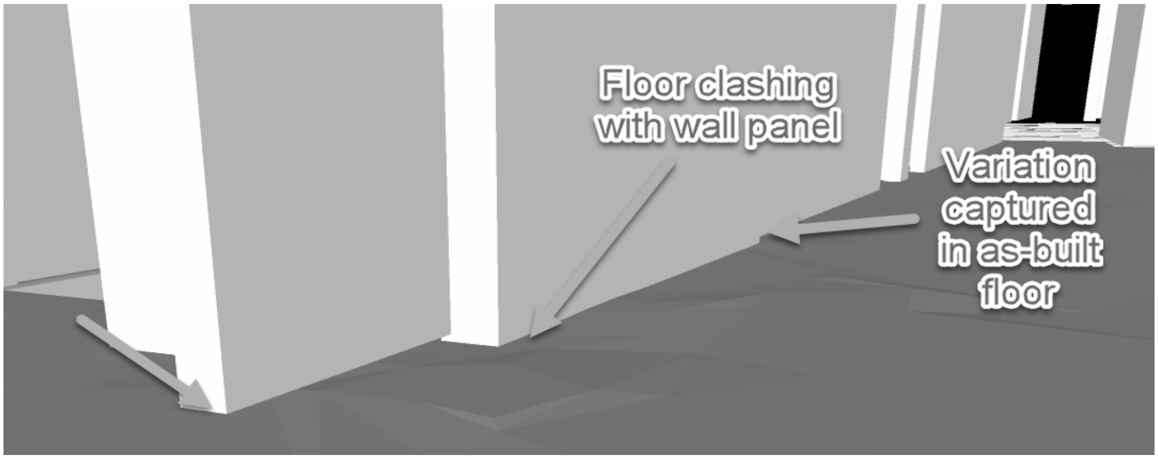

Figure 3: As built floor clash check with wall panels

Evolving the workflow along the course of these projects, during the prefabricated wall panel designing process for project M, the drywall modelling team utilized coordination and reality capture feedback loop during the wall panel designing phase. The cut-outs and openings were coordinated in the wall panel for fabrication model. The panel was fabricated with the MEP openings in the panel. This allowed transferring of on-site efforts to factory conditions. (Figure 4)

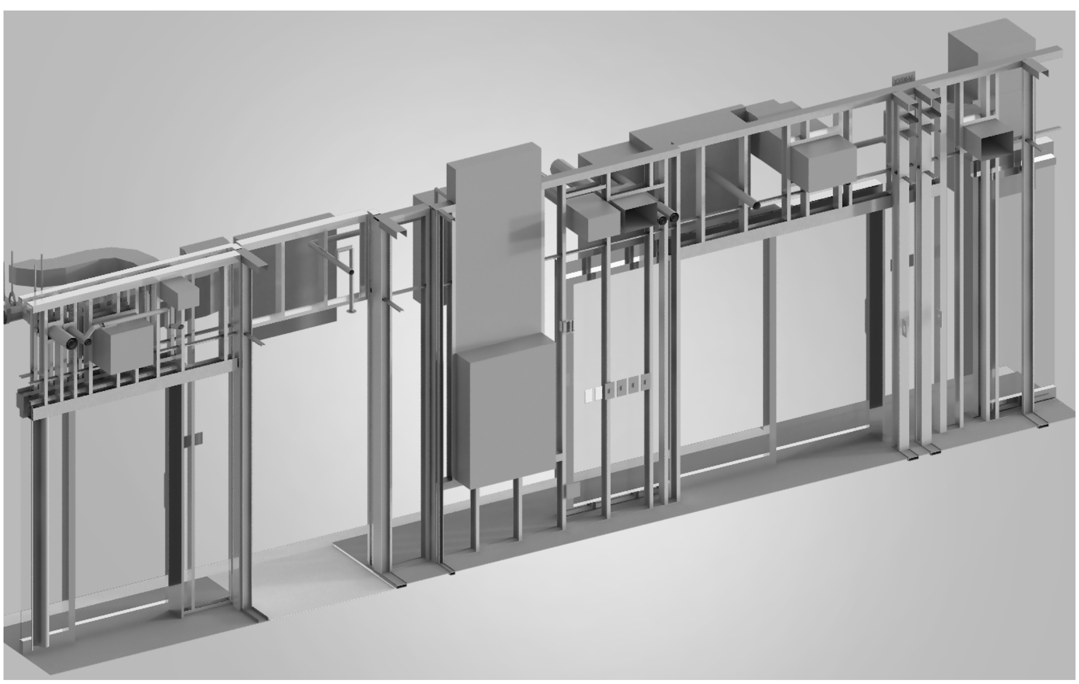

Figure 4: MEP openings coordinated with drywall panels

Further, the team identified clearance available accounting for deflection and as-built layout of the deck above for every wall location. This analysis used the laser scan of the space after concrete was poured on the deck above. Since the wall panels were full height (up to deck level), the coordination with flutes was necessary. The location of crest and troughs for flutes is captured in the point cloud data. The point cloud data is aligned with the 3D stripped architectural model for analysis of existing conditions while designing wall panels. The height for wall panels is adjusted to match the top track with trough of the fluted deck (Figure 5). The kickers/posts for supporting the wall panels are also adjusted to align with the fluted deck. The spacing of top track hole series is generated by referring the distance between the flutes (~6"), using the point cloud data (Figure 6).

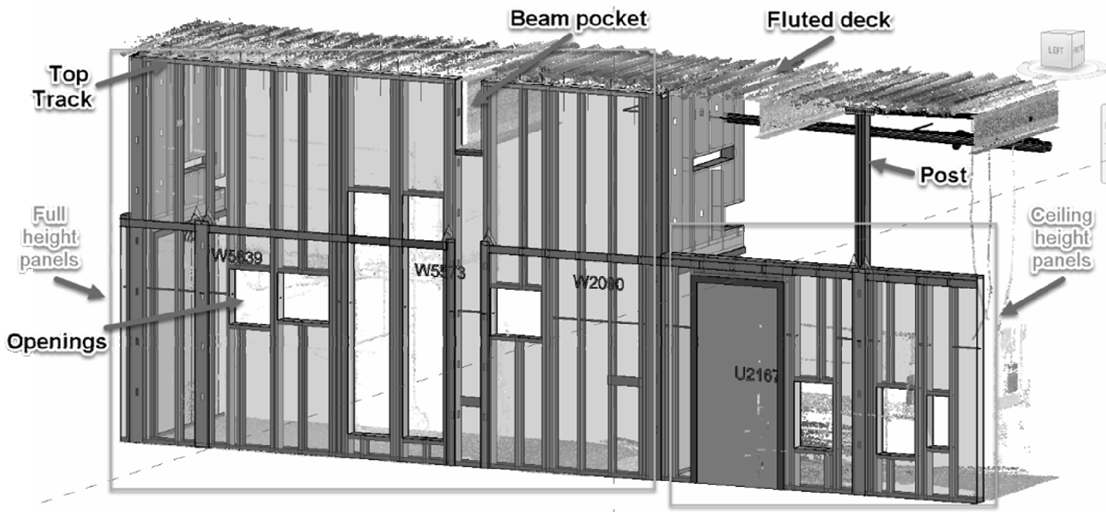

Figure 5: Point cloud data referenced on the wall panel design model

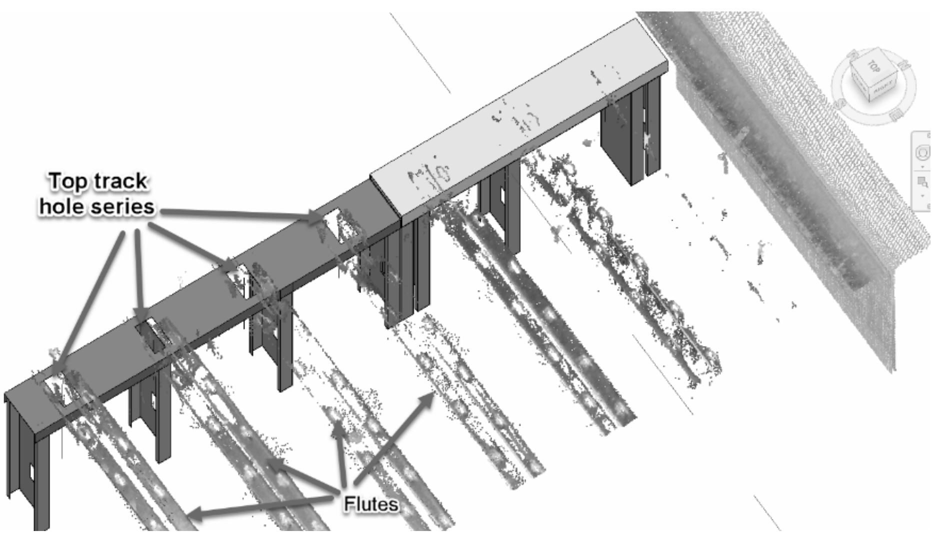

Figure 6: Top track hole series punched referring to flute locations in laser scan

A report was generated following this workflow, which shows the adjustment in height with 1/8th inch accuracy for individual wall panel. For 9 levels, each having around 100-110 wall panels, the adjustment was reported for 60-70% panels (Figure 7). The report was then used to alter the parameters for fabrication.

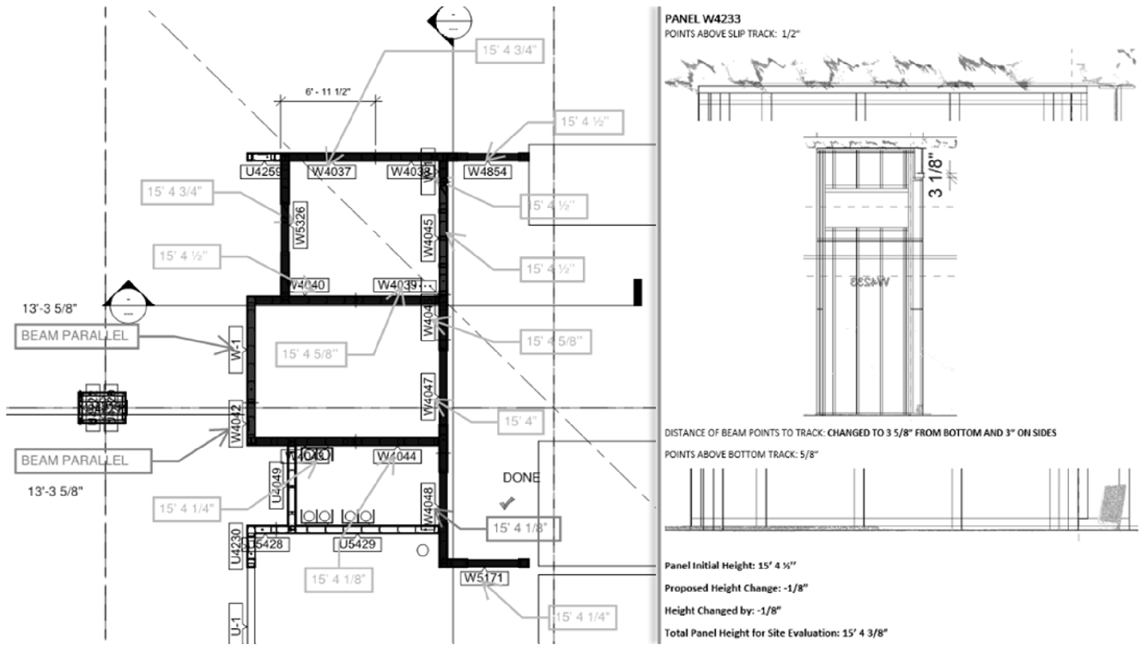

Figure 7: Wall panel adjustment report

CHALLENGES, LIMITATIONS & SUCCESS

The timeframe for laser scanning the site and for incorporating the as-built conditions in the design model is critical because of constraints in the schedule and timeline for BIM execution. The drywall subcontractor has reported multiple instances where wall panel clashed with beam/column onsite as the steel model used for coordination was not detailed out or updated. It is essential that the level of detailing required of interfacing systems modelled by other subcontractors is identified early on and incorporated in BIM Implementation Plan and in buy-out.

The adjustments made to sub-contractor's model after coordination causes clashes in a prefab panel. In on-site drywall construction, such adjustments would be made in the field; possibly at loss of productivity for one or both crews. It is imperative that a communication protocol is established to communicate changed made after coordination sign-off. Additionally, VDC methods can be employed to detect incremental changes in the model.

A further challenge is posed by the deviations that happen on the site during installation. Laser Scanning provides the most accurate way to capture field changes. Some of the challenges associated with laser scanning follow.

Laser scanning process is time and money consuming effort and therefore should be planned properly (Gleason 2013). There is requirement for high-end processing computer systems to deal with the point cloud data. The scan alignment to model is a factor which plays important role in defining overall accuracy of process. Overlaying point cloud data and 3D model is possible only if both model and point cloud are using same coordinates. But generally, laser scanning is done without geo-referencing. Therefore, the scan is not referenced at the coordinates of design model. Therefore, we need to align the point cloud to 3D model using best-fit approach (Murphy et al. 2009). This is a limitation of using the reality capture approach for feedback from site, especially in situations where the tolerances are less than one-quarter inch.

In both the case studies, the team has been working on providing better and more usable information using VDC methods. The use of reality capture feedback addresses field deviations efficiently. Further automation and streamlining of certain processes will enable wider implementation of these methods. Further study needs to be done to arrive at statistically relevant metrics. However, we may conclude that the impacts of deploying VDC and Reality Capture in prefabrication results in streamlining flow and provide better quality of work.

CONCLUSION AND FUTURE WORK

Using VDC methods increases the predictability and provides feedback loop. Modelling using BIM allows digital fabrication. Using this approach company D claims high productivity (25-30% faster erection/installation schedule) without mass production and lesser labour involvement. For full height interior framing, installation productivity being 100 linear feet/person/day in current technique vs 25 linear feet/person/day in traditional method. Coordination of different trades allows predictability. Additionally, in the second case, it has been demonstrated how reality capture provides feedback in design phase to create accurate model for digital fabrication of building components.

The approach of using heat & contour maps helped to avoid waiting period in the process of wall panel installation. The identification of defects helps the team to strategize the execution process.

The usage of heat & contour map is during the execution phase, whereas the 3D as-built floor model can be utilized in design coordination phase. The extraction of as-built floor/roof model from point cloud using Dynamo renders to a highly detailed as-built model which may not be always useful considering the lag in operating the model while designing. The optimisation of this output is being researched for better utilisation in above mentioned workflow.

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APPENDIX

1. Which issue does the site team face while installation effort is carried out? [KINDLY FURNISH THE MATRIX BELOW] (few mentioned from previous questionnaire)

   a. What is the severity and frequency of issues corresponding to these conditions (**on scale of 1-5**; **1**- no time or money lost; **2**- time lost, no impact on cost; **3**- time and money lost; **4**- major impact on project timeline; **5**- major impact on project cost)

   b. What is the usual procedure followed by DBC site team

Condition	**Severity (impact on cost and time for project)**	**Frequency (how often does it happen)**	**Standard procedure followed**
Wall panel clashes with beam/column	2	1	Add pocket for beam, lower pocket for beam
MEP clash	2	1	Add/most studs to accommodate MEP. Alternate is for MEP to move, requires re-coordination.
Not enough height clearance	3	1	Cut top of wall and add slotted track.

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AN EXPLORATION OF BIM AND LEAN INTERACTION IN OPTIMIZING DEMOLITION PROJECTS

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ABSTRACT

Construction and demolition wastes have an adverse environmental impact. The demolition wastes are resulted from the linear economic behaviour that the Construction industry is currently adopting. IT-enabled processes like BIM have been used to eliminate wastes in Construction Projects. The alignment of these processes with Lean Construction principles was seen to reap high benefits. This research investigates the possibility of extending BIM functionalities to support deconstruction processes in alignment with Lean Principles. Based on the existing interaction matrix between BIM functionalities and Lean Principles and its subsequent extensions, the synergies between BIM and Lean are explored from a deconstruction perspective. The evidence of using BIM capabilities in deconstruction projects is mainly interpreted from research in addition to the current initiatives in the demolition and renovation projects in The Netherlands. The main aim is to integrate discrete efforts in industry and academia towards leveraging the recovery rate of salvaged elements. The evidence is then validated against Lean principles and the results reveal a major conformity between BIM and Lean. This exploratory research may contribute to the adoption of a structured framework in deconstruction projects that exploits BIM and Lean capabilities towards achieving a circular economy.

KEYWORDS

Lean construction, Building Information Modelling (BIM), Pull, Deconstruction, Waste.

INTRODUCTION

Construction industry is the major contributor to the overall waste streams generated worldwide (Wang et al. 2010). For instance 25 to 30 % of all the wastes generated in EU

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is owed to construction and demolition waste (C&D) (European Commission 2016). The current practice of buildings demolition undergoes a linear economic approach. Large portions of wastes are generated and less amounts of salvaged materials are being recovered and pumped back into the supply chain (Hosseini et al. 2014). In recent years, IT-based processes like Building Information Modelling (BIM) was introduced in deconstruction projects. The exploitation of BIM capabilities has taken many forms including the development of BIM-based deconstruction plug-ins (Akbarnezhad et al. 2014), and the visualisation of the 4D deconstruction scheduling (Ge et al. 2017).

On the other hand, there are insights in literature that shows the implicit reliance on lean principles in planning the deconstruction projects. These principles promote pulling data from downstream instead of the traditional push approach. This can be done by selecting the building elements to be dismantled based on the end-customers' needs, thus engaging them in the early decision making. In this context, (Schultmann and Rentz 2002) proposed that the nearest manufacturing typology that best suits deconstruction processes is 'Make to Order' production. This means that the process relies on applying just-in-time concepts where the presence of inventory is minimal. In addition, 'Make to Order' means that the production line will capture the production signal only when a demand exists on a certain product.

However, highlighting the potential of Lean-BIM interaction was merely mentioned in deconstruction projects. In fact, most of the researches that exploit the effect of BIM—Lean integration in reducing the amounts of Construction and demolition wastes (C&D) are focused on wastes generated during the construction phase only. For instance, (Cheng et al. 2015) has investigated the use of BIM functionalities in enabling the waste minimization in construction processes. Among these functionalities were design validation, quantity take-off, phase planning and site utilization planning. Therefore, the perspective of optimizing demolition and deconstruction processes haven't yet been explored within a Lean-BIM interaction perspective.

LEAN-BIM INTERACTION MATRIX

In order to capture the synergies between Lean Principles and BIM functionalities, (Sacks et al. 2010) have provided a framework for analysing these interactions. They were arranged in a matrix, where each BIM functionality is analysed against each Lean Principle. The result can be positive, which indicates a full compliance to the indicated Lean Principle, or negative, where the BIM functionality opposes in its implementation the Lean Principle.

This framework is regarded suitable for exploratory research where the conformity between 2 processes need to be identified. This constructive approach was also extended and built upon by other researchers in phases like the operation and maintenance (Oskouie et al. 2012). Accordingly, this research extends the use of Lean-BIM matrix to capture the conformity patterns between Lean and BIM in deconstruction and demolition projects.

EXTENDED LEAN PRINCIPLES

For the selection of the principles, some criteria have been used. First, the production control approach adopted by Pull-planning has been a key-issue in choosing the relevant principles. Second, the criteria provided in (Sacks et al. 2010) for the development of the Lean Principles have been used. However, some modifications were done, besides the addition of more concepts to account for the variations between construction and deconstruction processes (see Table 1). Lean principles were classified into 2 main categories: strategic management and operational planning. As for the strategic management-related aspects, they fall under 4 sub-categories: the decision making, transparency, value creation and developing partners. While the operational planning is divided into 2 sub-categories: inspection and flow of the process. The synergies between these principles and BIM functionalities can be inferred from the explanations of each interaction in the matrix.

Table 1: Lean Principles

Lean Principle		Key
Early planning the decision-making process	Planning the decision-making structure early in the process	A
	The early involvement of the stakeholders in the process	B
Consider all options		C
Processes must be more transparent with decentralized decision making		D
Careful selection of technology that reaps high value to the end-customer		E
Ensure Comprehensive requirements capture		F
Focus on Concept Selection		G
Ensure Requirements Flow-down		H
Verify and Validate		I
Cultivate an extended network of partners		J
Go and see for yourself		K
Pull from Downstream	Project planning is based on the end-customer needs	L
	Minimize inventories of goods awaiting further processing by levelling the production	M
	Resource management based on production flow	N
Reduce Variability	Creating a smooth workflow by removing variations in workloads (one-piece flow)	O
	Getting Quality right at the first time and reducing defects in products	P
Reduce cycle time		Q
Collaboration		R
Flexibility		S
Standardizing the Process	Finding simplicity even within complex projects	T
	Structuring of the work to separate the standard activities from those relying on the information change	U
	Using Visual Management	V
Institute Continuous Improvement		W

EXTENDED BIM FUNCTIONALITIES THAT SUPPORT DECONSTRUCTION PROCESSES

BIM Functionalities mentioned in this context were retrieved from literature involved in deconstruction planning and from innovative practices in the Demolition projects in the Netherlands. These functionalities were classified based on the processes they are contributing to. There are possible extensions to these functionalities that can be added later. However, the main concern was to integrate the current discrete approaches that have been already adopted. The integration of more functionalities and testing their reliability can be expected in future work. Table 2 shows each BIM functionality included in the study and the key representing each one in the matrix table.

Table 2: BIM Functionalities

BIM Functionality	**Key**
Data Capturing	
Digital documentation of buildings through laser scanning and photogrammetry	1
Modelling	
Rapid generation of the BIM model	2
Visualization of the BIM model	3
Integrity of information provided in the model	4
Collaboration	
Collaboration provided among stakeholders through BIM platforms	5
Collaboration in the modelling environment	6
Interoperability	7
Object-based Programming	
Manual input of deconstruction-related parameters	8
Importing data from external libraries and creating new parameters of them	9
Re-use of model data for predictive analysis	
Exporting model data to external plug-ins	10
Rapid evaluation and Simulation of Deconstruction Alternatives	
Simulating the Schedule scenarios	11
Detecting the clashes (resulting from dismantling an element)	12
The quantification of elements and materials to be dismantled	13
Automatic Generation of Reports	14
Online/Electronic based Communication	
Updating the Deconstruction progress on-site	15
Visualizing the dismantling process on-site	16
Synchronizing BIM models with online applications	17

CASE STUDY

Moondriaan Building is a facility that used to be a Care Center for people with needs in Heerlen in The Netherlands. The building was abandoned for several years and was decided to be demolished. Resource Limburg was hired to take care of demolishing the building. The vision was to undergo the process of deconstruction for elements that have re-use potential and then demolish the rest of the building and sent the materials to the recycling facilities. Resource Limburg also has a role in marketing the salvaged elements.

This is done either through contacting the extended network of partners or showcasing the elements on their web shop (Resource Limburg 2017). Therefore, Resource Limburg can also be regarded as a consultant to the owner for guiding the deconstruction process.

The workflow of the process starts with the capturing the data on different building elements. The company has used laser scanning technology and panoramic 360 images to digitally document the building conditions. These conditions were evaluated by the Company's architects and experts. The evaluation is then formulated into linguistic terms that determine the quality of each element. The elements and their conditions are then updated to a database. On site, elements are dismantled and stored on separate places inside the building (see Figure 1). Nearby customers, whom the company had relations with and who were interested in obtaining the salvaged elements, were invited to the site. In addition, the elements on the database were showcased on the Web-shop.

Figure 1: Different Collections of Salvage Elements stored inside the Building

DISCUSSION

The need to detect the conformity of Lean Principles and BIM functionalities in deconstruction processes is explored using the Lean-BIM interaction matrix derived from (Sacks et al. 2010) as listed in Table 3. In this matrix, several interactions were noticed. These interactions are susceptible for further enhancements, extensions and verifications in future research. Hence, they can be regarded as an exploratory foundation for more structured demolition practices. Most of the interactions are a collection of discrete efforts in research and practice in optimizing deconstruction planning. Table 4 shows the explanation for each interaction in the matrix. For brevity reasons, the interactions, of which evidence was found in construction projects only, were marked by 'X' and were not explained. These interactions are mostly applicable to deconstruction projects and can be inferred from evidence provided in (Sacks et al. 2010). There were also few interactions that had no available evidence, yet, they have been proposed by the authors. These interactions are regarded to be of possible potential in deconstruction projects.

Consequently, the mentioned interactions in Table 4 are mostly derived from both literature and practice. As for practice examples, they were mainly obtained from case studies in the Dutch construction industry. They represent an initiative, by social enterprises active in the construction sector, to adopt a more circular economic behaviour in demolition projects. This is done by introducing BIM technologies. It was found out that Lean principles were implicitly adopted in some of the pilot projects involved.

Table 1: Lean-BIM Interaction Matrix. Cell Numbers refer to the interaction explanation in Table 4. The numbers in brackets represent negative interactions.

BIM Functionality \ Lean Principle		Early Planning the decision-making process		Consider all options	Transparency and decentralized decision making	Careful selection of technology that reaps high value to the end-customer	Ensure Comprehensive requirements capture	Focus on Concept Selection	Ensure Requirements Flow-down	Verify and Validate	Cultivate an extended network of partners	Go and see for yourself	Pull from Downstream			Reduce Variability		Reduce cycle time	Collaboration	Flexibility	Standardizing the Process			Institute Continuous Improvement
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Data Capturing	1	1	x		2	3	4	5		6		7					6,7	x	x		x		7	6
	2	x	x					x										10						
Modelling	3			x	x			x	x	11		x					x		x		x		x	
	4					(12)	x		x	11		x					x				x		x	x
	5		x	x	x		x	x			x								x				x	
Collaboration	6						x		x	11				x	x	x		x	x	x	x		x	x
	7						x			13	x							x						
Object-based programming	8						x, (14)			(14)										15		15		
	9						16			17										15		15		
Re-Use of model data for predictive analyses	10	x	x	x			18, 17	x		13, 19			18			20	20	20	x	17	(21)	22		17
Rapid Evaluation and Simulation of Deconstruction alternatives	11	23	23	24	24	x	24	x	24	x		23		x	x	x		x	23	x			24	23
	12			24	24	x				x		23						25	25		25		24	23
	13								x							x		x		x	x			
Automatic Generation of reports	14															x		x		x				
Online/Electronic based communication	15					x				x			x	x	x	x	26	x			x		x	
	16					x				x		x									x			x
	17	27			x						28		x			x							3	

Table 3: Interaction Matrix: Explanations of Cell Contents

Index	Explanation	Evidence
1	The current scanning processes which captures the building data, are quick and efficient. Once the spatial data is collected on-site, the decisions on the building deconstruction can be planned sufficient time before actual demolition activities take place.	(Ge et al. 2017; Resource Limburg 2017)
2	Visualization of the actual building conditions through digital documentation is a transparent process. Instead of written reports, witnessing the current building conditions contribute to a transparent decision-making process.	(Resource Limburg 2017)
3	Using the state-of-the-art scanning technologies reap the highest values to the end-customer. The end-customer can visualize the panoramic, 3D point cloud, or 360 images of the salvaged building elements captured.	(Resource Limburg 2017)
4	Point cloud data ensures capturing of comprehensive data-sets. This gigantic amount of data (Big Data) carries accurate details of the building elements condition.	(Böhler and Marbs 2004)
5	Careful Consideration and evaluation of preliminary alternatives is supported by the presence of a digitally documented model of the project.	(Resource Limburg 2017)
6	Through the digital documentation of the initial building conditions, validating the quality of the dismantling processes can be achieved. This is done by comparing the salvaged element conditions after being dismantled with the initial conditions that was digitally documented in the beginning of the project.	Not yet available
7	Visualization of the building digital documentation ensures the detection of defects of the building elements through visual inspection	(Resource Limburg 2017)
10	The rapid generation of the As-Built model for the salvaged buildings saves more time for the next sequential processes in the planning of the building deconstruction	Not yet available
11	Through the visualization of BIM objects representing the elements to be salvaged and the surrounding objects on the BIM model, the deconstruction sequence of such elements can be verified and the possibility to dismantle them is validated. The same for clash detection that ensures the model integrity.	Not Yet Available
(12)	BIM provides a set of tools and capabilities that are way more efficient than 2D CAD drawings. Model integration and detecting discrepancies between BIM objects is one of them. However, the full potential of model integration is hindered by the loss of some data and the difficulty to explicitly detect the relationships between different BIM objects based on certain criteria.	(Ali and Mohamed 2017)
13	Interoperability encourages the migration of data to external applications for validation and/or analysis.	(Pazlar and Turk 2008)
(14)	The manual entry of data increases the probability of having errors. Therefore, analyzing these data may yield unreliable outcomes. Additionally, it's difficult to validate or verify them.	(Alanjari et al. 2015)
15	Attaching parameters to BIM objects can be done either using manual entry of values or importing data from external libraries. Thus, there is flexibility in the addition of parameters independent of the source type.	(Akbarnezhad et al. 2014)

Index	Explanation	Evidence
16	BIM follows an object-oriented approach in creating the hierarchy of BIM objects. Therefore, this process provides possibility of defining new parameters and linking them to the BIM objects. Adding parameters can capture comprehensive data about different criteria. Parameters can bring additional information to the model about the connectivity of the BIM objects or the location of nearest recycling facilities…etc.	(Akbarnezhad et al. 2014; Krijnen and Tamke 2015)
17	Verification of parameter values added to a BIM model can be achieved. By developing a plug-in that can be added to the BIM authoring tool, different parameters can be retrieved and analyzed.	(Akbarnezhad et al. 2014)
18	Due to the early evaluation of building elements recovery potential by analyzing BIM objects data, the quality of the end-product is increased and becomes more consistent with the client needs (buyers of the salvaged elements).	(Akbarnezhad et al. 2014)
19	Exporting model data to external applications validates these data against rules and regulations. It also verifies the suitability of the element conditions for deconstruct ability. Some applications extend their scope to predict the transportation costs, logistics, and the relevant impact on the environment for the salvaged elements	(Akbarnezhad et al. 2014)
20	Predicting the recovery potential of the building elements, represented by the BIM objects, ensures that the salvaged elements with high re-use potential can be identified and dismantled. Thus, variability resulting from the uncertainty of the element conditions is reduced. This helps in preserving the quality of these elements during the deconstruction process. In addition, it saves the time needed on-site to evaluate the building elements.	(Akbarnezhad et al. 2014; Eastman et al. 2011)
(21)	Detailed predictive analysis and the generation of multiple parameters to be added to the model could increase the complexity of the model. This would hinder the easy extraction of information from the BIM model	(Alanjari et al. 2015)
22	Through the use of the BIM objects data in an external application, an analysis can be done to separate the elements with high recovery potential from the rest of the elements with no recovery potential.	(Akinade et al. 2017)
23	Using BIM collaboration tools, it's possible to for multi-disciplinary teams to work together early in the project to create different scenarios for the deconstruction strategies using BIM collaboration platforms. These platforms support the visualization of deconstruction processes with the progress of the project, the dismantling sequence and the mobilization of salvaged elements. This environment leverages the decision making based on the selection of the most appropriate deconstruction strategy.	(Eastman et al. 2011; Ge et al. 2017)
24	4D scheduling presents a visualization of the deconstruction sequencing with the progress of the schedule. This is used to identify conflicts in time, space and assessing the deconstructability of salvaged elements. Safety, and efficiency of production is enabled, and production flow can be tracked and improved.	(Eastman et al. 2011; Ge et al. 2017)
25	Simulating the path of the dismantled elements out of the building is enabled through BIM Collaboration tools. This ensures an accurate dismantling process on-site and saving time by virtually evaluating different scenarios before settling on the optimum one.	(Autodesk University 2013)
26	The visualization of deconstruction steps on a BIM model on-site (using rugged devices) reduces the error of dismantling an element and ensures its proper dismantling to preserve its condition.	Not yet available

Index	Explanation	Evidence
27	A Web shop can be an example of the external applications supported by BIM processes. This web-shop can show the data attached to BIM objects which represents the salvaged building elements in real world. The elements sold on the Web shop can then by synchronized with the BIM model for efficient deconstruction planning. Based on the demand of building elements, the stakeholders can take early decisions on the destiny of the salvaged elements and materials.	(Resource Limburg 2017)
28	Integration of different stakeholders involved in the recovery and re-use of salvaged elements through online portals can create long term relationships between them. It can also be regarded as an initiative for adopting circular economy in construction practices.	Not yet available

CONCLUSION

This paper extended the BIM-Lean interaction matrix to cover the deconstruction and demolition processes. The synopsis of interactions was supported by evidence from literature and practice. The interpretation of the matrix interactions could be directed towards the adoption of a BIM-Lean approach in future deconstruction projects. For example, the exploitation of BIM related technologies can be used to apply the lean principles in the context of showcasing the salvaged elements on a Web-Shop. This platform can be linked to the BIM model for updating the deconstruction scheduling. Finally, this exploratory research can yield, in the future work, a generic framework for the planning of deconstruction projects both on the strategic and operational level.

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'SITE LAYOUT PLANNING WASTE' TYPOLOGY AND ITS HANDLING THROUGH AR-BIM CONCEPT: A LEAN APPROACH

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ABSTRACT

Site layout planning (SLP) aims at the efficient placement of temporary facilities on a construction site. Improper planning can lead to tremendous wastes in terms of unnecessary transport of materials and other resources around the site. A plethora of research has presented SLP as an optimization problem, but a few have focused on the wastes involved and that occur due to an improper layout of the construction site. To develop the 'SLP waste' typology, a comprehensive literature review was done, and the experts of SLP were interviewed. The identified wastes were found to be resulting due to inefficient layouts, improper coordination and collaboration among the project stakeholders and conflict of their interest. The interviewed experts highlighted the inefficiency of two-dimensional (2D) drawings and requirement of three-dimensional (3D) visualization that can aid in envisioning the future site scenarios. Therefore, utilizing Augmented Reality (AR) integrated Building Information Modeling (BIM), a conceptual tool 'AR-BIM' is proposed, and the anticipated working is briefed out in this study. The tool is under development and is expected to ease out the planning of site layouts and will aid in enabling lean, along with value generation in construction projects.

KEYWORDS

Lean Construction Sites, Site Layout Planning, Team Collaboration, Waste Elimination

INTRODUCTION

Lean construction is applied to minimize waste, with a motive towards value creation, and addressing the end user requirement (Aziz and Hafez 2013). In construction, "Waste" is defined as any deviation from the absolute minimum in terms of labour, equipment and material required for creating a product (Alarcon 1997). The paradigm of 'Lean Construction' is now being adopted across the world (Song and Liang 2011). The basic premise of lean philosophy is to enable stronger collaboration and coordination among

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the project participants to streamline the construction process flows. Construction site layout planning (SLP) pulls in project stakeholders to plan and fix the location, shape and size of the temporary facilities required. Consensus on the decisions towards SLP is achieved utilizing two-dimensional (2D) drawings. These 2D drawings lack the three dimensional (3D) spatial constraints, due to which the wastes are generated. SLP is a decision-making process that calls for better visualization, coordination and collaboration so that an efficient layout can be prepared. Emerging technologies like Building Information Modeling (BIM), Computer Simulations (CS) and Augmented Reality (AR) promise better coordination and collaboration among project stakeholders. The applicability of the technologies mentioned above has been explored in all phases of the project, individually and in integration with one another (Zhao 2017). There exists research in the domain of Building Information Modeling (Sacks et al. 2010a), Simulation (Marzouk et al. 2011) and Visualization (Sacks et al. 2007) in conjunction to the lean construction, but the applicability of these technologies for site layout planning is understudied. The present research understands how the visualization of the process helps in adoption and implementation of lean (Rischmoller et al. 2006) and can aid better coordination and collaboration among the project stakeholders by enhancing the process transparency (Song and Liang 2011). Thus, this paper presents a conceptual tool and highlights its applicability for making lean site layouts by bringing leanness to the process of SLP.

LITERATURE REVIEW

WASTES DUE TO FAULTY SITE LAYOUT PLANNING (SLP)

Time and cost are major project evaluating parameters in the traditional model of measuring project performance. Alarcon (1997) suggested 'Effectiveness, Efficiency, Quality, Productivity, Quality of work life, Innovation and Profitability' as seven performance elements. The study also highlighted the controllable wastes in three categories of wastes. The study of the Brazilian construction sites by Formoso *et al.* (1999) brought up 8 major classification of wastes as (1) Overproduction, (2) Substitution, (3) Waiting Time, (4) Transportation, (5) Processing, (6) Inventories, (7) Movement, (8) Production of defective products. The losses due to the inadequate planning of stocks and locations of storage may lead to vandalism, material waste by deterioration, burglary, and robbery that results in monetary loss and such wastes can be attributed to the class of 'Inventories'. The wastes mentioned above, are also considered in research conducted by Osmani *et al.* (2008). A study of Abu Dhabi construction industry presented 27 construction wastes. The author Al-Aomar (2012) was able to classify the identified wastes into 7 categories. The wastes identified by researchers indicate that proper planning of site space can resolve and eliminate the wastes at the planning for site layout. Therefore, the following section highlights research conducted in the domain of site layout planning.

SITE LAYOUT PLANNING

Ballard and Koskela (2011) presented construction project as "a product development process, though not necessarily of a product the design of which will be copied multiple times." The site development involves many decision-making steps related to size, shape, location, and duration of temporary facilities (TFs) on the construction site (Zolfagharian and Irizarry 2014). Researchers have defined the task as an optimization problem, but the sub-optimal decisions related to the TFs can result in losses or wastes. The research in this domain emphasizes more on finding the algorithm based solution to the problem resulting out an optimal solution to the planners. Sadeghpour and Andayesh (2015) have indicated that advancements in the field of automation and visualization as a potential area for the researchers to investigate. Studies conducted in the last decade depicts a shift in concern from time, cost, and quality to safety, productivity and efficiency on project sites. Pérez *et al.* (2016) reported the use of BIM technology to plan logistics and workspace on sites as fairly limited. The planning of site layout is considered to be a combinatorial task where project stakeholders require collaboration and coordination among and across teams for decision making.

BUILDING INFORMATION MODELING (BIM) FOR LEAN CONSTRUCTION

The implementation of BIM has shown a reduction of wastes involved in design development, the generation of project documents and coordination documents (Kumar and Mukherjee 2009). Sacks *et al.* (2010b) explored the synergy between lean construction and BIM by supporting planning and day-to-day construction control on sites utilizing KanBIM. The implementation of such BIM-based lean construction management system supports human decision making, negotiation among stakeholders, and granularity of planning on a daily level. The study by Liu *et al.* (2011) explored the potential of BIM systems to minimize construction waste. Liu *et al.* (2015) presented a framework for waste minimization utilizing BIM by reducing conflicts, rework, and errors.

IMPLEMENTATION OF LEAN THINKING THROUGH VISUALIZATION

The visual management has been considered as, one among the most important methodologies of attaining lean production (Koskela 1997). The criteria for assessment of a visualization tool, to support lean construction provided parameters like; continuous improvement, knowledge communication, and the relation with other tools. The use of computer-aided visualization can benefit planning of projects, monitoring and recording performance benchmarks, an increase of workflow, and release of bottlenecks. The major focus has been on visualization aspects of BIM but to visualize the workflow, 4D BIM, 4D CAD and other technologies like augmented reality can be utilized. VisiLean, a tool for providing lean production management had been proposed to provide clear visualization of workflow along with simplifying the implementation of BIM on construction projects (Dave et al. 2011). The presented research is undertaken to understand the impact of tools like AR and BIM in waste minimization process.

RESEARCH METHOD

The study adopts a qualitative approach through expert interviews to achieve the above objective. To identify the themes to be discussed with the experts a comprehensive literature survey was done. The keywords used for searching the literary content were 'Lean Construction,' 'Waste Minimization', 'Site Layout Planning', 'BIM', 'Visualization', 'Augmented Reality' and the combination of the terms was also tried out. The wastes that generate due to faulty site layout planning were identified from the literature and expert interviews, were classified into two major categories as identifiable and unidentifiable to the layout planners. A semi-structured open-ended interview on the adoption of BIM and Lean and potential of BIM and AR in Lean was conducted with 15 experts. The interview data were analyzed utilizing the method highlighted by Appleton (1995). The following section provides detail of the authors' interaction with the construction industry experts and highlights the requirement of a visualization tool for enabling lean since from the layout planning stage of the project. The findings also provide an idea of how visualization can help stakeholders in identifying wastes and eliminating them.

RESEARCH FINDINGS

WASTES FOR THE CONSTRUCTION INDUSTRY AND ELIMINATION STRATEGY

Waste on construction sites is considered to be the waste only if it is visible and easily identifiable. The construction industry experts irrespective of experience, when asked about the wastes on the construction site promptly indicated material wastage. The following reasons were brought up for the wastes, generating on construction sites:

Wastes Due to Rework

Every respondent emphasized this category of waste. The construction site rework generates a huge amount of waste that is very hard to handle. The rework generates enormous debris on construction sites, which needs to be cleaned from the execution site. This waste not only results in the material wastage but also results in the wastage of man-hours and money.

Eliminating Rework

The respondents underlined proper designing and contract documents can eliminate the rework. According to the interviewees, the designs of the project should be readily available, and no last-minute change should occur. This requirement of the experts corresponds to the traditional construction practice.

Overproduction and Over Procurement of Material

The interviewees reported major materials required on construction sites are steel and concrete. The requirement of concrete is calculated on a daily basis and is provided to the batching plant on the day of requirement. If the concrete is produced on site, the wastage of concrete was considered under overproduction, and if it is procured from some concrete supplier, it is categorized as over procurement. The same procurement categorization was reported for the steel.

Eliminating the Over-Production and Excess Procurement

The researchers in the past have mentioned the utilization of technologies like BIM for quantity take-off. The quantity take-off tools, work based on the level of details to which the three dimensional model of the project conforms. As measures for reducing wastage due to excess procurement and production, the experts highlighted the tolerance, within which the waste generation is not considered alarming for the project and hence is not given much concern. The interviews resulted out that these tolerances vary from project to project and process to process. To the authors, defining of tolerance does not seem to be an approach for waste elimination, and no way close to the lean practices for the construction.

Waste Due to Offcut

The industry experts listed out this wastage as the cutout pieces of the material like steel bars, timber, marble, and tiles. The reason attributed to these wastes is the improper detailing in the design and unskilled workers. These wastes are sometimes utilized on the construction sites and therefore are of no major concern in accordance with the interviewees' response.

Elimination of the Cutouts

Since the construction industry utilizes this waste on the project, this does not imply that its elimination should not be targeted. The existing technologies like precast and prefab can eliminate these wastes from construction sites. The pre-engineered components will eliminate the waste of scrap material, but is likely to generate the following waste.

Waste Due to Improper Storage

The experts reported this wastage in reference to the improper storage of materials and pre-engineered components. The material storage wastage was reported as a result of bad inventories and poor storekeeping. An unorganized way of stacking the pre-engineered components lead to huge monetary loss, due to deformation of the components.

Elimination of Waste Due to Improper Storage

The experts indicated the proper storekeeping, along with employment of Radio Frequency Identification (RFID) tagging system helpful in eliminating the wastage due to improper storage. Hence, the techniques mentioned above can aid in eliminating the occurrence of waste to a certain extent if employed appropriately.

IMPROPER SLP WASTES AND WASTES IN THE SLP PROCESS

The past researches have focused and indicated the reasons and the eliminatory or diminution measures for the wastes mentioned above, but the count focusing on the wastes involved in the processes like designing and planning, employed for aiding construction is relatively low to assist the construction industry in eliminating the process wastes. The succeeding section will provide comprehensive knowledge on the wastes due to faulty site layout planning and the wastes involved in the process of SLP.

Waste of Excessive Handling

The waste results out due to the improper planning of the location of the storage facility and the location of material consumption. The experts highlighted the negligence of the team responsible for planning and the team in charge of the storage for this wastage. One of the respondents highlighted the responsibility of the storekeeping team stating that: "*If the material on construction site is not unloaded at the designated location then the team responsible for the storage should be held responsible for the waste of time and cost to be incurred in shifting the material as well as for the locked up space due to unloading at an inappropriate location.*"

Unnecessary Movement

This referred to the unrequired movements of vehicles and labours. The industry expert attributed this waste to the improper planning of site layout depicting: *"The location of labor huts and routes on construction sites are a job for the planning team to carry out before the execution on construction site starts."*

Blocked Space

The blockage of construction site happens due to improper envisaging of the future scenarios by the planning team and the poor housekeeping of the site. While interviewing the waste of space was highlighted by maximum respondents, and their response is summarized here: '*Construction site planning happens as soon as the contract is awarded based upon the prevailing geographic conditions and the provided area for the coming up facility. In a hurry to start the execution, the planning of SLP is not given proper concern, and as a result, as the construction progresses, the site becomes a fouled up place. The major mess is due to improper housekeeping resulting in space blockages on site.'*

Inefficient Coordination and Collaboration

The process of SLP is considered to be a teams' task majorly deciding upon the location of facilities required to aid the main construction. The team comprises of stakeholders from different field of expertise like project manager, site supervisor, site engineer and sub-contractors. The task is accomplished by collaborating using 2D drawings as a mode of information share. Since few studies have highlighted the inefficacy of the drawings (Cheng and O'Connor 1996) sometimes, this results in the waste of discussion utilizing 2D drawings and results in a waste due to inefficient coordination and collaboration.

Typology of Wastes and Possible Approach for its Minimization

The wastes reported by the interviewees were the resulting wastes due to the improper layout of the site and also the wastes that exist in the process of SLP. Based upon the responses the SLP wastes are classified below.

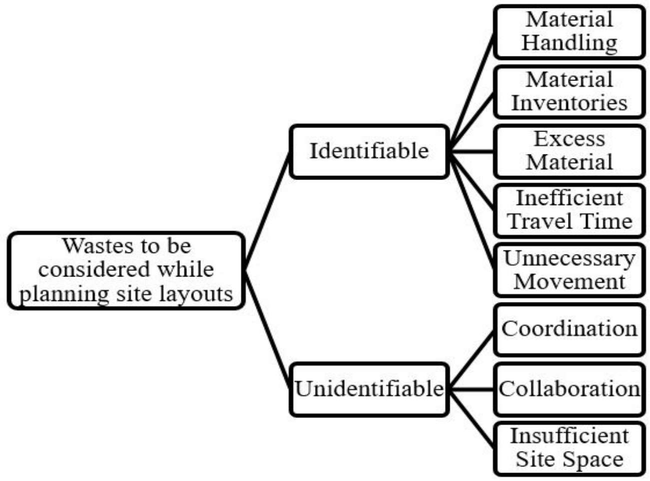

Figure 1: Categories of wastes considered while SLP

Figure 1 depicts the wastes which are anticipated by the stakeholders while planning for site layout. The identifiable wastes are easy to figure out and are considered during layout planning but since the wastes listed down in the unidentifiable category are hidden wastes of the process, which are left unnoticed.

The interviewed experts highlighted a pressing need to have some tool which can make the decision-making task easier and can aid the planners in eliminating the identifiable and unidentifiable wastes. The respondents highlighted the requirement of such tool as: '*The task of site layout planning is essential to be executed properly. It can be considered to be the foundation task of the project and if not accomplished in a righteous manner then can result out huge wastes on site. There would be a loss of worker's productivity, equipment productivity, and materials. Therefore, a tool is required through which all possible alternatives can be evaluated through permutation and combinations and all the solutions can be made clear to all the stakeholders involved in the task.*' To this end, the authors have considered the developed typology and have come up with an approach to tackle the unidentifiable wastes involved in the process of SLP.

CONCEPTUAL TOOL FOR SITE LAYOUT PLANNING

The developed typology indicates the coordination and collaboration among project stakeholders as unidentifiable wastes involved in the process of SLP and the identifiable wastes are resultant of an inefficient SLP process. Thus, the authors hypothesize that addressing of the unidentified wastes in SLP can eliminate the wastes generated as result of the process. The planning for layouts of the construction site requires envisaging the future scenarios and making decisions based on the desired objectives. The study by Cheng and O'Connor (1996) reported the task is a job for stakeholders with expertise and have own concerns and interests in locating the support facilities. The deficiency of 2D drawings and the dynamic nature of construction site, motivated the authors to propose a conceptual tool that can aid the stakeholders, in enabling a better platform to collaborate and coordinate. The tool is defined and proposed to mitigate the wastes in the process of planning site layouts and the resultant wastes due to the improper planning of layout. The technologies like Building Information Modeling have proved its potential in 3D visualization and Augmented Reality for establishing collaboration in teams can be employed for the tool. The unification of these technologies will result out an innovative tool AR-BIM, for collaborating and visualization simultaneously. It is anticipated that the merger of the technologies should not restructure the whole process of site layout planning and therefore the tool would be an aid for value generation. The construction industry has adopted the BIM and AR for the construction progress monitoring (CPM) and facility management (FM). Therefore, the proposed tool is also expected to achieve leanness at the project planning phase.

EXPECTED PERFORMANCE OF THE TOOL PROPOSED

The proposed AR-BIM tool is expected to enable coordination and collaboration among the project stakeholders involved in the process of SLP. The proposed tool is in the development phase, and thus the working presented here is an anticipation. The tool will help in 3D visualization of the site scenarios by superimposition of the digital model on the real world, utilizing the basic functionality of augmented reality. The tool will enrich the site drawings with the 3D spatial information as depicted in figure 2 when brought in its field of view.

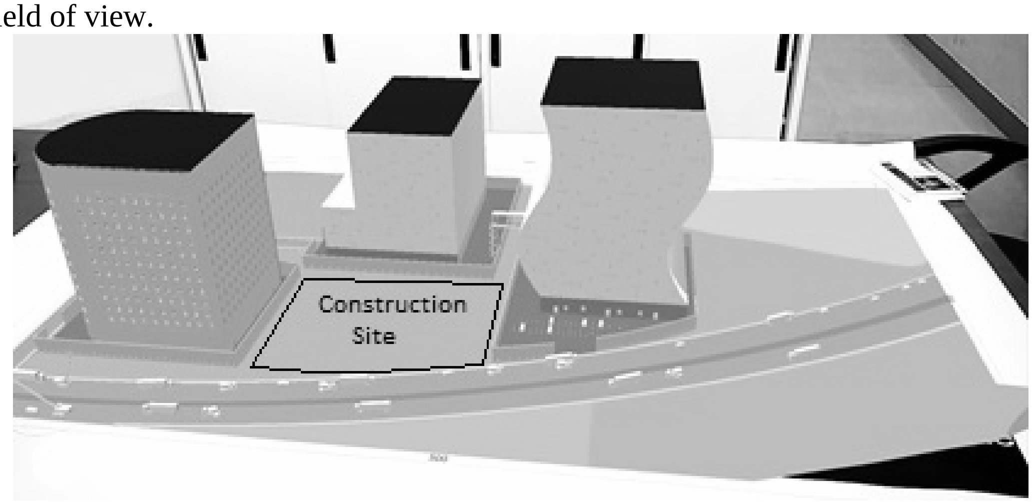

Figure 2: Visualization of site features through AR-BIM tool

When the stakeholders will get involved in the decision making task of SLP, the visibility of features like site access, terrain and site surroundings will come to fore and aid in the SLP process. The adoption of BIM technology for the conceptual tool will aid the stakeholders from different trades to collaborate; utilizing a common information model which will enable resolution of conflicts and will bring the process transparency. The integration of AR and BIM will help out in planning for site layouts by superimposing the BIM models of the site and the required TFs over the 2D drawings using the fiduciary marker technique for target tracking as shown in figure 3.

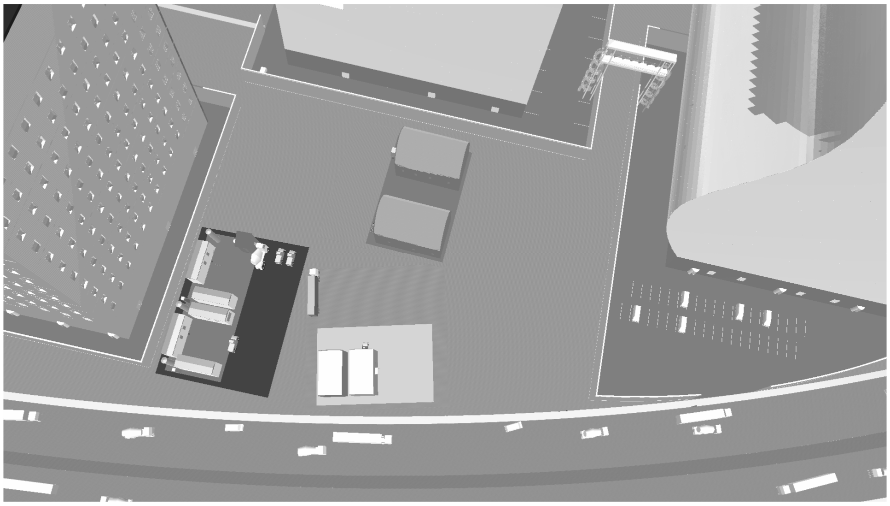

Figure 3: Rendering of TFs on the construction site

The AR-BIM tool would be handy for the end users, such that it will not restrict the movement of the stakeholders involved in the SLP task. The flexibility of moving around the visualized 3D model in the augmented environment will aid in utilizing the spatial information available in the BIM model. The tool is also expected to enhance the big room concept involved in the lean construction by eliminating the delays in decision making and improving the trust among the stakeholders involved in SLP.

LIMITATIONS OF THE RESEARCH

The aim of the study is not to generalize the findings; however, since the study surveyed top construction companies and experts, the findings were consistent and thus some inferences had been made. The study is also limited to examining the site layout planning; further study can incorporate other processes of the project. Notably, the outcomes in this study are on the results of the conversation with the construction industry experts. There is an earnest need to do the case study based research which also can ensure the applicability and effectiveness of the proposed tool.

CONCLUSION

The study was conducted to understand the construction sites' wastes and the wastes resulting due to bad site layout planning. The approach was constituted such that the process of site layout can be made lean by eliminating the wastes involved in the process of SLP and the wastages due to the improper planning of site layout. The experts' interview helped in identification of the anticipated wastes by the planners as well as the wastes that remain unnoticed. To this end, it is a preliminary study concerning the waste of inefficient SLP, and a conceptual tool is proposed. The proposed AR-BIM tool is an integrated result of the visualization technology and a collaborative tool. The applicability and adaptability of the proposed tool remain questionable and provides the future scope of research.

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ENVISION OF AN INTEGRATED INFORMATION SYSTEM FOR PROJECT-DRIVEN PRODUCTION IN CONSTRUCTION

Ricardo Antunes[1] and Mani Poshdar[2]

ABSTRACT

Construction frequently appears at the bottom of productivity charts with decreasing indexes of productivity over the years. Lack of innovation and delayed adoption, informal processes or insufficient rigor and consistency in process execution, insufficient knowledge transfer from project to project, weak project monitoring, little cross-functional cooperation, little collaboration with suppliers, conservative company culture, and a shortage of young talent and people development are usual issues. Whereas work has been carried out on information technology and automation in construction their application is isolated without an interconnected information flow. This paper suggests a framework to address production issues on construction by implementing an integrated automatic supervisory control and data acquisition for management and operations. The system is divided into planning, monitoring, controlling, and executing groups clustering technologies to track both the project product and production. This research stands on the four pillars of manufacturing knowledge and lean production (production processes, production management, equipment/tool design, and automated systems and control). The framework offers benefits such as increased information flow, detection and prevention of overburdening equipment or labor (Muri - 無理) and production unevenness (Mura - 斑), reduction of waste (Muda - 無駄), evidential and continuous process standardization and improvement, reuse and abstraction of project information across endeavors.

KEYWORDS

Lean construction, SCADA, machine learning, LiDAR, BIM.

INTRODUCTION

In manufacturing, the operation is constantly monitored by the supervisory control and data acquisition (SCADA) system. The system monitors, gathers, and processes real-time

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data from devices such as sensors and cameras, recording events into a log file and/or displaying the operational information to local and/or remote locations through human-machine interface (HMI) software. Because the information is available as soon as possible corrective actions can be taken almost immediately. With the current advancements in computing, intelligent models can also run in real time to detect future issues supporting preventive actions. Despite SCADA systems and automation being standard production tools in manufacturing their use in construction is minimal and limited to isolated equipment.

In manufacturing, the production moves from machine to machine, worker to worker, or a combination of both. The route of production is fixed (Antunes and Gonzalez 2015; Hayes and Wheelwright 1979). Thus, the positions of sensors and actuators are fixed and planned according to the production routes and its flow. Once set, the positions only need to be modified if the production routes change. In construction production routes are flexible. "Jobs arrive in different forms and require different tasks, and thus the equipment tends to be relatively general purpose (Hayes and Wheelwright 1979)." Some production routes will only exist long after the beginning of the project by the time that others would be extinct. Construction must then rely on general purpose sensors that, as the equipment, can be used in different applications through the project life-cycle, often, requiring those also to be mobile. Hence, traditional instrumentation (and sensor positioning) used in a manufacturing SCADA systems do not work in construction, as the instrumentation must be mobile.

Building Information Modeling (BIM) can be considered as the closest system to a SCADA applied in construction. BIM is the only system in construction that may contain the production layout. However, BIM focuses mostly on production planning (Nederveen and Tolman 1992; Rossini et al. 2017). The monitoring and control are still performed manually regardless of the use of BIM. The production aspect of BIM, as well the general industry, relies on primitive project management practices such as critical path and Gantt charts [the latter neither being the first nor the most sophisticated production tracking approach (Antunes 2017; Wesolowski 1978)]. These obsolete practices have been abandoned in the industries with high productivity, such as information technology. Construction occupies the bottom of productivity charts even showing negative indexes of productivity over the years (National Society of Professional Engineers 2014). Some common issues are lack of innovation and delayed adoption, informal processes or insufficient rigor and consistency in process execution, insufficient knowledge transfer from project to project, weak project monitoring, little cross-functional cooperation, little collaboration with suppliers, conservative company culture, and a shortage of young talent and people development (Almeida and Solas 2016).

Although much work has been done on implementing information technology and automation in construction their application on an integrated flow of information is sparse. This paper proposes a framework based on the current literature and technology to implement automatic monitoring and control for construction management and operations that could be useful to address the biggest issues of production in construction. Conjointly, this research uses four pillars of manufacturing knowledge and Lean production: production processes, production management, equipment/tool design, and automated systems and control. The goal should be achieved by both top-down and bottom-up approaches. The top-down approach will tackle the production system collecting information about the construction environment and its changes. The bottom-up approach will analyze the worker's activity. By using smart-tools, embedded hardware, Internet-of-things (IoT) and tracking the effort of labor can be measured and related to project progress. The two approaches are stitched together by a machine learning engine which makes sense of the data and the production theory comparing what has been done with the plan provided in the BIM model.

TECHNOLOGY

BUILDING INFORMATION MODELING

BIM is a powerful, yet 'promising' tool for the design and construction industries. 'Promising' standing for both what it can do at the present and in the future. BIM is still seen as a new technology in construction despite the increasing adoption and awareness of BIM over the years (McGraw Hill Construction 2012; National BIM 2017).

The concept of BIM can be pinpointed back to the year of 1962 when Engelbart presented a hypothetical description of computer-based augmentation system (Engelbart 1962). The application of computational solutions in construction was researched a bit later

(Eastman 1969, 1973). The research focused on the automated space planning using artificial intelligence in the bi-dimensional realm. The term 'Building Information Management' appeared 30 years later (Nederveen and Tolman 1992) while the first commercial implementation using this term is credited to ArchiCAD (successor of Radar CH from 1984 for the Apple Lisa Operating System). Historically, it is important to note that BIM did not derive from bi or tri-dimensional CAD. BIM (concept) is contemporary of CAD development. Nevertheless, BIM as a tool built upon CAD three-dimensional design tools for building modelers, which was a fully developed graphical tool for building modeling available at the time.

The manufacturing industry explored further benefits of the tool besides graphical modeling, in particular, parametric information technology tools (Autodesk 2002). Forms in CAD drawings evolved to objects with the development of object-oriented programming languages and their implementation to CAD systems in the early 1990's. Objects can bear graphical and non-graphical information bringing advances in both areas. From a graphical perspective, instead of drawing elements, one by one the user could design them separately and insert and reuse objects in the desired location. The group of lines, forms, and surfaces is interpreted as a three-dimensional geometrical model of the element it represents, for instance, a door or a window. The non-graphical perspective gives meaning to that object. The object contains multiple graphical information, such as the drawings of the door opened and closed. The object can have parts, and these parts can be of different materials with different properties. The objects may also contain production information attached, such as cost, labor, schedule, and effort what will give

BIM means to serve as a planning tool. Furthermore, changes required can be done in the element and automatically replicated where it has been used rather than laborious one by one changes. Overall, the reusable objects can bare more details and libraries of objects could be developed and shared.

VIRTUAL REALITY AND AUGMENTED REALITY

Both virtual reality (VR) and augmented reality (AR) make use of 3D models to create a scene in which the user can freely observe and/or interact with the models. What set these technologies apart is how they use the background where the objects lie. Virtual reality fully immerses the user providing a background to the environment. The user has the perception of being physically present in a non-physical world. Conversely, augmented reality utilizes the real environment as the background to project the models. The user is partially immersed. Each one has different applications. Using 3D models, VR can display a fictional scenario, for example, a functioning underground subway station even before excavations begin. AR requires a background, thus, at least part of the station must be in place. That is due to the fact that AR requires the recognition and tracking of environment specific points for object placement. Both VR and AR are useful as HMI.

LIGHT DETECTION AND RANGING

Light Detection and Ranging (LiDAR) is a remote sensing method, which uses light reflection to measure distances. The emitter shoots the light (ultraviolet, visible, or near infrared) which is reflected and then captured by the receptor. As the speed of light, c, is known, the time between emission and reception, t, is used to calculate the distance, d, from the emitter to the reflector and back to the sensor, i.e., $t=2d/c$. An Global Positioning System (GPS) receiver and an Inertial Measurement Unit (IMU) provide the absolute position and orientation of the sensor. Thus, it is possible to calculate the position coordinates of the reflective surface. One implementation of LiDAR consists of a vertical array of emitters mounted on a rotational plate creating a linear scan that sweeps the surroundings at each rotation. The result is a cloud of points which describes the environment around the sensor. Despite the fact that the cloud of points provides accurate measurement; the data does not identify objects. Basically, this cloud consists of x, y, and z coordinates of each point. Making sense of what a group of points is often is a manual task. Another limitation of LiDAR scans is the 'shadowing.' Because the technology relies on reflection, it can make sense of lies behind a reflective surface or at the non-reflective surface, such as water. The shadowing effect can be eliminated by scanning the environment from different locations and thus overlapping cloud points [once the LiDAR scans are almost ever combined with Global Positioning System (GPS) and inertial measurement units].

LiDAR has been integrated to BIM aiming to identify defects (Wang et al. 2015). That happens by comparing LiDAR measurements against BIM model specifications. Deviations out of determined bounds are then identified as defects (*Muda* – Level II). A quadcopter (any other carrier is possible, such as an aquatic or terrestrial drone or even a backpack) inspects the site using LiDAR (inspection may also be considered *Muda* of over-processing given the idea that the task should be done correctly instead of being inspected for the approval). In this approach the defect flag rises without human interaction, it however does not characterize a real-time system. The first reason is that the defect will only be detected when (and if) the drone finds the issue, not at the time the defect occurred. The second is that real-time systems require a timely response to the event. A response out of the time-frame often results in catastrophic failure. The response to the identified defect is not time-dependent. A real-time system depends on both the logical result of the event and the physical instant features (Kopetz 2011). For instance, the quadcopter drone moves forwards when detects on obstruction in its trajectory (event). The trajectory correction (response) must happen in a timely manner otherwise the drone will crash.

IMAGE

Image analysis can be an important tool in construction with several applications during the project life-cycle. A simple application can the defect inspection, where the inspector reports the non-conformities by taking pictures of the items out of specification and which will feed a punch list to be addressed by the contractors (*Muda* of rework). The pictures are used as evidence of the status of the non-conformities detected.

Additionally, because special cameras/lenses/sensors can capture infra-red and ultraviolet, which are invisible to the human eye, the collected information can be used for evaluating thermal and light insulation. Depending on what the cameras are mounted, they can provide visual information from specific angles that are known to be dangerous for human inspection (e.g., in confined spaces), or even impossible (e.g. for the pipelines). The combination of multiple images provides even more information. Aerial mapping, elevation level, and 3D mapping are some examples in which several images are stitched together. Moreover, the image analysis process can be repeated periodically what will result in the visual representation of the evolution of a particular area or item over time. Nevertheless, image do not supply accurate measurements to what they represent. To add accurate quantitative data to images, these can be combined with LiDAR (Fei et al. 2008) or with sequenced BIM models (Skibniewsk 2014).

CHRONO-ANALYSIS

Chrono-analysis is the assessment of footages to evaluate production. The footages are captured by cameras positioned around the shop floor to record an activity done by the worker(s). The time spent by the worker(s) on each task of the activity can be measured by watching the recordings. The tasks are classified into three major categories: value-adding, non-value-adding but necessary (*Muda* – Level I), and non-value-adding and unnecessary (*Muda* – Level II). One of the mantras of Lean is “eliminate *Muda*.” Accordingly, first, the analyst will identify each task that composes the activity. For instance, the footage of the activity contains the recordings of the set-up, the core task, breaks and the cleaning. Next, the analyst chronographs each task. Then, the analyst plan on how to eliminate or at least minimize the time spent on non-value-adding tasks (set-up, breaks, and cleaning). Then, the analyst plan on how to eliminate or at least minimize the time spent on non-value-adding tasks (set-up, breaks, and cleaning). Later, the analyst implements the plan and potential solutions. The analyst's records new footage of the activity execution and tracks the time spend on the tasks. After a comparison of the times to the original results, the analyst updates the activity standard with the solutions that resulted in improvement. Chrono-analysis can be seen as lean focused, more detailed, and evidential implementation of time and motion analysis. The *caveats*: chrono-analysis is usually a laborious process conducted eventually rather than continuously; the benefits for tasks with a low level of repetitiveness are minuscule.

PRODUCTION THEORY

The traditional theory about fundamental mechanisms of production in repetitive processes in construction is at an embryonic stage and does not yet fully establish the foundations of a production model. The traditional and convenient approach to project-driven production in construction is to rely on linear steady state models. By considering the transient state, Productivity Function produces models that are more accurate in describing the processes dynamics than the steady state approaches (Antunes et al. 2017). The Productivity Function provides a mathematical foundation to develop algebraic for the calculations of cycle times (average, best- and worst-cases), throughput at capacity (Antunes et al. 2018), and the influence of the transient state time in the production variability (Antunes et al. 2016).

Productivity Function has been applied in feedback loop control yielding a controlling approach [Productivity Function Predictive Control (PFPC)] that can achieve high performances even when processes operate closer to capacity (Antunes 2017). Moreover, this performance enhancement is higher when PFPC is applied to processes in a parade-of-trades (Tommelein 1998). The PFPC shown to be a robust approach to plan, control, and optimize production and supply chain in construction with direct implications to management practices such as *takt* time. A benefit of PFPC is its focus on minimizing the variances of output to the set point or plan. The PFMPC can operate satisfactorily even without an accurate model (Antunes 2017). In practice, the use of adaptive PFPC (APFPC) can be useful. This adaptive version estimates a Productivity Function cyclically within a period; thus, the control relies on a model that is accurate to the current time frame. Therefore, if the production system evolves (which is the goal of continuous improvement) that makes the model obsolete, APFPC can relearn the process and estimate a new model automatically.

Although the Productivity Function can describe a variety of systems (including multi-variables systems), a structure that can embrace nonlinear and/or time-variant systems is required; and respectively, the introduction of linear time-varying space-state models which can also describe nonlinear systems. Nevertheless, the evaluation of these function from the data is based on the back-propagation algorithm (Antunes 2017), which is a machine learning tool.

MACHINE LEARNING

Machine learning is the term used to describe a field in computer science where the machine is trained on how to do a task instead of being programmed. Thus, by being trained (or training itself) the machine can develop its own way of how to execute the task (Silver et al. 2017). The training can be either assisted or unassisted. Assisted training means that the inputs and outputs are provided to the machine that makes sense of the conditions to determine the output. For unassisted training, only the inputs are available. That entails enormous flexibility to machine learning and its applicability. As such, machine learning can mix a variety of input sources (features) to determine or classify the output, being capable of performing simple (such as an and operation) to complex tasks. For instance, it can evaluate labor processes as numerical values to estimate a non-linear productivity function (Antunes 2017), or identify and track different elements at once in a video feed (Gordon et al. 2017).

FRAMEWORK

The top-down and bottom-up approaches interact joining theory and practice in continuous improvement loop. This suggestion stands on two tenets: observer effect and *Genchi Genbutsu*. In physics, the term observer effect (Bianchi 2013) defines the influence of the observation act to the event. It means that by observing an event, the observer may alter the event, and consequently modify the observation. This effect is also known in the human sciences, where subjects have their behavior affected by being observed. In this sense, the awareness of being observed may modify the production system and its model. Thus, production is constantly observed, and the information is used to modify production. *Genchi Genbutsu*, a principle of the Toyota Production System, which means ‘go to the source and get the facts to make the right decision.’ In this approach, instead of asking for information updates the progress status is obtained in real time from positioned sensors or upon inspection from the drones. Next, the machine learning engine will merge the information (LiDAR, images, sensors) with BIM to identify the product progress and deviations from the specifications (similarly as in the SCADA). In parallel, the production information (progress and workers information) is checked against the production theory and models to evaluate productivity, forecast conclusion dates and assess corrective actions (as in APFPC). These two combined and jointly with the project plan are then presented to the ‘control room.’ Therefore, the ‘control room’ can rely on accurate information in the decision-making process, which results in a data-driven continuous improvement loop (Figure 1).

For instance, if a fixed camera detects that a disposal bin is being filled at a certain rate the replacement of that bin can be ordered from the control room without the worker’s requisition (that means eliminating the requisition task (*Muda* Level I), the work stoppage (*Muda* Level II) by waiting that the bin replacement or having to replace it (setup/cleaning, i.e., *Muda* Level I). And as *Muda* decreases *Mura* also decreases (Antunes et al. 2016). Similar reasoning works with suppliers. For example, if the casing were not cemented in place, the suppliers can be notified to avoid bringing more to the site. This integration with the supplier may avoid *Muda* (Level I) in one or more situations: inventory - use extra space to store more that its needed; waiting - if the trucks need to wait around the site; motion - case the truck needs to go back. Because information is compiled in the SCADA and centralized in the ‘control room’ it can be accessed and shared with ease, such as in a library.

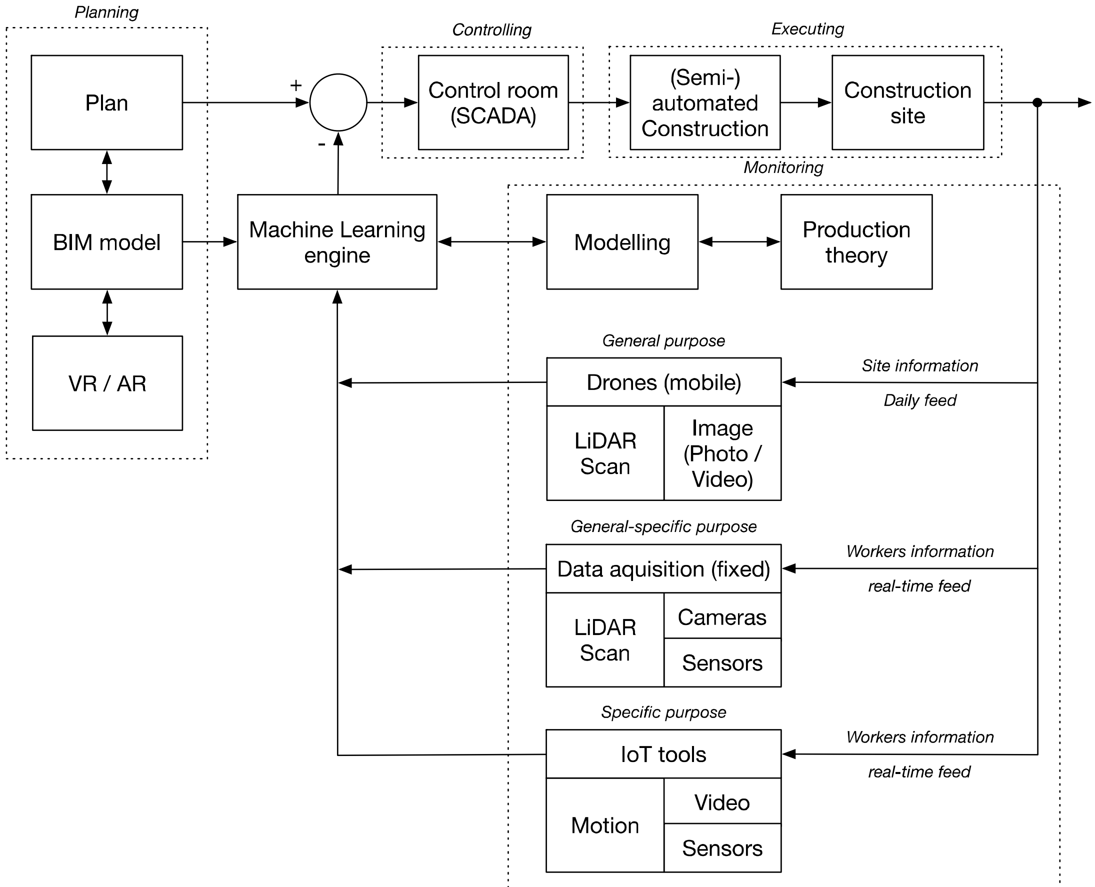

Figure 1 Theoretical framework for an information integration system for construction

CONCLUSIONS

Cross-functional cooperation in construction is low mostly because the parts have no information about what is happening outside their area. The same can be said about suppliers. The establishment of the ‘control room’ centralizes information from the plan, labor, process, and production. Moreover, once the control-room has information about the progress of the current and next activities on-site, it will be able to coordinate cross-functional activities and supply chain.

Building information security and maintenance may use the product legacy information gathered in construction eliminating redundant work by analyzing the building. This work has already been done during construction (reducing over-processing). There is a compiled log of who did what, when and how for every part of the building including divergences between the original design and every change and defect occurred during construction. There can be extensive details of how the process has been done (and evolved). The production knowledge has further benefits. Especially, due to the network effect. The network effect adds value to this framework with use and adoption. This means that data can be generalized to a broader audience with more information such as season of the year, weather condition, geo-localization, altitude, winds, local culture, diversity, or any other feature. Hence, future endeavors will establish the production base-line using historical evidence rather than the usual labor/time relationship.

Using the chrono-analysis continuous assessment jointly with the data (production progress and workers effort) from previous projects informal processes tends to be eliminated. Better processes are developed and standardized. More accurate historical information is persistent and can be generalized to different projects enabling comparison and continuous improvement methodologies from project to project. New builders will be trained in the benchmark process instead of the "I have been done this for the last *x* years" (and repeating the same mistakes over and over) approach. As such, the conservative company culture, lack of innovation and delayed adoption will be addressed by the marked. Companies will quantitatively assess and qualify the performance of contractors in previous projects. In an intensive third-party contracting industry such as construction, low productivity companies that often make mistakes are costly, and consequently, put at the end of the supplier's list or dismissed. Construction needs an increase in the number of builders, but it really needs builders with better performance.

A more automated construction industry should experience a set of benefits, such as better decision-making processes, increase information flow, and increase productivity. These benefits have a collateral impact on the whole society. More productivity means that more projects can be done using fewer resources. Accordingly, more infrastructure can be built and maintained. It can increase the affordability of the housing prices.

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USING BIM-BASED SHEETS AS A VISUAL MANAGEMENT TOOL FOR ON-SITE INSTRUCTIONS: A CASE STUDY

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ABSTRACT

In recent decades, design and construction have had to specialize, which has gradually fragmented the industry. This scenario is relevant in hospital projects, where a large number of specialties interact, especially when the operation of the center must be guaranteed. For this reason, it is essential to reduce the communication time between workers and decision-makers to respond quickly to unexpected problems. The purpose of this article is to describe the use of Visual Management using Building Information Modeling (BIM) to deliver task instructions in the field. A case study of a Chilean healthcare center is described, whereby through the active participation of the consulting team, the use of BIM-based sheets as visual instructions was gradually implemented, taking as input the BIM product and process models. The most relevant results were the fulfillment of the initially estimated deadlines without the delays that historically occurred in these types of projects and the reduction of response times for requests for information. It can be concluded that the use of these BIM-based sheets directly addresses the root causes of information management problems in construction and that it is essential to use technology within a Lean collaborative methodology.

KEYWORDS

Visual Management, BIM, on-site instructions, Lean, healthcare

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INTRODUCTION

Studies of construction projects in the field reveal that only 30% of the work is productive and 70% are used in activities that do not add value, such as waiting time for instructions, moving materials or finding the right equipment (Elfving 2007); in contrast, acceptable productive time is 60% (Serpell 2002). Productivity has been shown to be strongly linked to the achievement of sustainable growth and development. In particular, construction productivity has remained stable for decades, unlike the manufacturing industry where productivity has doubled in the same period (Changali et al. 2015).

Current construction projects are becoming increasingly complex and time-bound and require a high level of collaboration between the design team, the developer and the project construction team. To successfully carry out the project, the team faces the challenge of coordinating multiple activities and tasks with numerous specialists in an efficient manner, allowing for increased productivity and a continuous workflow (Koskela et al. 2002).

In recent decades, as a result of the growing complexity of projects, design and construction have had to specialize, leading to a gradual fragmentation in the industry (Dainty et al. 2001; Love et al. 2002), where the number of specialties involved increases in relation to the complexity of the project. Generally, design and construction teams work at different stages of the project, and their interaction is mainly through plans, technical specifications, Request for Information (RFI), etc. (Sacks 2014). This information is dispersed in different documents, with limited structure and available in inadequate visual formats, slowing down processes, hindering information flows and increasing response latency (Mourgues et al. 2007). The workflow described above does not respond to the requirements of current projects, as they demand a high level of interaction requiring new management approaches and technologies to respond to these challenges.

This scenario becomes even more relevant in regard to hospital projects, where a greater number of specialties and their work teams interact, and a high standard of construction quality is required (Dave et al. 2015; Rybkowski et al. 2012). In cases where the project is an extension or remodeling of an existing infrastructure, the difficulty of guaranteeing operational continuity without neglecting the service provided to the patient (brownfield project) is added.

To increase agility and respond rapidly to unexpected problems, it is essential to shorten the communication time between workers and decision-makers (Hamzeh et al. 2012; Mourgues et al. 2012). There is currently software focused on task planning with visual systems that allow stakeholders to work collaboratively (Sacks et al. 2010).

Typical root causes of problems related to information management in construction are as follows: (1) information that is not in a visual format, (2) stratified and unstructured information, and (3) unmanageable digital formats. Table 1 shows the root causes of these problems and links them to the types of waste that is generated (Laine et al. 2014).

Visual Management (VM) is one of the key elements for the correct implementation of Lean Production, as it provides an easy way to understand the production information (Liker 2003). In recent years, there has been an increase in the use of Building Information Modeling (BIM) in construction; it is therefore interesting to link this methodology with Visual Management (Khanzode et al. 2006).

Table 1: Root causes and waste related to information management in construction (Laine et al. 2014)

Root cause	**Type(s) of waste**
Non-visual format: customer and designers cannot perform functionality review for the whole building with reasonable effort	Waiting, extra processing, underutilisation of skills
Scattered information: defects and inconsistencies in the design can pass the verification and are found when completing the work on site	Defects, waiting
Non-structured information: most of the information is in documents and therefore representation is fixed to one format only	Defect, transport
Digital format and devices unsuitable for execution: work on-site is difficult without using printed and laminated blueprint drawings and any update requires unnecessary work	Motion

The use of the BIM methodology with VM would help to correct the waste identified in Table 1. An example of this is the experience reported in the use of BIM-station onsite. BIM stations are tools to improve transparency of information in the field for all stakeholders, where the BIM coordinator keeps the models and drawings updated through a server (Murvold et al. 2016).

The objective of this paper is to describe the use of Visual Management using BIM to deliver instructions on the tasks that must and can be done in the field. To fulfill this objective, a case study of a hospital in Chile is described, whereby through the active participation of the consulting team, the use of visual instruction sheets was gradually implemented, using the BIM product and process model as input information.

BACKGROUND

BUILDING INFORMATION MODELING (BIM)

For the purpose of this article, we use the BIM definition given in the BIM Handbook (Eastman et al. 2011), which defines it as a modeling technology and associated set of processes to produce, communicate, and analyse building models. Despite these technological developments, BIM is significantly less used in execution, where paper drawings (generated in 2D) still dominate (Murvold et al. 2016). One of the most common problems associated with 2D-based communication during the design phase is the considerable time and expense required to generate critical assessment information about a proposed design, including cost estimates, energy-use analysis, and structural details. (Eastman et al. 2011).

VISUAL MANAGEMENT (VM)

Correct representation of information can help mitigate the complexity of production systems, even in chaotic and unpredictable production environments (Kurtz & Snowden 2003). Therefore, VM tools can be a contribution to on-site construction management. Among the benefits of VM are that it directly supports other management efforts, such as production management, safety management, performance management, and workplace management (cleaning) (Tezel 2011). In addition, the use of VM tools increases the ability to process information and reduces feedback time for action taking, such that control can be integrated into execution (Alvarez & Antunes 2001). The use of virtual tools improves the transparency of planning, being an instrument for collaborative use in planning and control meetings (Viana et al. 2014). Their other benefits may include greater discipline in the workplace, continuous improvement and work facilitation (Tezel 2013).

INSTRUCTION ON SITE

Workplace communication is mainly based on 2D drawings and informal verbal explanations. However, due to rework related to incomprehension of design and/or construction information (Mourgues et al. 2007) or errors due to old, incorrect and irrelevant drawings (Harstad et al. 2015), low productivity usually is the result. However, the fast development of information technologies offers new possibilities for portability and access to information on construction sites (Harstad et al. 2015), such as the method of delivering Virtual Huddles information (workstation meetings assisted by Virtual Design and Construction VDC -3D and 4D-) (Mourgues et al. 2007); the use of tablets to achieve communication between design and construction professionals (Harstad et al. 2015); the development of an automated method (FIPAPM, Field Instructions from products and process models) such that the user can produce working instructions based on formats or templates using VDC (Mourgues et al. 2012); or BIM stations, placed on the construction site, where workers can access the information they need, having 3D models available for all (Murvold et al. 2016).

IMPLEMENTATION METHODOLOGY

To achieve this objective, a case study of a healthcare center in Chile is described. Through the active participation of the consulting team from GEPRO and researchers from the Production Management Center of the Catholic University of Chile (GEPUC), the use of visual instruction sheets was gradually implemented, using the BIM product and the process model as input information. The case study was intervention of consulting team in development of design and construction of the project, for 18 months approximately.

The consulting team was tasked with supporting the owner in project management to ensure deadlines and quality standards. To guarantee the fulfilment of these objectives, Lean and BIM were planned to implement together and form an integrated project team, where owner, designers, contractors and consultants would actively participate.

Using BIM, it is possible to build precise virtual models of a building, which support design through its different phases, allowing better analysis and control than in a manual process (Eastman et al. 2011). When the models are finished, they contain the geometry and information needed to support the building construction and fabrication processes. The challenge faced by the consulting team was how to bring the information contained in these models to the field clearly, precisely and quickly.

Through experience acquired in other projects, the consulting team was certain that the field workers themselves can provide the best feedback on how to communicate the information extracted from the BIM models. Therefore, based on this feedback and supported by the collaborative environment of the project, different schematics of sheets were iterated, and testing was conducted to include information, such as 2D drawings and 3D images.

In the following sections of the paper, the case study context is described and then a mixed qualitative and quantitative analysis is presented. The qualitative analysis focuses on the degree of satisfaction of internal clients, participation and commitment in the planning and control meetings, the designer-builder relationship and the response time upon request. The quantitative approach focused on indicators of compliance with the construction deadline and RFI.

CASE STUDY

CONTEXT

The case study was developed in a healthcare center in Santiago, Chile, that initially opened in 1982 with a total infrastructure of 15,000 m^2. In 2017, the infrastructure is more than 237,000 m^2, growth that has forced the original services to adapt to new capacities. One of these is the hospital kitchen and dining area, which daily serves 500 hospital beds and more than 4,000 employees. This service area of 1,072 m^2 had to be remodeled and extended to a surface of 3,040 m^2 while maintaining operational continuity and a strict infection control protocol, in addition to complying with an adjusted work schedule.

The brownfield condition of the project, the non-existence of as-built plans with a record of modifications made over time and the poor information on existing installations dating from 1982 made the scenario more complex. For these reasons, the engineering designs initially proposed had to be adapted to what was found in the field during demolitions, generating multiple versions during construction.

Habilitation and construction projects in this healthcare center operated under a traditional workflow, according to Figure 1. The design team, composed of architects and engineers, delivered a set of 2D plans and technical specifications in text format to the construction team, composed of the contractor and subcontractors. These documents were the main communication tools between the teams. Historically, this workflow brought problems of interpretation, lack of information or verification of constructability, poor coordination between the specialties and lengthy response times, which compromised the execution of the deadline driven project.

With this incomplete information, the owner ordered design of the main engineering works (climate, electrical, sanitary and sewerage), with the goal of evaluating the technical-economic feasibility of the project, in order to subsequently bid the construction based on a design-bid-build system.

Parallel to the bidding process, the consulting team moved to site permanently to update information of existing infrastructure in-situ, by means of direct observation, as conditions of constructed building made impossible the use of advanced technologies (i.e. laser scanner). With the updated information, BIM model of existing elements was made, that when compared with basic engineering designs revealed incompatibilities and inconsistencies between them. So, it was necessary to adjust the design to achieve a buildable project.

As a result, a coordinated BIM model was already in place in early stages of construction, including existing and planned infrastructure. Model that would be used as a working tool during execution of project.

BIM VISUAL MANAGEMENT PROPOSAL

Given the project scenario and to ensure its success, it was necessary to change the approach and introduce methodologies and tools to respond to the problems associated with traditional design-build flows. To address the resolution of these problems, it was decided to implement Lean and BIM together as an alternative to the workflow presented in Figure 1. Last Planner System (LPS) techniques and BIM models were indispensable for planning, recording, adapting and coordinating projects in real time. The BIM sheets have been transformed into working instructions for Mechanical, Electrical and Plumbing mounting.

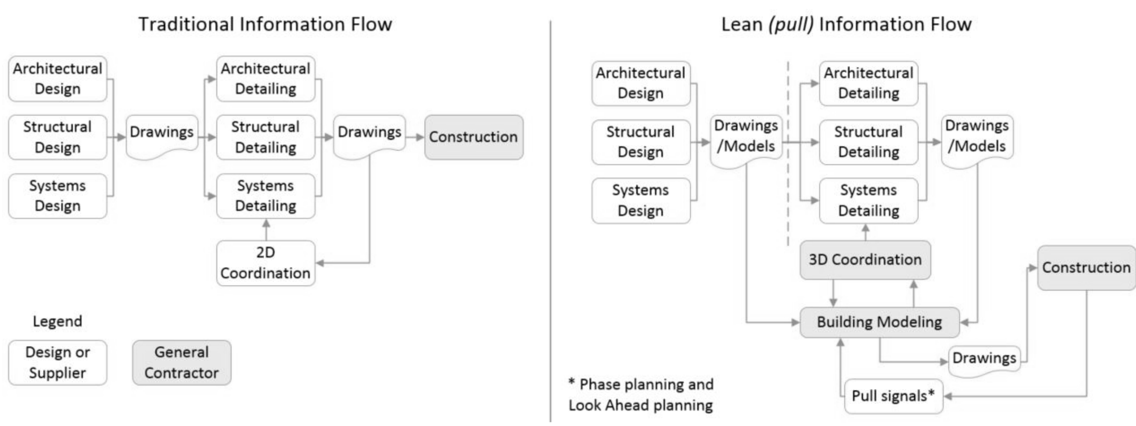

Figure 1: Traditional and Lean (pull) information flow (Sacks 2014)

The new workflow (Figure 1) and the expanded design team (architecture, specialties, client, users and consultants) provides the construction team with a coordinated product model (BIM), which is the main vehicle for communication between the teams. The instruction to generate a BIM sheet comes from a need that is identified in the weekly Last Planner System® (LPS) planning meetings and carried out by the integrated project team (extended design team and construction team), and it is based on the work planned for a given period.

As construction progresses, the on-site builders are responsible for the pull signals, determining the BIM sheets that will be required to support the corresponding field work or construction work. Once this signal is emitted, the project's BIM team prepares the sheets for on-site use. These BIM sheets are intended to provide visual information in a consolidated and precise way, under a standard structure and in a format compatible with the execution, since they can be printed in a manageable format (A3) and taken directly to the field. This addresses the root causes of waste related to construction information management, as described in Table 1. The Supplier-Input-Process-Output-Customer (SIPOC) diagram of the BIM sheets process is shown in Figure 2.

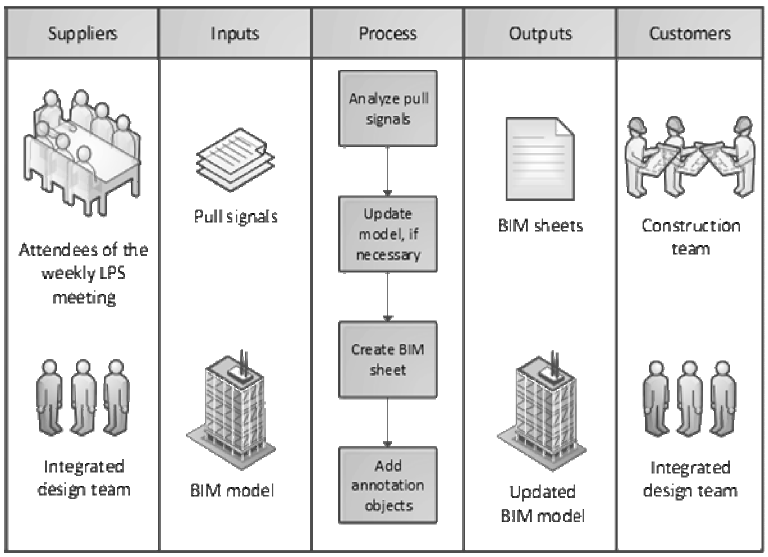

Figure 2: SIPOC diagram of the BIM sheets emission process

Each sheet is presented in an A3 format which contains a series of drawings and images obtained from the updated and coordinated BIM model. Generally, the information contained on these sheets consists of a floor plan, 3D images and sections to effectively communicate the solution of a complex sector of the project (i.e. Figure 3). The elements included in each A3 sheet were defined at the weekly LPS meeting and respond to specific requirements of each sector or specialty.

BIM sheet contains different 3D images and 2D drawings, depending on the need of each subcontract. The previous work of coordinating the designs of the specialties in a BIM model and its previous verification with the installers in the weekly meetings, ensured that in addition to compatible and error-free designs, A3 sheets were obtained with the specific information requested by those who would use them.

This experience was the first incursion of the construction company in the use of LPS to manage planning and BIM for the coordination of specialties, so in conjunction with the consulting team was chosen to use simple means and not too disruptive.

The final evaluation of the construction company, client, designers, suppliers and subcontractors was positive, highlighting that they achieved greater reliability in the construction processes and certainty of deadlines. In an interview at the end of the process, 76% of the respondents stated that the use of the cards was decisive in saving time in the field. 46% stated that they had interacted directly with the model on some occasion to resolve conflicts virtually. Finally, 67% consider the BIM model and the A3 sheets as a fundamental communication tool in the field.

Considering the initial conditions of the project and the uncertainty at the time of construction, a large amount of RFIs could have been generated, which would have led to continuous review and clarification of problems. With the proposed methodology, the number of RFIs was significantly reduced, as the problem-solving was carried out in the working meetings with the integrated team, recorded in the BIM model and taken to the field in a sheet format. Fifty-six BIM-based sheets were generated in addition to the traditional construction documents (plans, technical specifications, RFI), during the execution of this project over a nine-month period.

The BIM sheet (Figure 3) was used as a systematic communication tool for coordination of specialties and conflict resolution in site. The process and solution embodied in the file, brought together the efforts of all actors promoting a collaborative climate and committed to work, achieving greater integration of the end user, who contributed with their operational experience to improve efficiency in the life cycle and not only during design and construction.

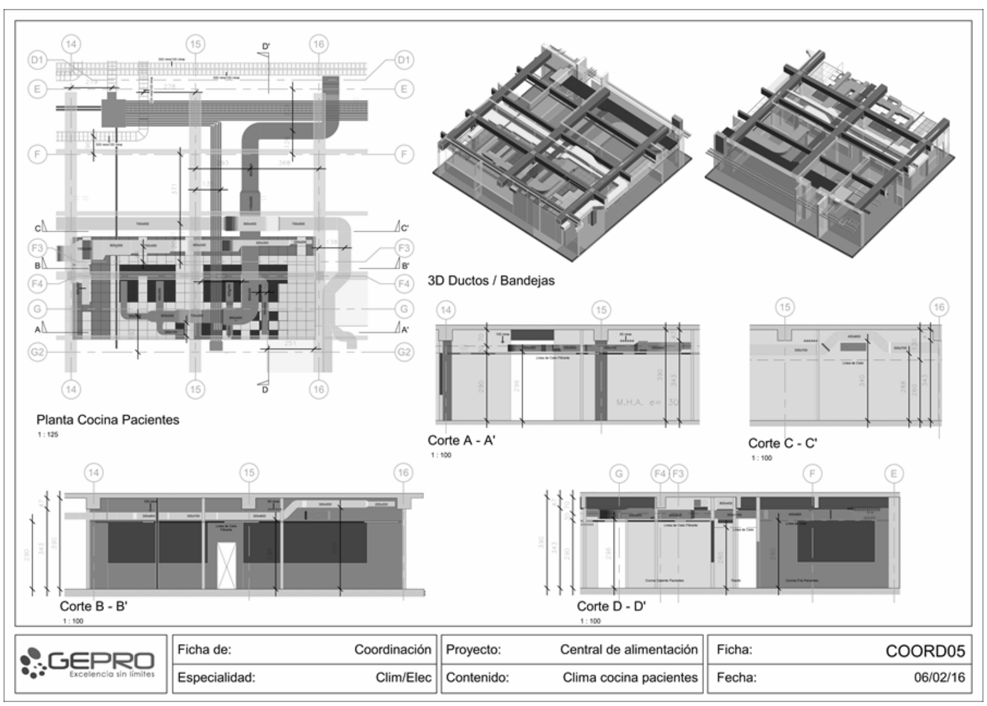

Figure 3: Example of a BIM-based sheet

Among the quantitative data, the estimated deadlines for execution of the work were met without delays. This should be considered a success because in similar projects previously carried out by the same client, the project schedules were exceeded by 50%. Further, without the proposed methodology (Figure 1), it was unlikely that the information required in the LPS meeting was available in due time, whereas when implementing the integrated team methodology, pull signals and work instruction sheets, the information was available just-in-time.

CONCLUSIONS

From the case study we concluded that the use of BIM tools or instruction sheets alone does not guarantee success, time related benefits or reduction of rework. It is necessary to use a collaborative working methodology in which the work processes follow the principles of the Lean philosophy. This is fundamental in complex brownfield projects with multiple and numerous specialists. The use of these sheets directly addresses the root causes of construction information management problems and of the main waste. For example, the tab visually consolidates information, deletes waiting for information, extra processing and defects. This workflow makes sense in projects where the design stages overlap with construction, better known as Fast-Track projects, because the information must be handled in a just-in-time way.

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MODELLING AND SIMULATING TIME USE OF SITE WORKERS WITH 4D BIM

Ruben Vrijhoef[1], Jan Tjerk Dijkstra[2], and Alexander Koutamanis[3]

ABSTRACT

This paper presents a research endeavouring to model site work in a 4D BIM model. Next simulations are performed with this model in 5 scenarios including specific interventions in work organisation, notably changing positons of facilities for site workers. A case study has been done in a construction project in the Netherlands. The research has showed the possibility to model time use of site workers in 4D BIM. Next the research has showed potential to perform and calculate specific interventions in the model, and prospect realistic changes in productive time use as a result.

KEYWORDS

BIM, time use, simulation, site work, labour optimisation.

INTRODUCTION

Building Information Modelling (BIM) has proven to have several benefits in visualisation, automatic generation of drawings, code reviews and construction sequencing (Eastman et al 2011; Papadonikolaki et al 2015). In terms of planning, BIM can be used to do four-dimensional modelling. According to Doloi (2013), one of the attributes that influences the cost performance in construction projects at a high level are planning and scheduling deficiencies.

With labour productivity on construction sites between 40 and 50% it is relatively low compared to other industries (Aziz & Hafez, 2013; Forbes & Ahmed, 2011). Whereas, in the Dutch construction industry labour takes up 40 to 60% of the total construction costs and is therefore one of the largest expenses (Nasirzadeh & Nojedehi, 2013).

The improvement of labour productivity can have advantages for the profit of contractors and lead to lower costs for the clients (Eastman et al. 2011). Problems that

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contribute to this low labour productivity are for a large part related to waste and inefficient organisation of labour, materials and equipment.

RESEARCH PROBLEM STATEMENT

The problems causing low labour productivity are mostly related to time and place planning flaws. Different solutions can be found to solve these problems. Currently building information models are mostly used in the design and engineering phase of the project combining the data of different parties into one model. 4D building information models provide the link between space and time (Eastman et al., 2011). If time use by site workers could be modelled in a 4D model, it could help clarifying solving part of the productivity problem. In a 4D building information model the 3D data should then be linked not only to the schedules but also to site work information and show various types of time use, productive and unproductive (Eastman et al., 2011).

RESEARCH OBJECTIVE

The first goal of the research is to provide insight into site labour and movement of workforce with a 4D building information model. This focuses on how to model and visualise the element of site labour and movements of workforce into a 4D building information model. The final product of this part will be a framework that describes which data is needed to properly model the labour and movement of workforce; how to accurately model this into the 4D BIM; and how this can be visualised within this 4D model.

The second goal is to provide insight in the potentials of certain interventions with 4D building information modelling. This is to find indications of the increase of the amount of productive time on construction sites by simulating interventions that reduce walking distances and waiting time particularly. The result of this part provides insight in the effect of interventions that might increase the productive time based on simulating interventions in the model for instance changing the place of an elevator or toilets.

CONCEPTUALISATION OF TIME USE ON SITE

Productive time is well connected to output and productivity. If the productive time is known the output of construction can be calculated. For instance, waiting and walking time is also related to productivity. Productivity may therefore improve when waiting and walking times are reduced, since the available productive time is increased (Thomas et al., 1990). However reducing waiting and walking time does not inherently mean an increase of productivity in itself but increases the available time the workforce has for working.

This contrasts to waste as seen as activities that do not add value to the client's end product. More specifically it can be defined into value adding and non-value adding activities. Value adding activities are those, which convert materials and/or information in the search to meet client's requirements. Non-value adding activities, those which are time, resource, or space consuming, but do not add value to the product (Aziz & Hafez, 2013). Vrijhoef (2016) and Eaton (2013) show that the activities can be divided into three categories.

Working time within this research is the time the workforce may use for value adding but also for non-value adding work. This means productive as well as unproductive work time, or activities connected to work and work organisation. Besides time categories waiting and walking are distinguished as non-working times. So in this research the activities are divided between walking, waiting and working. However this does not necessarily relate to productive versus unproductive, or value adding versus non-value adding classifications (Figure 1). The research is indicative though form also these classifications.

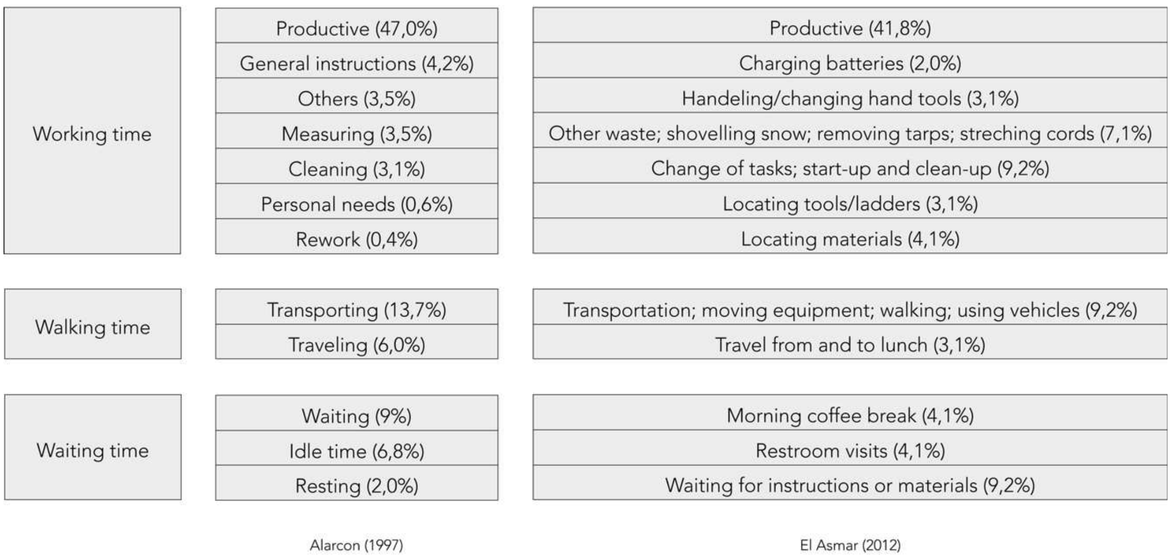

Figure 1: Division of working, walking and working time, compared to prior classifications of time use on site (Alarcon 1997, El Asmar 2012)

RESEARCH METHOD

RESEARCH DESIGN

The exploratory design is chosen to conduct this research. According to Fellows and Liu (2015) the exploratory design is to test, or explore aspects of a theory. As this research look into the extent in which a 4D building information model can provide insight in labour and movements of workforce and can help to indicate potentials for the increase of productive time, further research has to find out what the actual change in productive time when this framework is applied. Because the theoretical framework that largely derived from an in-depth literature study, provides the theory behind the research. This theoretical framework acts as a guide for which variables to collect, adopt and analyse. Since this research is mainly focussed onto a single construction project and does not provide concrete number, qualitative research is chosen as the overall strategy.

CASE STUDY

The case used for the data collection within this research is the construction project of 'het Noordgebouw' near the central station of the city Utrecht in the Netherlands. This is a building of 23,000 m2 that will accommodate offices, dwellings, retail, restaurants/cafes and a hotel. Within this construction project the main contractor is using a BIM model which is enriched with the models of subcontractors. Besides materials to the project are delivered JIT based on daily work packages shipped from a central hub facility.

Because the construction project itself is relatively large this research will narrow down for the time use modelling on one subcontractor i.e. interior walls. This work is consisting of multiple components of metal stud walls covered with plasterboard and all the wiring and electricity in and on the wall.

4D BIM MODELLING

The particular aim of this research aimed at modelling and simulating time use on site has required a 4D BIM modelling. In addition in the case study a 4D model had been made for various operational aspects of the project.

With the 4D model both the temporal and spatial aspects of a schedule had been presented, and this way of communication appeared more effective than a traditional Gantt chart. Second, the 4D model provided a basis for multiple stakeholder communication. Third, it helped planners with site logistics, coordinate access to and from the site, and locations of large equipment like cranes. Fourth, it helped to coordinate the trades on the project. It assisted planners with the coordination of expected time and space flow of trades on site as well as the coordination of work in small spaces. Fifth, project managers could compare different schedules easily, and quickly identify whether or not the project was on schedule.

Added to the 4D model Dynamo is the software used within this research to model and calculate the additional data to identify the time use. Dynamo is provided by Autodesk and is based on visual programming. It creates its own geometry and reads and writes to external databases. Revit has been used as the database of the parametric geometry to and from which Dynamo was able to write and read the data needed (Sgambelluri 2014).

MODELLING WALKING PATHS

The simulation and analysis of a dynamic subject, like pedestrian circulations, relies on a representation consisting of a number of interrelated components (Table 1).

Two types of modelling walking paths have been considered: Euclidian distance and City-block distance. The Euclidean distance, also called straight-line distance is a metric is inspired by the 'distance on the ground' (Pan et al., 2013). The Euclidean distance is based on the Pythagorean theorem. The city-block uses the sum of the x and y coordinates. This is often called the Manhattan metric as it is relating to the walking distance 'around the block' (Sarstedt & Mooi, 2014). In the research of Manning, Kahana, and Sekuler (2006) they found that when a direct path is possible theoretically, still the most realistic path distance is equal to the city-block distance. Therefore, the city-block distance is a better representation of a real world situation and use in this research.

Table 1: Route analysis data (Koutamanis et al., 2001)

Data	Operationalisation
Starting point	The location from where one or multiple actors depart. In buildings, the centroid of a space can be seen as starting point or a doorway. Multiple starting point indicate an aggregation of routes.
Destination	The endpoint of an actor, the place it wants to end at. Multiple destinations are not necessarily product of aggregation, a route can also have intermediate destinations such as stairs and elevators.
Path	The path has a starting point and destinations which can be complemented by intermediate destinations. The path can be the actual path or an approximation of it.
Means of transportation	How movement is achieved along the path, this includes the speed the actor travels at and the capacity of these means.
Activities	These are the activities that take place along the path. Two options appear: activities related to the transportation; or the intervening opportunities, such as relations to other routes, activities and actors.

IMPLEMENTING THE MODEL

As basis for the final model a backbone had been deduced from the Revit model of the case project. Next the construction site lay-out and waiting and working times in spaces had been added (Figure 2). The next step was to map the rooms and the room locations with their coordinates. With the coordinates of the rooms the lines of the walking paths and distances were calculated. The vertical distance together with the means of transport, and the average speed related to that mean of transport gives the time needed for the vertical travel.

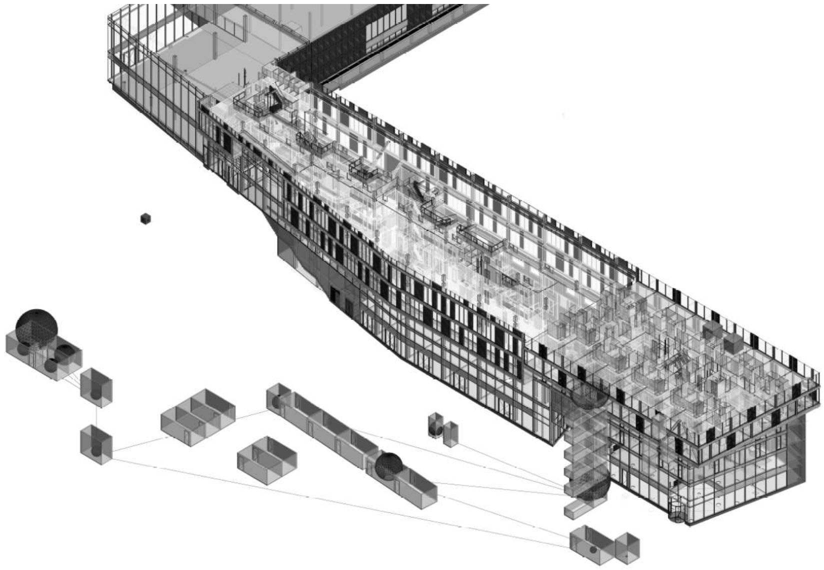

Figure 2: Visualisation of the benchmark simulation in the case BIM model

SIMULATION OF BENCHMARK AND INTERVENTIONS

A total of five simulations were performed within this research. The benchmark simulation was the real situation in the case project. In addition four virtual interventions were simulated: extra elevator; toilets on levels; elevator to corner; elevator near work.

Table 2: Overview of performed simulations

Type	Description
Benchmark	Simulation with the characteristics which are similar to the current construction site lay-out and typical workday
Intervention 1: Extra elevator	The capacity of the elevator is doubled, from one to two elevators. Assumed is that this intervention decreased the waiting time for the elevator by half.
Intervention 2: Toilets on levels	This intervention eliminated two up and down movements per typical workday. Achieved by placing toilet on every level of the building.
Intervention 3: Elevator to corner	The elevator and staircase relocated from the centre of the building to the corner of the building. This should decrease the walking distance on ground level.
Intervention 4: Elevator near work	The elevator is relocated from the front side of the building to the rear side, next to the workspace. This reduces the walking distance on the building levels but increases the walking distance on ground level.

RESULTS IN THE SIMULATION

Of all categories, the working time stays constant among all categories. The other categories do change due to the simulations. The sum of those categories is called ‘travelling time’ i.e. the sum of horizontal city-block time; vertical time by elevator; vertical time by stairs and waiting time are presented in Figure 3. This figure shows the results of all changeable categories during simulations per level. The time calculations due to interventions have been based on changing distances multiplied with known speeds of people and elevators, and reduced waiting in case of additional elevators.

From Figure 3, the following trends can be observed. First, for all simulations a large difference appears between level 4 and level 5. Which in fact is the result of the contractor's elevator policy saying the elevator can only be used from level 5 and up. Till level 4 using the stairs is mandatory for all staff. Second, the increase of time per simulation is progressive as the level rise. This is the result of previously mentioned reasoning, that with a higher level the vertical travel time increases. Due to the fact that the travel time is a product of vertical height. Third, comparing the different interventions with the benchmark results in the following ranking.

Intervention 4 is the only intervention that results in longer travelling time than the benchmark; 1:02 minutes longer in average per level. Second is Intervention 3. Which is only slightly better than the benchmark, with an average improvement of 1 second per level. Third, is Intervention 1, which has quite a difference compared with the previous two interventions, of 21:38 minutes in average per level. Fourth, the intervention with the largest improvement and difference from the benchmark is Intervention 2. This intervention reduces the average travelling time per level by 33:28 minutes.

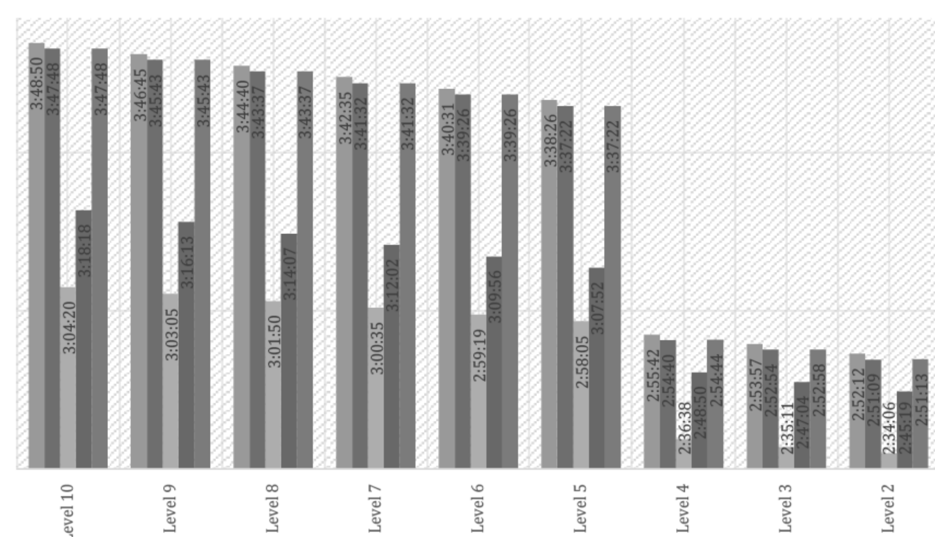

Figure 3: Total traveling time (sum of city-block time; vertical time by elevator; vertical time by stairs and waiting time) for all five simulations per level of the building

ANALYSIS OF THE RESULTS

Further analysis of the ratio between walking, working and waiting showed that the share of working time varied between 62,3% and 70,4%. Though, when comparing this to the real activities performed by the dry-wall contractor and its crews it appeared not to be comparable with the realistic productivity figures found. Remarkable differences appeared between the three crews of the dry-wall contractor.

Comparing this to the construction schedule the reason was found that the three crews performed different construction activities in addition. Crew 2 and 3 in particular performed many more construction activities than included in the working time calculations. This had to do with the fact that the dry-wall contractor was not only building the walls but appeared to be installing the ceilings as well. Therefore, the second and third crew are also working on the ceiling and other activities as well. This would have resulted in a larger share of working time for crew 2 and 3 in particular. Crew 1 was mainly building the metal-stud walls and therefore came closest to the calculated total working time (Figure 4).

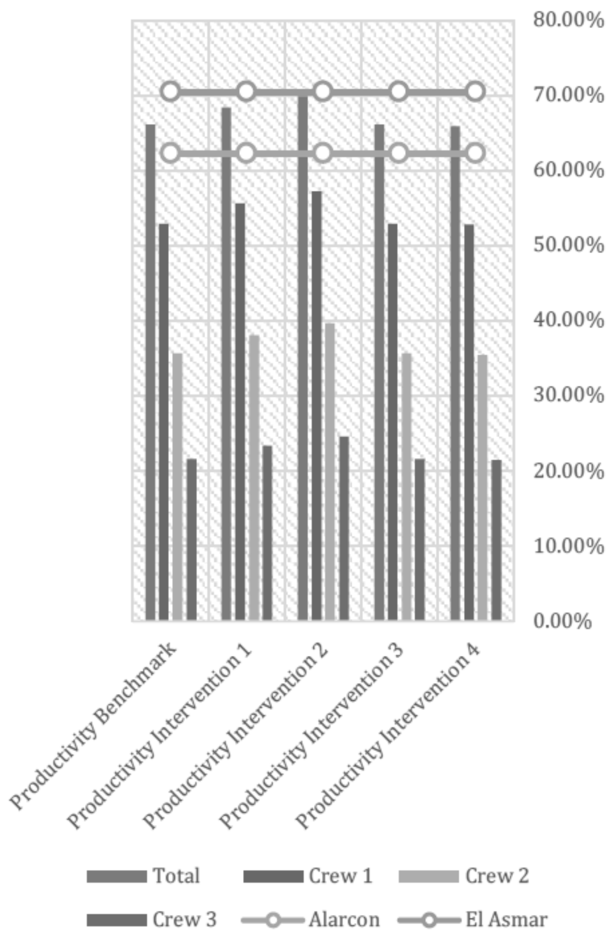

Figure 4: Average share of productive working time per simulation

The differences between the different simulations, show that the Intervention 4 seems the least effective in improving in productive working time shares among all crews. It even seems to reduce the productive time slightly. Second is the Intervention 3 which improves the productivity just a small bit, but it is almost equal to the benchmark. Third, is the Intervention 1 which shows the second best improvement of the share of productive time. For the total productive working time the improvement is approximately 3.5%. Fourth, the best improvement would be achieved applying Intervention 2 i.e. an improvement of approximately 5.5% of the share of productive time.

DISCUSSION

When looking at the approach to productivity in which the working time is divided by the total time. The working time has remained constant during all simulations. Improvement have been found in the increase of the share of productive time, when the share of walking and waiting time were reduced with the interventions presented.

The order in which these rooms are modelled is subject to debate, because of two contradictory reasons. First, the model presented within this research is meant to be used in the early stages of a project. Within the early stages, it is generally hard to tell which subcontractor is going to execute the job and what the operational process is going to be. Second, during the early stages of the construction process, uncertainty is high (Winch, 2010). Thus, the typical workday can help generate certainty. As the typical workday is used as part of the model to help make decisions in i.e. the construction site lay-out, it helps to provide information within the process.

Within the model of this research, the horizontal walking distances are drawn on the ground level or on the different levels of the building. Excluded from the current model are the walking lines on the building levels, e.g. to the place where the materials are stored, or where waste is collected. This would increase the walking distances of the construction worker and makes this category of the model more prominent.

Within this research the working time, which is set as a constant, is used to gain productivity numbers that can show this productivity increase. Without the working time the different simulations can be compared with each other to show which construction site lay-out is the most productive, since the model focusses on the decrease of time used for waiting and walking. Nevertheless, the importance of the working time can be explained when different projects want to be compared. Without the working time, no productivity figures can be presented, and it becomes hard to compare different projects.

The ratio between walking, waiting and working time ratio is used to compare the results of the simulations with the data found in literature. Items categorised are for example ‘locating tools and ladders’ or ‘locating materials’ which are categorised under working time. It can be questioned if this does not belong to walking time, which would increase walking time by 7,2%.

CONCLUSION

Currently, no modelling exists to provide insight in walking, waiting or working times of construction workers, or to visualise their movements, waiting and working times. This model is a first step in providing this insight, as it shows how simulation can be done which generates figure on walking, waiting and working times of construction workers. Furthermore, it generates visual images which provide even more insight the movements and waiting times of construction workers.

Providing this insight shows indications and locations of non-value adding activities. This helps to indicate potential interventions to decrease the amount of non-value adding activities. This would increase productivity in terms of the ratio between value adding and non-value adding activities, when addressing the potential to increase and use the additional available working time in a productive manner on construction sites.

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TOLERANCE COMPLIANCE MEASUREMENT USING TERRESTRIAL LASER SCANNER

Saeed Talebi[1], Lauri Koskela[2], Patricia Tzortzopoulos[3]

ABSTRACT

Terrestrial laser scanning (TLS) provides remote sensing and a quick and comprehensive technique for deviation analyses. Its application for precision surveying purposes is becoming a common practice. There are many interdependent parameters that determine whether the accuracy obtained during the data collection and registration is appropriate to perform deviation analyses. Also, the accuracy of deviation analyses is reflected on visualisation/demonstration of results. However, the focus of previous research works has often been on either data acquisition, data registration, deviation analyses, or visualisation of results. The research described in this paper consolidates and formalises the existing methods in the literature and practice for data acquisition and data processing. In doing so, the aim is to develop a holistic method termed Tolerance Compliance Measurement (TCM) using TLS to obtain results from deviation analyses with the desired accuracy. Moreover, unlike the previous research works that mainly focus on assessment of flatness of surfaces, the appropriateness of the most common algorithms for assessment of different types of geometric variation is explored. The results show that the application of TLS and commercially available software are versatile although not complete for analyses of different types of geometric variation.

KEYWORDS

Laser scanning, deviation analyses, data acquisition, data registration, visualisation of deviation maps, demonstration of deformation analyses, geometric variations, enabling Lean with IT.

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INTRODUCTION

Fixing defects associated with tolerances is time consuming, costly and onerous (Milberg and Tommelein 2005). In spite of increasing calls for waste reduction and an improved quality of buildings, Forcada et al. (2016) estimate that tolerance-related defects are amongst the most common and recurring defects in construction projects and make up more than 9 percent of the overall number of defects. One of the factors that can help minimise defects is to improve inspection methods used by surveyors and engineers (Yates and Lockley 2002). More specifically, defects associated with tolerances, called tolerance problems hereafter, can be mitigated by changing the inspection techniques and gaining better control of the magnitude of dimensional and geometric variations (Landin 2010). Conventional inspection methods use sampling techniques (Phares et al. 2004), some of them are limited to the need for surface contact (Bosché and Guenet 2014), and they depend on inspectors' subjective assessments (Anil et al. 2011). However, the use of conventional inspection methods has remained time-consuming, laborious, and therefore ineffective, although some of them are relatively accurate (Phares et al. 2004). As a result, such methods often cannot identify tolerance problems early and comprehensively during the construction process (Akinci et al. 2006) and results obtained from them may not be reliable (Phares et al. 2004). For instance, when assessing the flatness of concrete slabs by using the total station, only a few points representing the whole surface are collected. The elevations of the collected points are measured to determine their vertical deviations from the nominal elevation (Tang et al. 2011). Such method gives an incomplete and sometimes incorrect understanding of the achieved flatness to surveyors because surfaces that have higher deviations than permissible limits may not be controlled (Bosché and Guenet 2014). Communication of surveying results obtained from conventional methods is another problem area as inspectors may have different approaches to report the results (Anil et al. 2013). The lack of an effective standard method for communication may result in misinterpretation among project participants (Phares et al. 2004).

The terrestrial laser scanner (TLS) has been proven to be useful for a variety of applications including deviation analyses. Various methods for: (a) data acquisition (e.g., Wilkes et al. 2017), (b) registration (e.g., Olsen et al. 2009), (c) deviation analyses (e.g., Holst and Kuhlmann 2016), and (d) visualisation/demonstration of deviation analyses (e.g., Anil et al. 2013) have been proposed. However, a review of the literature reveals that there is not any current research work that proposes a holistic process consolidating these four independent fields of research for measuring geometric variations. To improve the accuracy of data registration and data analyses, and to improve the interoperability of results, it is suggested to have a formal process specifically for measuring geometric variations using TLS. Such a process must be holistic, that is it should start from data acquisition and extend to visualisation/demonstration of analyses. This is because the accuracy of deviation analyses depends on the way data is collected and registered; the accuracy of deviation analyses is also reflected in visualisation/demonstration. Hence, it is not a sufficient practice to consider these steps independently, especially when using them to measure variations that require a high level of accuracy. Moreover, most of the existing research works in this realm of research are about the assessment of surface flatness, whereas the capability of existing commercially available software for deviation analyses can also be used to assess other types of geometric variations (Nahangi and Haas 2014). Here the question arises: What method of deviation analysis is most suitable for each type of tolerances? This question can be addressed if types of tolerances are well-defined and they are associated with different methods of deviation analyses.

The topic of tolerances should be investigated from the lean construction perspective (Milberg and Tommelein 2005). This research employs one of the foundational elements of lean which is process standardisation. The standardisation of the best-known practice helps to maintain a regular timing and output of the process (Liker 2004), and to continually improve the design of that process (Womack and Jones 1997). This paper is a first attempt to propose a standardised process termed TCM using TLS: (a) to provide practical recommendations for capturing 3D data sets, thereby facilitating registration of data sets, (b) to propose a minimum viable workflow for data registration by which a high level of accuracy can be obtained, (c) to explore appropriateness of common methods of deviation analyses available for each type of tolerances, and (d) to explore effective methods for visualisation/demonstration of the results.

LITERATURE REVIEW

DATA ACQUISITION AND REGISTRATION

Two main parameters that impact the accuracy of data sets during data acquisition are: (a) distance, and (b) resolution setting (Kim et al. 2014). Scans with common targets and data should be aligned and merged to create a complete image of the scanning domain and to achieve registration with the desired accuracy (Olsen et al. 2009). Scans can be aligned together by applying either direct or indirect georeferencing methods. In direct georeferencing methods, targets with known coordinates are used. Coordinates can be obtained through the total station. In indirect georeferencing, software aligns the scans based on common data in neighbouring scans (Olsen et al. 2009). The final registered data is a set of points with known X, Y, and Z coordinates (Kim et al. 2014).

DEVIATION ANALYSES

The most common algorithm to measure deviations on surfaces is as follows: (a) a reference plane is set up, (b) data noises are smoothened, (c) the deviation between the points acquired and the reference plane is computed, and (d) surface regions, where their deviations are larger than the threshold specified by the user, are detected (Tang et al. 2010). In this algorithm, the reference plane is set up by fitting the best primitive shapes or triangulating the point cloud data set (Olsen et al. 2009). One type of deviation analysis is deformation analysis of the structural members. The deformation analysis can be performed in two ways: (a) the deformation in the surface of an object is determined from a given reference plane. The position and orientation of the reference plane can be either based on the nominal parameters in design, or its position and orientation are estimated as part of the deformation analysis; (b) the surface of an object is scanned twice or more times. The deformation is determined by computing the deviation between the position and orientation of surfaces at different points in time. The reference surface in this scenario is defined by the first scan (Holst and Kuhlmann 2016).

VISUALISATION OF DEVIATION ANALYSES

Once deviations were computed, they can be visualised in several ways by generating a colour map. There are two common categories of colour maps: continuous and binary colour maps (Anil et al. 2011). The focus of this paper is on the continuous colour map. In this type of visualisation, a colour to every deviation value is assigned according to a gradient colouring range (Anil et al. 2013). The continuous colour map itself can be either signed or unsigned. This paper utilises the former method, in which different colours are assigned to distinguish between positive and negative deviations (Anil et al. 2011). The reason behind these choices is that the authors believe they are more effective in practice.

DIFFERENT TYPES OF TOLERANCES

Talebi et al. (submitted) propose a method termed Geometric Dimensioning and Tolerancing in Construction (GD&TIC). The ultimate goal of this method is to develop a common language to facilitate the communication of tolerance information throughout the design, construction and inspection process. GD&TIC specifies the permitted variations in size, form, orientation and location of features on a component. Also, it consists of a total of six characteristics that represent the types of tolerance (Table 1).

Table 1: Tolerance types, their characteristics, and their applications (Talebi et al. submitted)

Type of Tolerance	Characteristics	Applications
Form: It establishes the shape of a surface.	Straightness: It represents how straight a surface is on a feature along a line.	It is used to control the beams and columns that are prone to deformation.
	Flatness: It demonstrates the amount of deviation of flatness that a surface is allowed to have.	It controls the flatness of a floor slab.
Orientation: It describes the relationship between features and datums at particular angles.	Perpendicularity: It is a condition used to ensure that a surface centre plane, or axis is exactly at a right angle relative to a reference plane.	The Perpendicularity Control should mainly be used for components for which plumbness tolerances are a major concern.
	Parallelism: It limits the amount of variation allowed over an entire plane, from being parallel to the reference plane.	When two surfaces should maintain constant distance, the Parallelism Control is used.
Location: It establishes the position of the feature relative to a datum.	Position: It is the location tolerance of a feature relative to its nominal position.	The Position Control is mainly used for three purposes: (a) to control the location of components such as columns and beams, (b) to control the distance between those components, and (c) to control the coaxiality between those components.
Profile: It is the outline of a part feature and the True Profile is the exact profile of part feature.	Profile of a surface: The Surface Profile Control limits the amount of variation that the surface of a feature can have in relation to its True Profile.	It is primarily used to control the level of surfaces

METHODOLOGY

The paper consists of a review of the literature and collection of empirical data. Previous studies in the realm of data acquisition using TLS, data registration, deviation analyses and visualisation were investigated. The field researcher (lead author) observed the practice of a firm delivering 3D laser scanning services for two days and the practice of a software vendor company making applications for automated deviation analyses for three days. The aim of these observations was to understand relatively advanced practices from data acquisition to visualisation of deviation analyses in the industry. Also, the empirical data was collected by scanning a building and a warehouse. All scans were acquired by FARO Focus 3D X130. The 3D data sets were registered using the FARO SCENE software. The deviation analyses were performed in: (a) the FARO SCENE software with deploying a plug-in application provided by a third party, and (b) CloudCompare, an open source software. A manual registration method with the aid of targets was deployed. A total station was used to obtain the coordinate system for the reference targets. The standardised process for TCM using TLS is proposed based on the literature review, empirical data and experience of the field researcher.

PROPOSAL: TCM USING TLS

In order to measure and visualise/demonstrate geometric variations more effectively, this paper proposes a standard approach for TCM using TLS. The proposed approach has four standard steps to be followed (Figure 1).

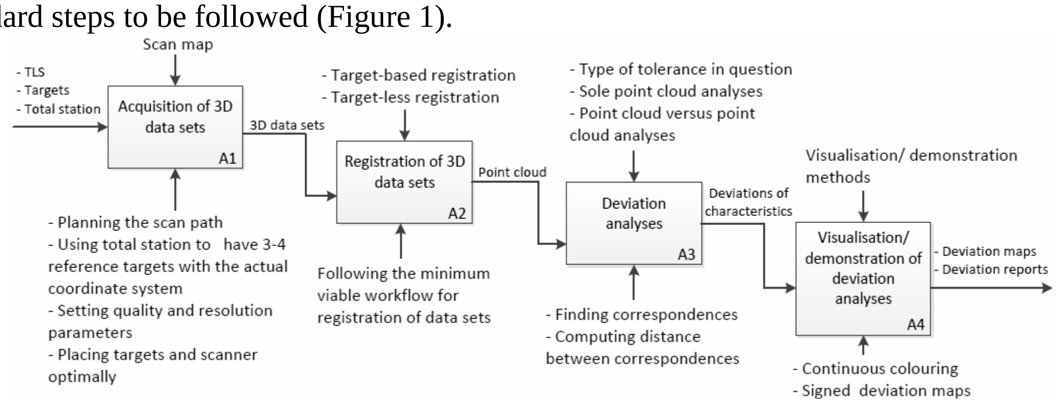


Figure 1: The proposed tolerance compliance measurement using terrestrial laser scanner.

ACQUISITION OF 3D DATA SETS USING TLS

The first step in the proposed TCM process is to acquire point cloud data sets using TLS. This section recommends the best practice to achieve the highest accuracy. Successful registration of 3D data sets within the deviation of 3 mm, which is a reasonably high accuracy based on the observed practice in the industry by the field researcher, much depends on the acquisition of 3D data sets.

Scan map

Planning the scan path in advance is important. The scan map consists of a floor plan that demonstrates the scan positions with the corresponding scan numbers in the field. The scan map is useful to help plan the scan path in an optimum pattern (i.e. zig-zag pattern) and optimum distances between scan positions. In other words, using this method will help the operator realise which scans have overlapping and common data, and accordingly which scans should be grouped into a cluster tree. Not planning the scan path proactively using a scan map may result in illogical scan positions, deficient registration, and eventually inaccurate as-built data sets. Figure 2 shows an example of a scan map.

Reference targets

In the proposed TCM process, it is essential to have a coordinate system in the as-built data set to ensure that the deviation analyses will be performed on a correctly levelled and sized data set. To apply the coordinate system, minimally three and preferably four reference targets (i.e. black and white checkerboard or sphere) should be used. First, the position of targets should be marked on the scan map: (a) to ensure that there is a triangulation for the targets because only this geometry leads to levelled and sized as-built data sets, and (b) to demonstrate that at least one scan position will capture the targets. The yellow marks in Figure 2 show the position of four targets in the scan map. The targets then should be placed in the field. A total station should be used to have those targets set up with an actual coordinate system. Having the coordinate system associated with the targets, the as-built data set can be aligned and rotated to a correct size according to the reference coordinate system.

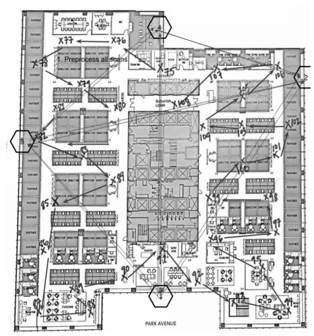


Figure 2: An example of a scan map demonstrating the scan path (blue lines), position of scans (red numbers), and position of the reference targets (yellow marks).

Quality and resolution parameters in TLS

The basic parameters of quality and resolution should be correctly selected to obtain an accurate as-built data set. Having higher resolution and quality can increase the accuracy of data sets but they also significantly increase the time required to capture data. It is recommended to have more scans at lower scanner settings, rather than having a lower number of scans with higher settings. Hence, an operator should hold a trade-off between the level of resolution and quality needed, and the time constraints to scan a space. To do so, relatively appropriate values for these settings based on the best practice observed and experience gained are suggested in Table 2.

Scanner and targets placement

Targets are needed only if the Target-based Registration is used. The distance between scan positions should not exceed 10-15 m. A minimum of three targets per scan should be deployed. Also, there should be at least three common targets between scans for redundancy purposes. Targets should not be placed in line; instead they should be spread across, and there should be variation in their vertical elevation. The scan positions should not be more than 15 m away from the target otherwise they will not be recognised by the software used in this research as the number of returns reduces. It is essential that the targets not be occluded from scan positions. This can be ensured by following the scan map. The overall scan positions should form a closed loop. This means starting from a point, doing all scans and finishing at the same point.

Table 2: Suggested values for Resolution and Quality in TLS.

Parameters	Settings
Resolution	For large interior areas and exterior areas, a high resolution (~1/4); for interior spaces, medium resolution (~1/8), and for small interior spaces low resolution (~1/10) are suggested.
Quality	This setting depends on the type of the material of which an object or surface is made. For non-reflective materials (concrete), the quality parameter of 2X, and for highly reflective surfaces and objects (shiny partition walls), a quality parameter of 3X or 4X are recommended.

REGISTRATION

There are two main ways of registering acquired data sets when using the FARO SCENE software: Target-based Registration and Target-less Registration. The Target-based registration relies on targets, whereas Target-less Registration relies on vertical planes (e.g., walls, columns). A minimum viable workflow for registration of 3D data sets is proposed in this paper (Figure 3). Following this workflow, the alignment deviation between targets should be less than 3 mm.

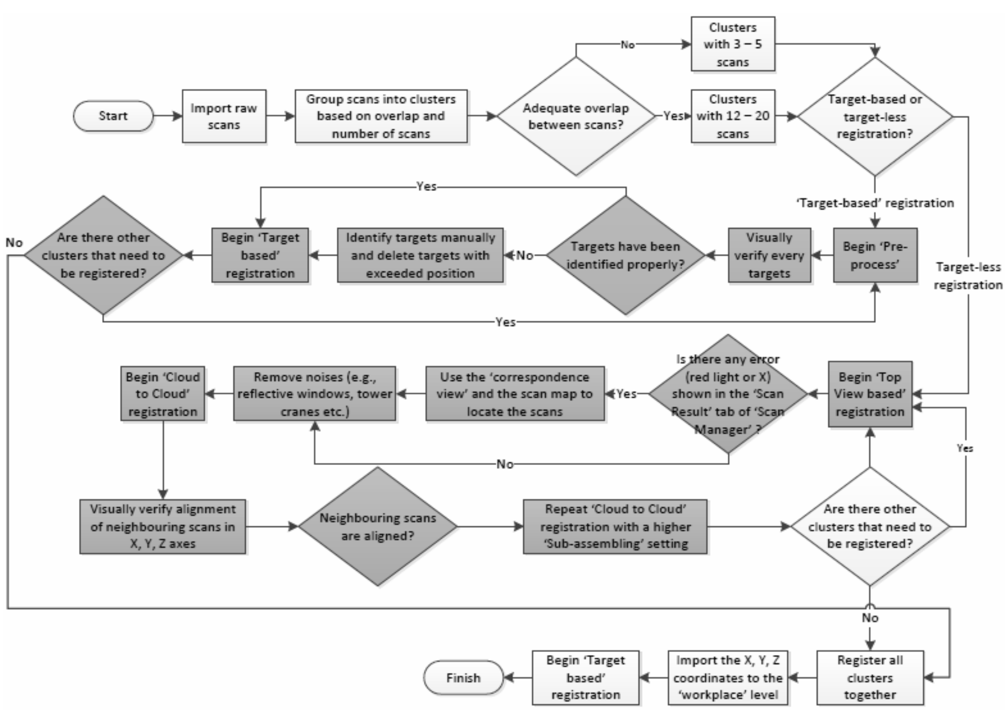


Figure 3: The proposed minimum viable workflow for data registration when using FARO SCENE software

In the Target-based Registration, pre-processing may be used to identify targets automatically and to apply filters. Targets in every scan should be visually verified to ensure they have been appropriately identified (i.e. there is a sufficient number of returns, targets have been identified only, the position deviation of targets is as low as possible). Eventually, Target-based Registration can be performed. If the operator has taken the recommendations for target placement into account, the desired accuracy is achieved.

In the Target-less Registration, there are two steps: Top View based registration and Cloud to Cloud registration. The former registration is used to align the scans together roughly, and then the latter registration is performed to refine the initial attempt and achieve the desired accuracy. Noises in scans should be removed before running the Cloud to Cloud registration. The deviations shown by the software are just an indication and do not demonstrate the overall deviation between scans; hence, visual verification is needed by checking the registered data set in Z axis (horizontal surfaces) and X, Y axes (vertical surfaces). In the next iteration of the Cloud to Cloud registration, Maximum Search Distance should be larger than mean scan point tension. The Cloud to Cloud registration is repeated until the mean scan point tension is lower than 3 mm.

Table 3: Categories of approaches for deviation analyses, algorithms to compute deviations, and the most suitable algorithms for each type of tolerances

Approaches used for deviation analyses	**Algorithms to compute deviations**	**Associated type of tolerances**
Sole point cloud analyses	Point to reference plane: A reference plane is established for a group of points in an as-built data set. The distance between the points in the data set and the plane is computed.	Flatness and perpendicularity (surface): It is a regular practice to assess flatness of surfaces (e.g., concrete slabs) and perpendicularity of vertical planes (e.g., walls) by using point to reference plane analysis.
	Point to reference line: A line of best fit, termed the reference line, is established and the distance between the points in the data set and the line is computed.	Straightness: Deflection in beams can be measured by defining a reference line across the bottom of a beam and measure the distance between points and the best fit line. Hence, point to reference line should be used if straightness in a beam is controlled.
Point cloud versus point cloud analyses	Selected points to selected points: The shortest point to point distance is calculated by computing the shortest Euclidean distance between a point given in the first point cloud to a corresponding point in the second point cloud. The only way to ensure that the points with similar coordinates from different scans are selected is to align,	Flatness and straightness: This algorithm can be used to calculate the deviations in a selected grid of points on concrete slabs over time (e.g., post-pour, after tensioning of PT) Straightness: Changes in camber of beams can be detected by calculating the deviations in manually selected points on

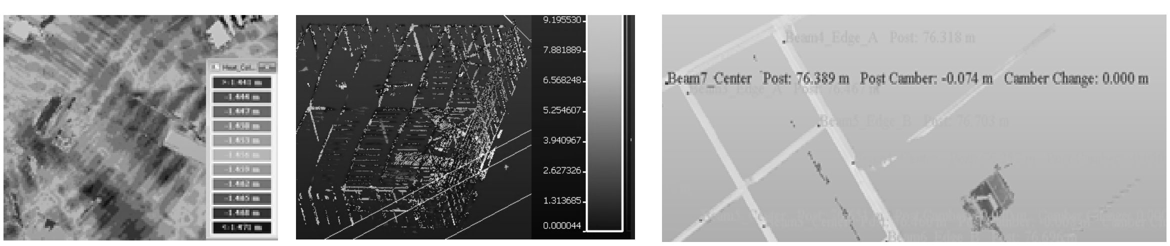
and size scans according to the reference targets and then select the points with the same coordinates. Otherwise, selected point to selected point comparison will have an error as it is not possible to set the scanner at the same position and select the same points.	the bottom of beams.
Reference points to corresponding points: A reference plane is established in the first scan. The Euclidean distance between a point in the reference plane and the nearest neighbour point in the second point cloud is computed.	Flatness, Straightness, Perpendicularity, Profile, Position: This algorithm will help control the deformation in beams and columns (Straightness), changes in the plumbness of any component (Perpendicularity), changes in the level of surfaces (Profile), and changes in the location of components (not distance and coaxiality between components) (Position) over time.

DEVIATION ANALYSES

In this paper, deviation analyses based on the data acquired from TLS are divided into two categories, namely: (a) sole point cloud analyses, and (b) point cloud versus point cloud analyses. These analyses have distinct algorithms to compute deviations, they employ a different number of data sets, and each analysis should be used to quantify a specific type of variation (Table 3). It was concluded that Perpendicularity (axis) (e.g., plumbness of columns), Parallelism and Profile cannot be automatically controlled using the described algorithms, although changes in them over time can be detected.

VISUALISATION OF RESULTS OF THE DEVIATION ANALYSES

Eventually, the deviations are visualised through deviation maps or are demonstrated numerically to reveal deviation patterns. The deviation maps can be produced in the form of heat map (continuous and signed map) (Figure 4a) and contour map. To demonstrate the results of: (a) deformation analysis for beams (Figure 4c), (b) change detection of beams (Figure 4b) and concrete slabs over time, the results are revealed numerically.



(a) (b) (c)

Figure 4: (a) Heat map for concrete flatness, (b) deviation map for changes in all types of variations over time, and (c) numerical demonstration of deformations in beam over time.

CONCLUSIONS

This paper is the first attempt to document a formal and holistic method termed TCM using TLS according to the literature, the best practice observed, and the field researcher's experience. This method has four steps: acquisition of 3D data sets, registration of data sets, deviation analyses, and visualisation/demonstration of deviation analyses. The critical practical recommendations to acquire data and to facilitate data registration were provided. The recommendations include preparation of scan map, placement of scanner and targets, and configuration of scanner settings. A minimum viable workflow for data registration, including both Target-based and Target-less Registration, was suggested. Following the workflow, the operator will be able to achieve less than 3 mm alignment deviation consistently. The most common approaches and algorithms used in the commercially available software for deviation analyses were categorised appropriately. Different geometric deviations were correlated with different algorithms of deviation analyses. It is envisioned that distinguishing between the types of tolerances facilitates selection of an optimal algorithm for deviation analyses. The results show that the algorithms for deviation analyses do not automatically measure all types of tolerances. One immediate future research will be to investigate how Building Information Modelling and TLS together can quantify each type of geometric variation.

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BELIEVING IS SEEING: PARADIGMS AS A FOCAL POINT IN THE LEAN DISCOURSE

Samuel Korb[1] and H. Glenn Ballard[2]

ABSTRACT

In many ways, the transition from traditional modes of management thinking and behavior to Lean approaches is what Kuhn referred to as a “paradigm shift”. Not only surface artifacts like behavior are different in a Lean organization – the most basic assumptions and patterns of thought are fundamentally different than those that have guided organizations for decades. The resulting paradigm gap between traditional thinkers and Lean thinkers may help to explain the conceptual disconnect between the two groups; the two have no common assumptions on which to base a productive dialogue about what degree of organizational excellence is possible. In this paper, we explain what paradigms are and why Lean management represents a paradigm shift. We then apply lessons learned from successful paradigm shifts in other fields to suggest what the Lean Construction community can do to nurture an industry-wide paradigm shift to Lean. By discussing this topic, we hope to bring the concept of paradigms to a position of greater prominence in the Lean discourse, in part helping Lean enthusiasts to understand why those mired in the traditional management paradigm just can’t seem to “get it” no matter how hard the latter group tries to explain.

KEYWORDS

Lean construction, Lean management, paradigms, paradigm shift.

INTRODUCTION

The term “Lean” was coined thirty years ago (Krafcik 1988), and the turn of the century (now eighteen years past) saw two seminal doctoral theses that brought Lean to the world of construction (Ballard 2000; Koskela 2000). And yet, even today, despite Lean repeatedly having proven advantages, the vast majority of construction projects are

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conducted using traditional styles of management that predate Krafcik's work(Azari et al. 2014). Why? In no small part, due to paradigms.

Paradigms are the filter through which one sees the world(Ballard et al. 2011; Ballard and Howell 2003). Facts have no objective truth on their own; they are given meaning through the lens of one's paradigm. This is the reason two people from opposite ends of the political spectrum can read the same news article but draw vastly different conclusions as to its veracity and what actually transpired. Lean Construction enthusiasts have often struggled in their conversations with construction professionals steeped in the old ways of doing things, often wondering how it is possible to confront the proven benefits of Lean with apathy and disbelief. The reason that the uninitiated are able to brush aside the claims of Lean are that in their prevailing paradigm, the claims are unbelievable and thus false. Cut project delivery times in half? Impossible. Bring projects in on time and under budget? Can't be done.

Lean, with its dependence on the twin pillars of Continuous Improvement and Respect for People (Korb 2016) is very much a paradigm shift from the current practice in construction, since it requires whole new patterns of thinking and behaving, not merely small tweaks to existing practice. As identified by Gehbauer et al. (2017), the traditional paradigms must be made explicit and addressed for Lean Construction to flourish.

In this paper, we will discuss what paradigms are and what is currently known about them, in order to bring this issue to greater exposure in the Lean Construction community. It is the hope of the authors that by making people sensitized to the concepts they can be more aware of and informed by them as they continue their work in advancing the cause of Lean in the AEC industry. We then suggest some possible tactics for overcoming the prevailing paradigms that the Lean Construction community can undertake as a whole, concluding on a note of hope for the future.

WHAT ARE PARADIGMS?

It was Kuhn's book" The Structure of Scientific Revolutions"(2012) which brought the concept of paradigms to widespread attention. Kuhn's focus was on the history of science, looking at how new developments are made and well as breakthroughs, and thus the main paradigms he focused on were scientific in nature. In his view, paradigms are the governing models in which scientists try to solve problems, such as the Ptolemaic geocentric model of planetary motion. Under this model, astronomers were forced to develop increasingly complex "epicycles" to explain the "aberrant" behavior of the heavenly bodies, since those were the problems they faced and the underlying model in which they understood the solar system to operate. When the Copernican heliocentric model was first presented, to someone who had labored for years in perfecting epicycles, it could only be seen as a farce (particularly, as Kuhn notes, since it didn't offer any more reliable predictions than the existing well-honed Ptolemaic model). Thus paradigms function (inadvertently) as constraints preventing the transitioning to new modalities of thought, in as much as they anchor one's beliefs about the realm of the possible.

Kuhn (2012) defined paradigms as follows: "Universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of researchers." Here, his focus on paradigms in the scientific context is clear, but the points of universal recognition and models for framing problems and solutions are applicable in many other contexts.

In Kuhn's view, rival paradigms are "incommensurable"; that is, one paradigm cannot be understood through the lens (the concepts and terminology) of the other. This bears strong similarity to the discourse disconnect between the Lean Construction advocate and the traditional construction professional referenced in the introduction; the claims of what improvements Lean is capable of bringing seem fanciful for someone who is party to the previous paradigm.

Kuhn identified five phases in the course of paradigm development and renewal, as shown in Table 1.

Table 1: Kuhn's five phases of paradigm development

Phase	**Description**
1	Pre-Paradigm
2	Normal Science
3	Crisis
4	Paradigm Shift
5	Post-Revolution (Return to Normal Science)

Kuhn saw the development of science as alternating between the periods of "normal science", in which incremental improvements are made to the body of knowledge that is in line with the current paradigm, and "paradigm shift," the more tumultuous periods were the old and new paradigms themselves are in conflict.

Returning to the realm of Lean Construction, we can roughly draw parallels of these five steps in light of the history of construction management.

Phase one is the pre-paradigm stage. This perhaps was the prevailing mode of construction management for millennia of human development, when construction was primarily of dwellings and simple structures for storage and agriculture. There was no need to manage projects; they were simply built.

Phase two is the development of a paradigm, brought about by the coalescence of problems that can't be solved in the pre-paradigm state. Going back to antiquity, there were examples of large and ambitious construction projects (such as the Seven Wonders of the Ancient World and their contemporaries) which were massive undertakings requiring the coordination of hundreds if not thousands of designers and builders. These no-doubt required the development of at least a rudimentary paradigm of construction management. And since then, through to the modern day, there has been a gradual building upon the practice, step by incremental step, similar to Kuhn's "puzzle solving".

Phase three – crisis – is arguably where the industry stands today: performance results are lagging expectations. The Egan Report (1998) highlighted the deficiencies and called for change. While other industries have improved their productivity over the years, construction has been marching in place or even retreating. Persistent problems exist that cannot be solved with the existing tools. Kuhn called these "anomalies," and an accumulation thereof indicates that a new paradigm may be required to address them.

The fourth phase is the paradigm shift itself, when the new paradigm arises, and after a period of penumbra, eventually trumps the old. In the case of Lean Construction, the hope is that this phase has begun. New exemplars of the Lean paradigm are bearing fruit, addressing some of the anomalies that the previous paradigm is not capable to dealing with.

In Kuhn's final phase, the new paradigm takes root and becomes dominant and pervasive, bring the cycle back to the second phase, normal science. Lean Construction has some ways to go before reaching this zenith.

WHY ARE PARADIGMS A PROBLEM FOR LEAN CONSTRUCTION?

Understanding what paradigms are, it is now possibleto direct attention to whyparadigms are a problem in the context of advancing Lean Construction.

Since paradigms are so pervasive and all-encompassing for those who hold them, it is sometimes not apparent to the holder that they are no more than models they have chosen; models that might not be the best or even correct in all aspects. The paradigm is accepted at face value as common knowledge or tautology. Consider the list of paradigms or paradigm-reflecting statements from traditional construction management that appear in Table 2; how widespread are these in the industry? And to what extent are they demonstrably true?

The answers to the above questions are as follows:

1. These statements, even if only as unspoken beliefs, are indeed widespread in the industry. Construction professionals in the traditional paradigm default to behaving in accordance with them when under pressure, believing them to be true.
2. On nearly every point, counter examples or at least counter arguments can be brought to disprove them.

Taken together, these points would seem to represent a conflicted state; how is it possible that these beliefs are both widely held and also not true? The answer is called confirmation bias. Confirmation bias (Plous 1993) is a tendency to accept evidence as true when it aligns with a pre-held conviction (such as a paradigm) and reject it as an error or inconsequential anomaly when the evidence is at odds with the pre-existing belief. This is exactly why no matter how many successful IPD projects or Lean Construction success stories one shares with a traditional thinker, they will be rejected as either completely false or as having some extenuating circumstance that is both uncommon and irrelevant to the majority of construction practice. Or in other words: "We're different."

Table 2: Paradigms in traditional construction management (Ballard et al. 2011)

Paradigm
Trust is for suckers.
Win-win is an illusion. What counts is that I win.
You can manage projects by managing contracts.
Risk is managed when transferred to someone else.
If you pay least price for each part of a project, you pay least price for the project.
Management by results yields the best results.
Variation in work flow is from external causes.
Resource utilization trumps project flow.
Control starts with identifying a negative variance between DID and SHOULD.
Social factors are interesting, but don't really matter.

Thus while it might be conceivable to overturn some of the statements in Table 2 with statistical studies (for example, tracking the causal drivers of total project price in projects with and without least-cost subcontractor selection), the effort would still likely fall on deaf ears, or ears shielded by the "hearing protection" that only a paradigm can offer.

Barker (1993)referred to the inability to take constructive action in the face of new realities "paradigm paralysis" in the sense that the situational blindness conformance to a paradigm demands will ultimately lead to sclerosis exactly when action is needed. He cites multiple examples of this happening in different industries, such as the Swiss dominance of the watch industry prior to the advent of the quartz watch. The quartz timekeeper was invented in Switzerland, but it had no place in their world of finely crafted and intricate mechanisms. The Swiss were not able to capitalize on the new technology since they didn't accept it, ultimately leading to them losing out on the majority of the watch market to Japanese companies who were not married to centuries of mechanical chronometer history. Another example concerns the development of many elements of the Graphical User Interface (GUI) by Xerox, who saw no future in what would go on to change the face of computing. Time after time, industry leaders are unable to adopt change, even when it is staring them in the face or they have even had a hand in developing it.

In construction, a complicating factor is the fragmented nature of the industry (caused in no small part by the reliance on subcontracted labor, which is another symptom of an underlying paradigm)which can constitute a barrier to spreading new ways of thinking and acting, since any one company represents such a small portion of both the market and the total value chain, one that must interface with the existing other parts of the value chain all of which are used to working in the prevailing methods.

Thus we have shown that not only are paradigms real, they are a real problem when it comes to implementing Lean in the field of construction.

WHAT CAN BE DONE?

What, then, is to be done? Given that the transition to Lean thinking involves a paradigm shift, and that paradigms are rarely shifted and only with great difficulty, in what ways can the Lean Construction community act to advance the adoption of Lean in the entrenched AEC industry? This section suggests a few possible paths of action, though it is the hope of the authors that once the centrality of paradigm-based thinking comes to light, other strategies will present themselves.

The following strategies are in line with those developed by the second author and Greg Howell and for the Lean Construction Institute shortly after its formation in 1997, which included the following elements:

- Change the vocabulary—from managing contracts to managing production.
- Work with early adopters to make them killer companies in their markets.
- Look for owners willing to embrace lean and help them help their suppliers.

GET THE WORD OUT

With any new concept or product, there will always be the “innovators”(Rogers 2003) who are willing to try it out primarily because they are neophytes. The innovators represent a fringe of the population who are willing to adopt the innovation before it has been fully proven. In other words, they don’t need to have their paradigm shifted to be willing to try out Lean; the promise of benefit is all they need to give it a shot.

With this understanding in mind (namely, that there are people who are inclined to be innovators), the question is how to reach them. The message must be out there so that they can find it, if they are to adopt it. As Lean enthusiasts, at a minimum, we must be looking for how can we give the subject greater exposure. By holding the flag high, people can find Lean. It is specifically those who are willing to listen who are the ones to focus on.

Once they are in the door, it becomes possible to present the rational case of Lean. Arguments about the benefits of Lean and evidence to back up those claims can be presented. Likewise, if it possible to identify common objections to the claims of Lean and present rebuttals, it will make it all the more possible to undercut the traditional approaches, at least for those people who are open-minded and not already invested in the pre-existing paradigm. The hope is that for these members of the population, an accumulation of evidence will have an impact, perhaps in conjunction with having an experience that is anomalistic to the traditional paradigm.

Practically speaking, this means highlighting the successful case studies of companies who have succeeded with Lean, continuing to generate a body of knowledge such as the IGLC has done and continues to do, and making inroads in other forums where construction experts gather.

EDUCATE THE NEXT GENERATION

Max Planck, the theoretical physicist and Nobel laureate, weighed in on the subject of paradigms in a now-famous quote: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it." If one harbors the notion that it is possible to convince others, it may lead to effort wasted on trying to convince those who are set in their ways, which in turn may retard progress elsewhere. If instead the advice of Planck is heeded, the lost causes may be recognized for what they are.

In other words, a more effective use of energy for those seeking to make the case for a new paradigm such as Lean, rather than engaging in fruitless arguments with industry stalwarts who have years of experience backing up their convictions, is to focus on the next generation of AEC professionals, namely those currently studying the field in universities.

Currently, there is a paucity of Lean Construction discussion in undergraduate civil engineering education; when construction management is taught, it tends to highlight the more traditional approaches, relegating Lean Construction to graduate-level courses. If Lean Construction were to occupy more of a focal point of the studies, students would be exposed to the concepts and the successful examples of Lean implementations while they are still young, before they go out to the real world of practice. In so doing, it may be possible to color the way they interpret the realities they then encounter, at the very least opening them up to nagging questions like "isn't there a better way?". By creating a generation of civil engineers growing up with Lean, it may be possible to cement a "new normal" reference frame for them as they join the ranks of industry.

This suggestion is complicated by the dearth of assessment criteria for academic programs, specifically measures of process (the quality of the Lean content being instructed) and outcomes (how much of an impact is made on the students), and as such the development of relevant metrics is an area for future work. In general, simulations and hands-on learning exercises can be more effective than merely spouting lists of the benefits. This is one of the reasons "going to Gemba" can be so powerful; it is there that the messages hit home in a visceral way. Sacks et al. (2018, ch. 9) relate the story of how the leadership of a construction company "learned to see" by spending time on the work face, out of the office, merely looking and observing examples of waste.

One risk with this education-focused model is that young civil engineers might not be gaining their true education in the classroom, but rather only once they get out into the field. There, they will likely be schooled if not by hard knocks then at least by those of the older generations. And the lessons they will be taught will likely be those of the traditional paradigm. So it will be necessary to monitor the long-term effectiveness of the Lean "vaccine" that will be administered to these bright young minds.

Encouragingly, there are signs of interest on the part of the next generation, who are trying to "pull" the information and education they need. The second author of this paper, through his exposure in developing the Last Planner® System (Ballard 2000) and his years of involvement in the Lean Construction community as an educator and thinker, receives requests from students (both current and former) from around the world to assist them as they work to learn more about Lean Construction and expand its deployment. Often they are hampered by a lack of local expertise (both on the academic side and the professional), leading to a further suggested path: make Lean Construction coaching available to people around the world who don't have access to the teachings or insights. The "coaches" in this scenario could be members of the IGLC community (itself a well-established world-wide network) who volunteer their time to assist and enable those sparks of interest wherever they may be kindled.

CREATE MARKET PRESSURE

A third tactic may be to attract and interest the owners of construction projects, and explain to them the benefits that Lean can bring to their projects. By informing the customers of construction services, it may be possible to change the market demand to the point where Lean becomes a requirement on the part of suppliers. This parallels some examples of the adoption of Building Information Modeling (BIM): in markets where large or influential customers demand BIM, the local suppliers are forced to develop BIM competencies if they wish to compete for business. Likewise in the Lean construction world, as evidenced by the experience of Sutter Health. Sutter has long been a pioneer in Lean Construction, and they now require Lean as a threshold criterion for their contractors.

At the same time, the risk of this kind of "top-down" customer-driven adoption scenario is that Lean becomes just another box to be checked without fully understanding it or integrating it into the organization's culture. This can sometimes be seen with BIM where companies will have an out-sourced BIM capability in order to meet contract demands but continue to work in-house the way they always have. In the same manner, for companies wishing to reap the benefits of Integrated Project Deployment (IPD), it is not sufficient to merely have an IPD contract in place; the ways of working and the manner in which the relationships are built among the project participants have to be fundamentally different from the old ways of working.

Likewise, there are situations where the marketing materials of a company extolling their Lean successes and how much they have implemented outpace the reality of their daily practice in the Gemba. As in any Lean implementation in the AEC field or beyond, company leadership needs to understand that their companies won't change until they do. And yet, requirement on the part of customers can often be an effective catalyst for change; only if they are forced will some people embrace something new. Thus if the customers can be reached and their desire or outright demand for Lean, there is a greater chance for wider adoption through market pressure. One stalwart in a market can lead to horizontal spread in that local market, since as customers they can stipulate the process (and not just the product) required.

One way to reach customers continues to be the Lean Construction Institute (LCI) annual congress. In its most recent incarnation, there were 1,500 attendees. The attendance rate has seen a steady 15% growth year-over-year in last 5 years, which means new people from the industry are becoming interested and getting exposed. These conferences serve as wonderful platforms for getting the word out as discussed above, since they highlight successes and address concerns, which can inspire further motivation and interest.

On observation about the LCI congresses is that over time the nature of the conversation has changed, with it now showing signs of maturity. There is a greater focus on the philosophy underlying the Lean approach, whereas earlier focus was more on Lean tools. This is a sign of improvement, since it indicates that the community is touching upon deeper issues beyond the superficial trappings of Lean as they continue their journey to implement Lean. The further they go, the more they will have to relate back, which will work to create a market imperative. At the same time, we need to continue the efforts to educate owners about what to require in the projects to improve their chances of Lean succeeding.

CONCLUSIONS

This then is a call to action for the Lean Construction community. First, it is imperative that the issue of paradigms is prominent in any outreach efforts, for ignoring their impact increases the chances of failure through not addressing them properly. Second, armed with an awareness of the pervasive and powerful nature of paradigms, we can begin working to change the prevailing winds of the industry. This can be through the strategies identified and described above, or in other innovative ventures designed to address this key topic.

On the one hand, the message of this paper has been somewhat pessimistic: by and large it is not possible to change people's paradigms, so don't even bother trying. Yet on the other, there is a message of hope. As Planck observed, revolutions can take a generation or more. So while a perceived lack of progress when measured in absolute measures of market penetration can be disheartening for innovators, the numbers may bely what may prove to be long-term exponential growth. In other words, there is not yet cause to lose hope or become discouraged by a slow pace of adoption of Lean. Change does happen, and in the case of Lean Construction, it is worth the effort. As advocates, it is incumbent upon us to be absolutely persistent but also patient. It may be hard, but it is the right choice to make. There is a small part of the population that is less tethered to presuppositions and more open to wonder and exploration – these are the ones that need to be reached. In turn, this makes possible the creation of market pressure. The cold facts of declining market share, revenues, or profit margin work wonders as paradigm solvents.

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LEAN METHODS TO IMPROVE END USER SATISFACTION IN HIGHER EDUCATION BUILDINGS

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ABSTRACT

End user satisfaction is one of the major indices that attest to the success of a project in terms of adding value to the client. Therefore, in order to rate the overall functions of a facility, the fulfilment of end users' needs is to be taken into consideration during the whole project phase (i.e. design through operation). Many clients believe that allocating more resources to the project automatically guarantees the success of the project. What they fail to realize is that in most cases, success, which should be translated in end user satisfaction, relies more on how the project was thought of, planned, constructed and delivered. This paper presents the case study of a high-budget engineering complex. In this study, different end users of the facility were prompted to fill a comprehensive survey about the overall quality of the complex. Interviews were also conducted with the client representative and other parties who were involved during the design/construction phases. After results were analysed and compared, an evident contradiction was detected: end user satisfaction rates were relatively low whereas client's representative overall satisfaction was optimistically high. Lean methods and tools were suggested that could be used to improve the design and delivery of similar facilities and establish a higher end user satisfaction rate.

KEY WORDS

Post-Occupancy Evaluation, End User Satisfaction, Higher Education, Lean Construction, Building Performance.

INTRODUCTION

Studies show that seven of the top ten industries with the highest growing rates in the USA for 2017 are construction related (Sageworks2017), and the pace of expansion in the global construction industry is expected to continue growing through 2021 with an average of 2.8% (Construction Intelligence Center2017). But how to measure success in

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the construction industry? And is value to the end user a factor frequently considered? In fact, success has been previously closely tied to only three main parameters: cost, time & quality. Other criteria has been added such as safety, functionality and satisfaction including user expectation and satisfaction (Chan and Chan 2004).However, many construction companies rarely implement new knowledge from recent research to assess different parameters related to the user's perspective in their work. Such companies ignore the fact that input from end-users is important as to learn from previous projects to continuously improve and apply this new knowledge to design future projects (Vischer 2009). One way to improve current practices is to implement Post-Occupancy Evaluations (POE) in order to assess the operation requirements of existing buildings; generate new knowledge about the human use of space and give feedback on key decisions made during the design and construction phase. Since the 1960's universities have been a main part of the POE exercise, given the fact that each university has its own design and construction standards and that there is no general design standard for higher education as a whole (Tookaloo and Smith 2015). Value for end users in higher education, is a building that creates optimal conditions for teaching, learning, and research (Spiten, Haddadi, Støre-Valen, & Lohne, 2016).

As per Hay et al. (2017), POE is considered a highly reliable index that allows researchers to learn from previous projects and improve in upcoming ones. Improvements need to be based on the needs, desires and satisfaction of the occupants. To achieve that and deliver projects with higher value to the users, Lean methods that improve value generation and eliminate waste can be applied. These methods can ensure value throughout the lifetime of buildings and should be considered more often and more seriously (Spiten, Haddadi, Støre-Valen & Lohne, 2016)**.**

However, POEs have a few short comings. It might show a focus on short-term thinking to achieve direct financial profits rather than long-term benefits to clients and society. Other issues include liability and accountability issues where participants in a project fear that POE will only focus on the negative aspects, holding different parties (architect, contractor, structural engineer, etc.) accountable and responsible for defects. Finally, another important issue is the lack of policies and legislations that demand the use of POE regularly. Eventually, applying POE enables a wider perspective and encourages owners to investigate the needs of the users, and offer satisfying building design quality in return.

Conducting research in different types of buildings (educational, residential, healthcare, etc.) enables a deep insight about the needs of the end users (Watson et al 2014). When talking about user's satisfaction, Ornstein and Ono (2010) define various ways of obtaining information including interviews with key persons and POEs through questionnaires with scales of values to measure users' satisfaction levels regarding the respective environments.

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Feedback is the information provided by an external agent regarding a process performance measure (Li et al 2012). The feedback model presented by Sombra et al. (2011), suggested that clients unsatisfied needs identified from satisfaction surveys should be transformed into new design parameters through the feedback model. They concluded that this feedback process can help create value for users and allows innovation to achieve continuous improvement. A contrasting but complementary view to feedback is feed forward, translated in end-user involvement in the pre-design phase and focused on good communication, understanding end-user value, and innovation to achieve adaptability in the building to cope with rapid changes in academia (Spiten, Haddadi, Støre-Valen, & Lohne 2016).These Lean behaviors (feedback and feed forward) help in realizing maximum value on a project.

Very few existing reviews provide a direct comparison and examples of facilities that satisfy their owners and dissatisfy their end users, especially when it comes to educational facilities. This paper provides a direct example of a high-budget educational complex that satisfies its owners and dissatisfies its end users. With this example, the paper attempts in improving future design and construction decisions in education facilities and reinforcing the importance of implementing some lean tools and shifting from traditional to more developed thinking for higher end user satisfaction.

METHODOLOGY

The building considered in this research is the Irany Oxy Engineering Complex (IOEC), one of American University of Beirut's newest engineering facilities.IOEC is made of 6 floors and 2 basements that provide the faculty of engineering with more than 60 highly equipped teaching and research laboratories, six state-of-the-art classrooms including an e-classroom and data center, and 85 cubicles for doctoral students. It is also the first building to register for LEED-NC certification, the gold standard of 'green design' in Lebanon (AUB, 2014).

The complex was subjected to a post occupancy evaluation exercise to measure the end-users satisfaction and evaluate whether implementing Lean approaches during the early lifecycle of design and construction could have enhanced it.

To carry out the study, an end-user satisfaction survey was designed and tested. The survey was distributed to different end users who use IOEC; that includes engineering students of different majors, staff working inside IOEC and professors. After gathering and analyzing the data, interviews were set with the operation manager of IOEC, a major end user of the complex, and AUB's Facility Design and Planning Unit (FPDU) representing the owner of the complex during design and construction. FPDU members were also asked to fill out the survey to compare their satisfaction level with the project to that of the end user. At the end, the importance and relevance of the results were evaluated, and suggest Lean solutions were suggested that may help improve the end user satisfaction for future projects.

The survey was divided into two major parts. The first part deals with personal information related to the end user such as gender and occupation, time spent inside the complex and his or her overall quality satisfaction with IOEC's classroom, offices, laboratories, lounges and cafeteria. The second part of the survey included eight main sections to calculate the satisfaction index. The first section was related to the complex's **accessibility** and whether the end users are satisfied with the horizontal and vertical circulation. The second section targeted the complex's **design and furniture** and whether the latter allows for comfortable learning, removes distractions and permits varied communication and comfortable mobility; this section also targeted washrooms. The third, fourth, fifth and sixth sections dealt with the **air quality** inside the complex, **thermal comfort** (temperature convenience and control), **visual comfort** (satisfactory lighting conditions)and **acoustical comfort** (noise level inside the classrooms) respectively. The seventh section targeted the overall **cleanliness** and the last section expressed whether the end users feel **secure and safe** inside the complex.

The minimum number of survey participants needed was calculated using Sloven's formula (Kanire, 2013):

$$n = \frac{N}{1 + Ne^2}$$

Where N is the total number of population benefiting from IOEC which is around 3800 (AUB, 2016) and e is the margin of error (assumed 0.01 for a 90% confidence level). Thus, the sample size n shall be 98 participants. They were asked to indicate the extent of their satisfaction with different building performance aspects by rating them on a scale from 1 to 5. After obtaining the results, the satisfaction index was calculated using the following formula (Dominowski, 1980):

$$Satisfaction\ Index\ (SI) = \frac{\sum_{i=1}^{5}(a_i [\square)(x]_i)}{5\sum_{i=1}^{5} x_i} * 100\%$$

The response for i is 1, 2, 3, 4, 5 and is illustrated as follows:

- x_0 = frequency of "Strongly Agree" response with a_0= 5
- x_1 = frequency of "Agree" response with a_1= 4
- x_2 = frequency of "Neutral" response with a_2=3
- x_3 = frequency of "Disagree" response witha_3= 2
- x_4 = frequency of "Strongly Disagree" response witha_4= 1

The scale adopted to establish the level of satisfaction is as follows (Hassanain, Mathar, & Aker, 2016):

- A satisfaction index value above 80% suggests that the respondents are "Strongly Satisfied"
- A satisfaction index between 70% and 80% suggests that the respondents are "Mildly Satisfied"
- A satisfaction index between 50% and 70% suggests that the respondents are "Dissatisfied"
- A satisfaction index is below 50% suggests that the respondents are "Strongly Dissatisfied"

RESULTS & DISCUSSIONS

A total of 104 end-users participated in this survey: AUB's engineering students majoring in different engineering programs formed around 93% of the participants (55% undergraduate, 37% graduate and 1% PhD), while the remaining 7% varied between Professors (4%) and staff (3%). Overall, the respondents spend an average of 4.6 hours inside the complex. The survey was also filled by FPDU members that represent the client. After processing the obtained data from the distributed questionnaires, the overall quality satisfaction for IOEC's different facilities and the satisfaction index for the multiple performance criteria by both the client and the end users were obtained and discussed below.

OVERALL QUALITY SATISFACTION WITH THE IOEC FACILITIES

End-users were clearly dissatisfied with most of the facilities including offices (68.67% SI), lecture rooms (64.45% SI), cafeteria (64.49% SI) and most notably lounges (57.35%), barely showing mild satisfaction at the level of the labs (70% SI). On the other hand, the client's representative had a totally opposite view. Results show a 100% SI with labs and 90% SI with offices, lecture rooms and lounges indicating strong satisfaction. The client's representative was also considerably satisfied with the cafeteria (80% SI). These significant differences clearly show that the facilities are not serving the needs of the end-users. The root cause of this significant difference would go back to the designs stages of IOEC were the client's representative should have better engaged the end-users and considered their entire needs in the preliminary stages; this in turn reflected in the end-users dominant dissatisfaction.

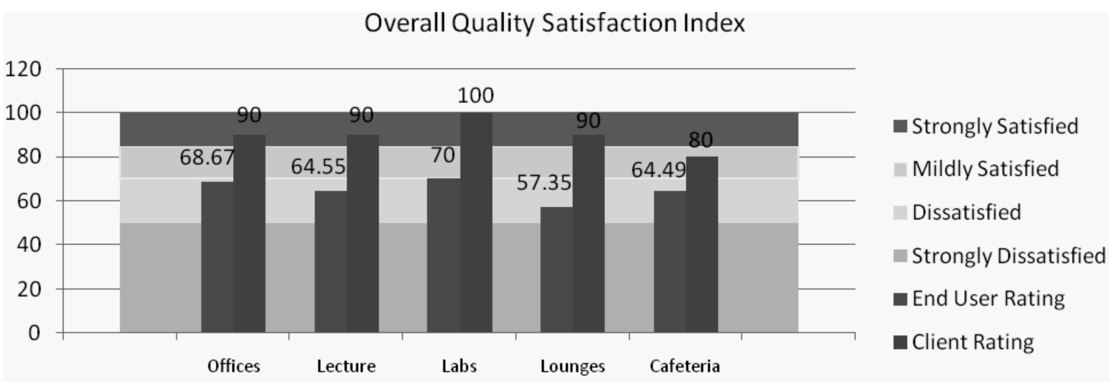

Figure 1: Overall Quality Satisfaction Index for IOXY's Major Facilities as rated by the End-Users and Client

END-USER FEEDBACK

Results of the survey as displayed in Figure 2 below show that users of the engineering complex, mostly students and faculty members, are generally satisfied with the accessibility to the complex (72% SI) and felt secure and safe inside the building (72% SI). Visual comfort also ranked high among the building users (71% SI).

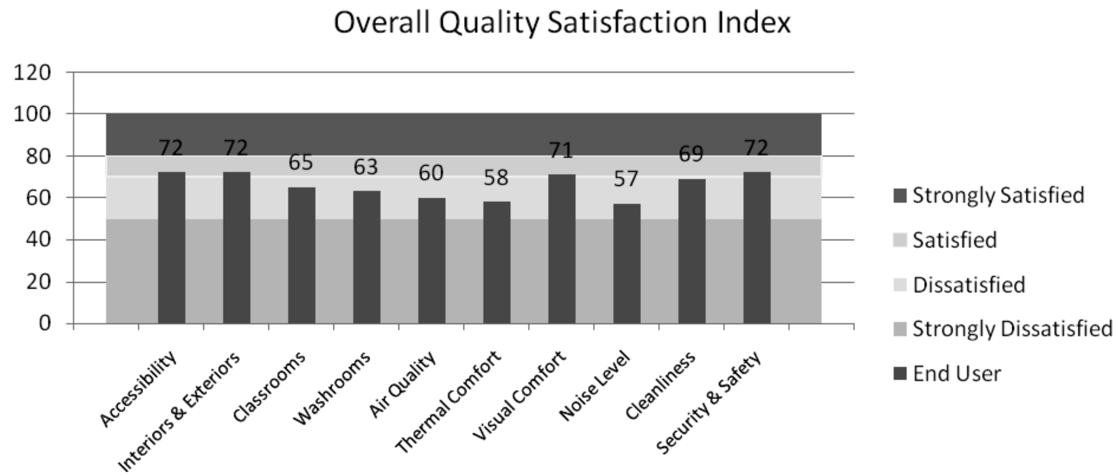

Figure 2: Satisfaction Index for IOXY's Performance Criteria as rated by the End-User

As for the Design & Furniture section, users were mildly satisfied with the exterior design (75%SI) and the corridor spacing (76% SI). However, users were dissatisfied with the interior design of the building (69% SI) and the quality and colors of the interior walls, floors and ceilings (67% SI). According to the participants, classrooms offer an easy in/out access (79% SI), but the design and furniture of these classrooms fail to provide a comfortable learning environment since it doesn't allow proper communication between professors and students (67% communication SI) and doesn't provide comfortable mobility (63% mobility SI). Student grouping is not facilitated (59% SI) and outside distractions such as light and noise are present (58% distraction SI).As for the washrooms, the users were satisfied with the easy access (70% SI) but dissatisfied with the services 63% SI indicating uneasy use) and the area and number of the washrooms that fail to accommodate large numbers at peak times (53% SI).

Furthermore, users were dissatisfied with the air quality inside the building (60% SI), thermal comfort (58% SI) and noise level (57% SI). The building cleanliness was on the border of satisfying (69% SI). According to the participants, the major reason for the dissatisfaction with the air quality and thermal comfort is the unavailable user access to air ventilation and temperature. As for the noise level, they believe the background noise level from mechanical and electrical systems inside the classrooms can get too high and thus affect the learning process.

CLIENT'S REPRESENTATIVE FEEDBACK

In contrast to the end-users' feedback, the client's representative showed a highly optimistic point of view. Results from Figure 3 below show strong satisfaction with the accessibility (93% SI), visual comfort (95% SI), air quality (87% SI), and the security and safety (100% SI) sections. The client was also satisfied with the noise level, cleanliness (both 80% SI) and the thermal comfort (73% SI). As for the design and furniture section, the client was strongly satisfied with the overall interior and exterior design (98% SI) and washroom services and ease of use (93% SI). However, the satisfaction index of the client slipped to 77% satisfaction index SI when it comes to classrooms because of some furniture changes after opening the complex.

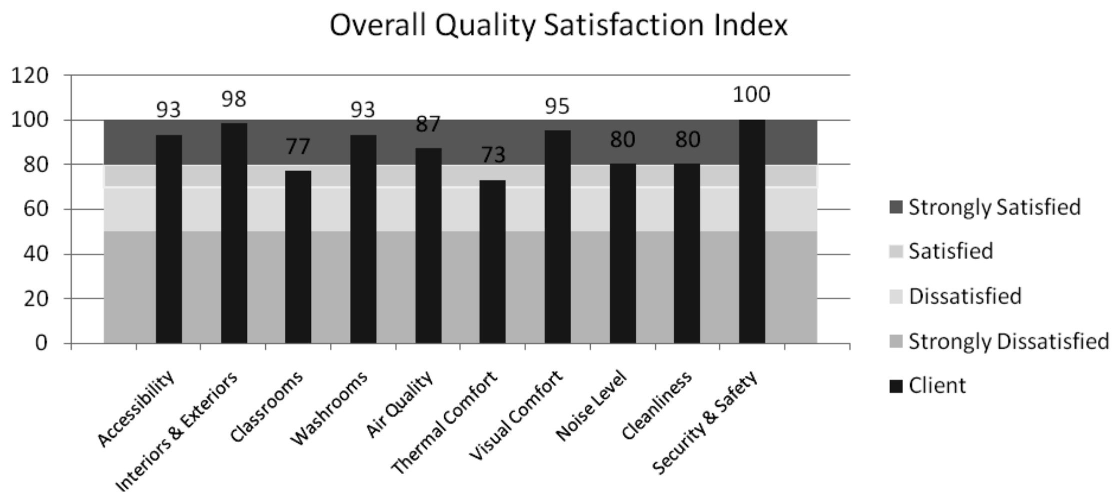

Figure 3: Satisfaction Index for IOXY's Performance Criteria as rated by the Client

FURTHER DISCUSSIONS AND THE EFFECTS OF IMPLEMENTING LEAN TOOLS AND BEHAVIOURS

Because of the obvious incompatibility between perspectives of the end users' and the client's representative and for further analysis, interviews were conducted with a senior project manager from American University of Beirut's FPDU (the Facility Planning and Design Unit representing the client), and the operation manager of the IOEC building (representing the end-user). The two interviews generated descriptive insights that the authors described and discussed using "what if lean was used" scenarios. Only sections that dissatisfy the end-user as seen in the table below are thoroughly and further discussed, leaving aside sections that satisfy the end-users such as accessibility, visual comfort and the security and safety inside the complex. However, it is important to mention that implementing lean tools and behaviors that will be discussed in this section may increase the SI of the satisfied sections even more.

Table 1: Satisfaction Index and Rate of Satisfaction (ROS) for the Major Survey Sections

	As Rated by End Users		**As Rated by the Client**	
Section	**SI (%)**	**ROS***	**SI (%)**	**ROS***
Accessibility	72%	S	93%	SS
Design & Furniture	66%	D	87%	SS
Interiors & Exteriors	72%	S	98%	SS
Classrooms	65%	D	77%	S
Washrooms	63%	D	93%	SS

Air Quality	60%	D	87%	SS
Thermal Comfort	58%	D	73%	S
Visual Comfort	71%	S	95%	SS
Noise Level	57%	D	80%	S
Cleanliness	69%	D	80%	S
Security & Safety	72%	S	100%	SS

*ROS: SS (Strongly Satisfied), S(Satisfied), D(dissatisfied) and SD(Strongly Dissatisfied)

To begin with, the design of the building took about two years. Such durations are unusual for the design of such a building. Hence, one would have to assume that difficulties emerged during the design. Common obstacles often include hindered communication between the different entities working during the design phase. The construction phase was also delayed three years after finishing the design. Both delays not only increased the direct cost of design, estimated at around $700,000, but also incurred other unnecessary costs due to the fluctuation of the prices of raw materials during this construction phase. Aside from that, there was no proper communication between the different parties involved in the design. The client's representative asked the different engineering faculties to forward them their needs and passed them to the design team without collaborative meetings between all three parties. Based on the insights above, the delays could have been avoided by using an integrated design approach: the client, designer and end users. Each engineering major would be represented by at least one faculty member who would carry the faculty and students' needs of the major that he or she represent. These representatives would collaborate during the design phase by conducting several meetings with both the designer and owner to discuss design details without having to use tedious requests for information (or RFIs). This approach would take into consideration inputs from end users who would be represented in the meetings. It would also enable the different entities to exchange information more easily, enhance communication, create a smooth working environment and ensure a common understanding of the whole design. In return, the final project would satisfy the end-users especially that their needs would be fulfilled. This approach can also be best achieved when it is coupled with Building Information Modeling (BIM) (Al Hattab and Hamzeh, 2013).It was also mentioned by the interviewees that the absence of false ceilings in the building was intended for educational purposes. However, the displayed mechanical equipment are causing noise problems and affecting students in class. Had an integrated design approach been used, different engineers would have been able to work in a way to prevent the acoustic and quality problems from happening. It should be added that during one of the interviews, the owner representative refused any suggested lean idea considering it as a "waste of time". Despite the obvious problems and delays, the owner's representative believes that miscommunication was never an issue during the design/planning/construction of the facility and the need for common meetings between themselves, design team and the end-users representatives was unnecessary.

Both the construction and design phases spanned longer than intended. During this period, new departments were introduced at AUB and needed to be accounted for. The chemical engineering program for example needed special lab equipment and machinery and allocated space. These changes in design impacted the cost. Other changes such as area expansion from 10,000 m^2 to 15,000 m^2 also contributed in cost increases. The construction cost of the buildings surpassed $24,000,000,in comparison to the intended cost which was less than $10,000,000. As mentioned before, using lean methods improve value generation and eliminate waste in both design and construction phases. Hence, the changes discussed above could have been easily prevented with the use of lean methods such as Target Costing. Target Costing is a way to account for a project cost without jeopardizing profit – or in the case of IOEC – while inducing cost savings and avoiding budget deviations. A suggested solution that could have helped in reducing the construction and design delays, predicting upcoming challenges and eliminating wastes would be implementing the Last Planner System (LPS) (Hamzeh et al. 2016). Implementing the system would have maintained better control of both budget and time while taking into account the changes that were happening in the engineering faculty. In addition to that, most of the design effort was deployed in the exterior design. In turn, mechanical, electrical and structural problems were generated and continue to be under maintenance. This is a major fallacy that happens often in the AEC industry. Local optimization jeopardizes quality and can disrupt the essential function of the building, in some cases. Therefore, the focus on globally optimizing the whole product and equally dividing the resources is the most suitable way to ensure quality, safety, aesthetics and functionality. For example, despite the fact that all floor tiling has the same print, it can be noticed while walking down the corridors or classrooms that the intensity of colors slightly differs. Aside from the low quality of the tiling, the general contractor did not abide by the provided installation plans from the tiling sub-contractor during installation. The above setbacks could have been tackled using Target Value Design (TVD) and Value Engineering. These measures contribute in maximizing value and sticking to a set budget. Another example of waste in the design and construction that would have been avoided by TVD was during the design of the exterior facades that control the intensity of sunlight and moderate the building's internal temperature. Some facades were designed and installed towards the North side; these facades are currently considered useless because the sunlight has no impact on this cardinal direction.

When it comes to classroom furnishing, modern classroom furniture that are both mobile and customized for student grouping was set up. However, traditionally minded stake holders objected to the modern furniture and asked for complete traditional classroom designs because some classes are to be used for exams. In return, all new furniture was removed and replaced by traditional designs, adding even more waste to the project. Innovative ideas would have been possible if stakeholders were involved and consulted early on in the design phase. The involvement of different stakeholders in the design phase not only guarantees enhanced communication and better understanding but also ensures quality, cost and time efficiencies. Collaboration of various parties and the alignment of interests of the shareholders is the basis of lean construction.

The insights gathered from the interviews, as seen above, explain the end-users' dissatisfaction with many IOEC services such as classroom furnishing, noise levels, thermal comfort and air quality and clearly show how the planning and construction processes of the complex affect the final product and the overall satisfaction rate.

CONCLUSIONS &RECOMMENDATIONS

The case study above for IOEC serves as a solid example to further proof the importance of involving end-users in the design of future projects, especially that the value of any construction project is always seen from the eyes of the customer. Big budgets and long planning processes do not necessarily guarantee end-user satisfaction if the end-users are not involved and value in the eyes of the end user is not explored.

The end user dissatisfaction in the engineering complex can be attributed to different reasons, some of which can be considered as subjective and the others mostlyrelated to the handling of the planning, design and construction phases. During the design and construction of the project, many issues between the different entities (contractor, AE, etc.) became apparent. These conflicts have contributed in one way or the other to the reduction in end user satisfaction.

In order to narrow down such conflicts in future projects, and fulfill a better end user satisfaction rate, a shift in planning perspective is needed and a number of lean management processes are to be implemented. Design and planning units in educational facilities such as the FPDU in AUB are encouraged to find lean innovative measures to improve design without impacting an increase in cost (e.g., Target Value Design, Target Costing, and LPS) and eliminate non-value adding activities and design concepts in order to reduce time and cost and increase overall value of the facility. They are also encouraged to command proper sharing of information and data (less tedious RFIs, enhanced communications) between the different stakeholders in order to help achieve value, explore different alternatives to come up with the most suitable in order to avoid rework or maintenance problems and apply global instead of local optimization. Most importantly, the design and planning team should align the client's needs with that of the end user and involve the latter as heavily as possible during the entire project phases to guarantee project satisfaction. Applying all the above is the first step towards Lean Project Delivery to increase the delivered value to the end user in terms of safety, quality and value fulfillment.

FURTHER STUDY

More studies can be performed to investigate the implementation of lean principles and methods that were suggested in this paper in future educational facilities construction projects. Further studied can even focus on convincing clients to shift from traditional to lean perspective to provide better quality projects and higher value to the end- user in the future.

ACKNOWLEDGEMENTS

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EVALUATION OF CUSTOMER VALUE BY BUILDING OWNERS IN THE CONSTRUCTION PROCESS

Janosch Dlouhy[1], Stephan Wans[2] and Shervin Haghsheno[3]

ABSTRACT

Lean Construction is mainly linked to the creation of value for the client/customer. Rarely do construction publications address methods or models to understand, determine, or define the core concept of this value. This paper gives an overview of existing approaches outside the construction sector and their applicability to the construction process is analyzed. The Means-End Model – widely used in scientific customer studies outside the Lean Construction context – is then investigated further and the Customer Value in the construction process is structured according to it.

KEYWORDS

Value, Customer, Client, Building Owner, Value Management, Means-End Model.

INTRODUCTION

Customer Value is a fundamental concept in Lean Thinking. Simultaneously, understanding Customer Value is the first and foremost Lean Principle to which all others (value chain, pull, flow and continuous process improvement) should align) (Haghsheno et al.2015. It is therefore important to define the term Customer Value and to understand what factors influence it. This is especially true for the utilization of Lean Principles in the construction industry, since construction projects are inherently customer driven (Fadhil Dulaimi 2005).

Contrary to this stands the existence of many non-value-adding activities in most construction projects (Bølviken and Koskela 2016). For this reason, it seems as if

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Customer Value is not given enough attention in construction practice. In addition, Lean Construction theory states that its biggest weakness lies in understanding the nature of Customer Value (Bertelsen 2004). Among the reasons for this, as identified by other authors, are:

- A commonly accepted and used definition of Customer Value does not exist (Drevland and Lohne 2015).
- Customer Value is an established field of interest in market and business research, but the results are barely used in the Lean Construction community (Drevland and Lohne 2015).
- Most IGLC publications respect the value of the building for the customer. The construction process is the value generator in this context. Since construction projects last for a longer period, the participants also have a rightful interest in the organization of the processes in that project) (Emmitt 2005; Binninger et al.2017). Only few authors include this perspective in Customer Value research for Lean Construction.

These facts show the need for a commonly accepted definition of Customer Valueand a better understanding of the influencing factors. With the goal to develop an approach to describe those factors, a literature study has been conducted. This paper then presents an approach for defining the Customer Value based on a Means-End Model.

CURRENT APPROACHHES TO CUSTOMER VALUE IN CONSTRUCTION

The term “Customer Value” implies two questions: ‘Who is the customer?’ and ‘what is value?’ Answering these questions is essential for establishing a better understanding of Customer Value. Depending on the scientific perspective, these questions might be answered differently.

THE BUILDING OWNER AS THE CENTRAL CUSTOMER IN THE CONSTRUCTION PROCESS

There are many participants in the construction process who can be the customer. To define Customer Value, it is therefore important to clarify for whom the value is investigated. Figure 1 illustrates this by showing a possible structure of a construction project in which a company is financing and using the building for itself.

While many customer relations are apparent in the construction process, one that is particularly important is that of the building owner to the other project participants. Since the building owner has big impact on the construction process due to his rights and duties, he is a central figure. While the end user is mostly interested in the usage of the outcome (building) of that process, the owner itself does also care about the construction, since it is his financial and temporal investment that allows the realization of the project. Sometimes (as seen in Figure 1) the building owner and the end user are even part of the same company or are represented by the same person, which gives him an even bigger importance. Also, in general language usage, the building owner is meant when talking about the customer or client. The building owner is therefore the target of the following analysis in this paper.

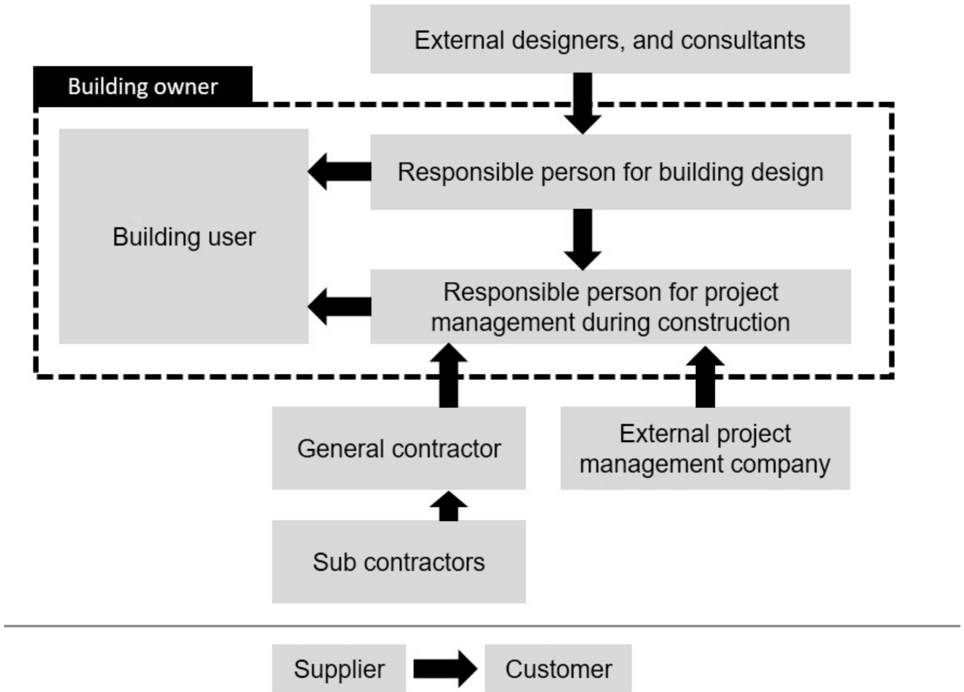

Figure 1: Possible customer relationships (arrows) in a company's construction project, where the supplier is delivering information, services or products.

THE VALUE OF THE BUILDING OWNER IN THE CONSTRUCTION PROCESS

The question "what the customer's value is" requires a wholistic answer. Many authors of various specialist fields deal with finding this answer. The result is a multitude of definitions and models. They all see Customer Value as something that is linked to the customer's wants or needs and they can be sorted into three categories: Component, Relationship and Means-End Models (Salem Khalifa 2004). In the following it will be analyzed whether these models are applicable to Customer Value in the construction process.

The Basis for this analysis is the idea of a process oriented customer value. Investigations must therefore consider, that this does not only concern a physical product, but also a process. This process has the goal of achieving a product (building). Additionally, business to customer (B2C) and business to business (B2B) relationships are possible. The resultant project organizational structures are noticeably different, and it is assumed the decision-making processes for business customers are more rational than those of private customers (Gerth 2015).

Component Models are the simplest models. They describe the various component parts, which may have a greater or lesser effect on Customer Value depending on the product and customer. Well known models include those from Kaufmann (Salem Khalifa 2004), Sheth (1991) and Holbrook (Gallarza and Gil Saura 2006). They provide good descriptions of the influential factors and how they differ from one another and they are well suited to evaluate product attributes (Khalifa 2004). As they do not give any subjective evaluations, they are also suitable for business relationships characterized by rational decisions.

They, however, do not assess the interaction between components or between customer and supplier. They are therefore less suited to assess Customer Value in interactive processes. While some categories can be applied to the construction process, the result is highly simplified and only few interrelationships are considered.

Relationship models (also “value exchange models”) place different components of value in relation to one another to analyze their effect on the customer. They have the common feature of comparing and weighing up advantages and disadvantages to the customer. For this they use conceptual pairs such as “benefits received – sacrifices made” (Salem Khalifa, 2004), “perceived advantages – perceived disadvantages” (Huber et al. 2001) or “positive consequences – negative consequences” (Woodruff 1997). Additional approaches are defined by Dodds (et al. 1991), Gale and Wood (1994) and Woodruff und Gardial (1996).

Relationship models are more complex than Component models and include many relationships that go beyond the sales process. The models attempt to describe these as rationally as possible and are therefore also applicable for B2B relationships. A weakness of Relationship Models is that they do not explain why particular attributes are evaluated as positive or negative, or important and unimportant by the customer as they do not consider the underlying goals of the customer. Additionally, Relationship Models are static. They compare positive and negative attributes at a point in time, meaning analysis of dynamic relationships such as those within construction processes are difficult to assess. This means that Relationship models have only limited applicability for processes.

Means-end models are a third way of discussing Customer Value. These seek to determine a connection between the attributes of a product or service (Means) and the goals of the customer (Ends). They do describe why certain attributes are of value to the customer and in relation to which goal. They are the most used approaches for describing Customer Value in literature on consumer behavior (Salem Khalifa 2004). One of the most well-known of this type of model is that of Woodruff (1997).

Means-end models explain how the customer values the attributes of a product or process. Hereby they include the goals of the customer. They explicitly address the consequences of a product or process caused during their use. Therefore, dynamic relationships are easier to describe than in the Relationship Models. Means-End Models rely less on specific attributes such as price and quality and thereby have greater flexibility in application. Due to their abstract nature, Means-End Models can be applied in many ways. However, some areas such as weighing up advantages and disadvantages are nonetheless better described by relationship models. The primary disadvantage is that the models do not show how many disadvantages a customer is willing to accept, and if these can be balanced out by the advantages.

Conclusion: analysis of the models shows, that the Component Model gives an overly simplified image of Customer Value and is too product-oriented. The Relationship Models are also not suited to processes due to their static approach and their inability to describe why certain factors are important to the customer. For this reason, the approach of the Means-End Models is best suited as the basis for a Customer Value Model. They are abstract enough to describe the complex execution of construction processes. However, to create a system based on the Means-End Models, the approach of the model must be adapted to suit the construction industry.

DETAILING THE MEANS-END MODEL FOR THE CONSTRCUTION PROCESS

The Means-End Model described above is made up of attributes and their resultant consequences for achieving the goals of the customer. Applying this to the construction process and customer, results in the following levels of hierarchy: "Attributes of the Construction Process", "Consequences of the Construction Process Attribute" and "Goals of the Customer in the Construction Process" (see Figure 2). These will be investigated in greater detail in the following paragraphs".

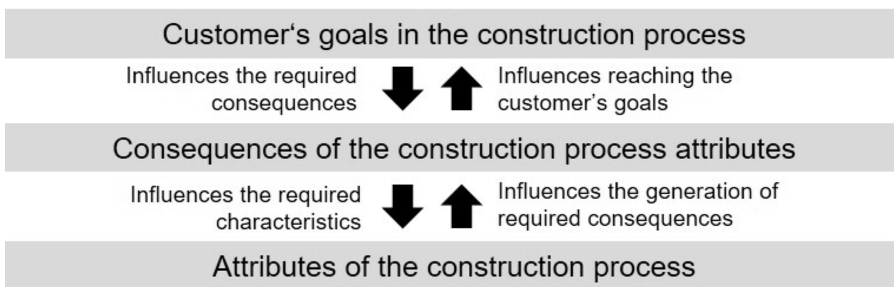

Figure 2: Concept of a Means-End Model for the Construction Process

ANALYSIS OF CUSTOMER GOALS IN THE CONSTRUCTION PROCESS

Aside from completing the building, the general customer goals (time, cost, quality; as well as simple and efficient consideration of customer rights and obligations (Wollensak 2013)), are the main motives of the customer. Requirements of the construction project and its participants result from these. Additional requirements do not lie in the customer's core interests, but rather are caused by environmental factors. These must be accounted for to prevent negative consequences. The resultant requirements, however, are made on his or her behalf. Together these customer demands and external conditions form the requirements whose fulfilment is the goal of the construction process (Kamara et al. 2000) (see Figure 3).

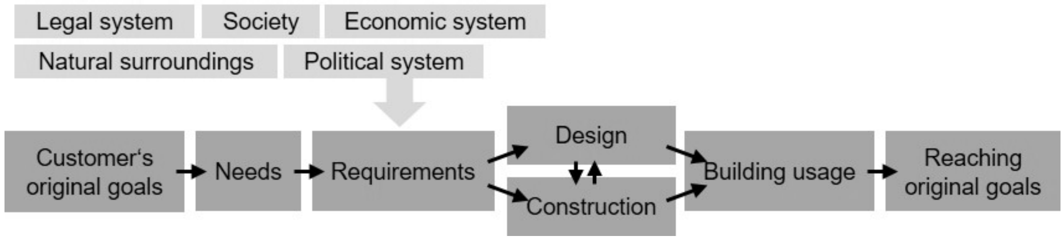

Figure 3: Influence of demands and conditions on requirements of a construction process

ANALYSIS OF CONSEQUENCES OF THE CONSTRUCTION PROCESS ATTRIBUTES

The customer's goals in the construction process are influenced by the consequences of the process characteristics. One could also call these the state of the construction process. Analyzation of the customer's goals and interviews with many leading responsible project managers in a worldwide operating enterprise resulted in four relevant consequence-categories: information, project structure, team and construction process. The detailed items in these categories can be found in Figure 4 and might be complemented in the future.

ANALYSIS OF CONSTRUCTION PROCESS ATTRIBUTES

The attributes are the attributes of the construction process. The characteristics that are of interestdiffer depending on the perspective on the construction process and the investigated topics. For example, a characteristic could describe the type of construction process, materials, type and number of workers, reporting and meeting requirements, type of logistics etc.

A MEANS-END MODEL FOR THE CUSTOMER VALUE IN THE CONSTRUCTION PROCESS

Using the goals, consequences and attributes that were analyzed before, the Means-End Model (Figure 2) can be detailed as shown in figure 4.

The system has three main principles: (1) The factors influencing Customer Value are the customer's goals in the construction process, the attributes of the construction process and the consequences of those. (2) The system gives examples of how these goals, consequences and attributes appear in detail and categorize them (3) Customer Value is the sum of its attributes and consequences seen by the customer as contributing to reaching his or her goals in the construction process.

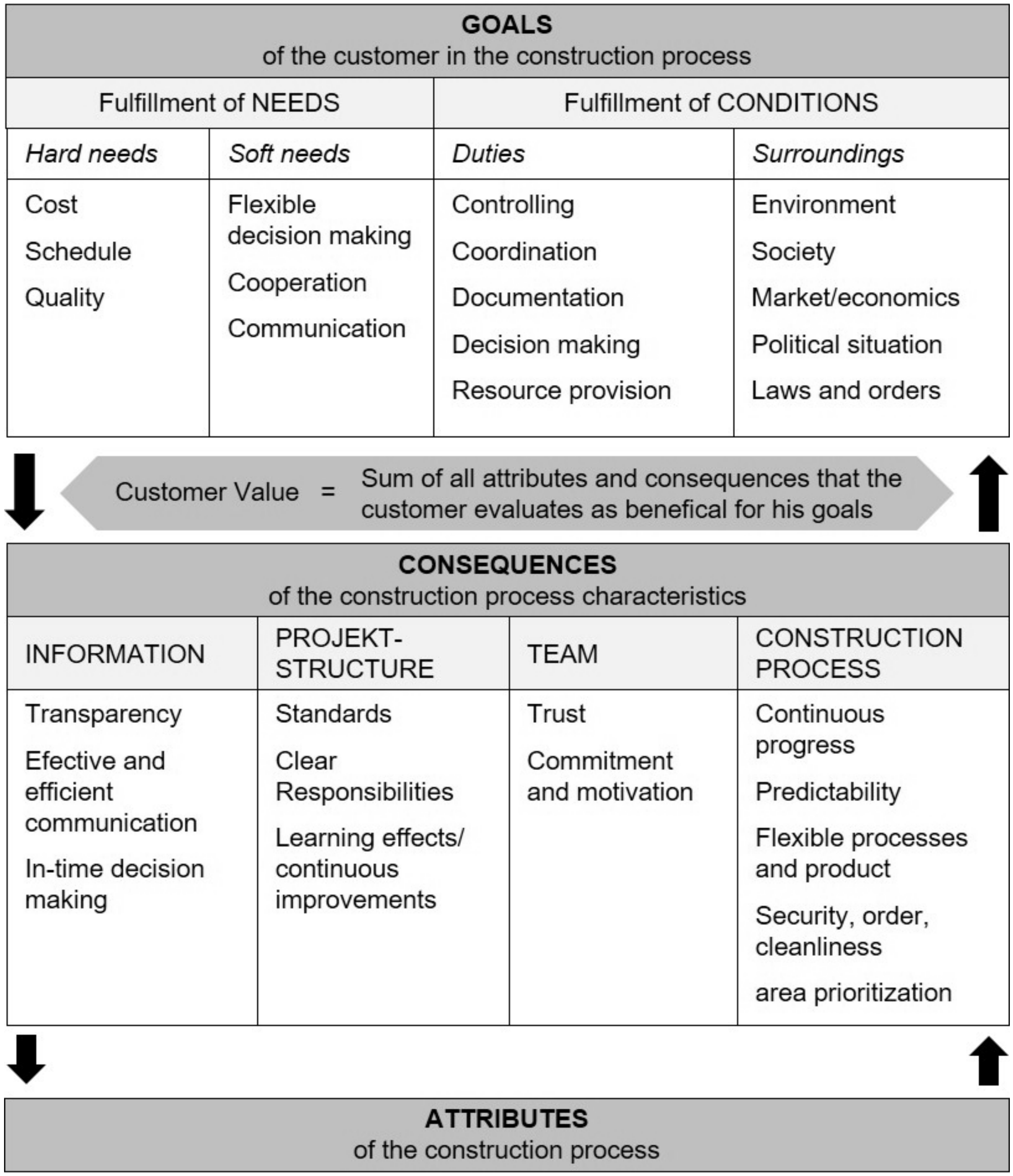

Figure 4: Detailed Means-End Model for the construction process

FINDINGS

The analysis of existing models for Customer Value showed that a Means-End Model is capable of structuring Customer Value in the construction process. The result is a process-oriented model of Customer Value, which to date has been rarely investigated in the context of construction projects. The Means-End approach shows, that Customer

Value is not a characteristic of the customer and is not equal to ethical or personal values. Similarly, Customer Value cannot be considered equivalent to requirements, wishes, goals or demands. Rather, Customer Value is the sum of the attributes and consequences which the customer has evaluated as useful for achieving his or her goals. A conclusion of the system is therefore:

Fulfilling customer requirements = Value Creation
but: Customer requirements ≠ Customer Value

Moreover, the system provides a framework for categorizing many other terms that play an important role in the construction industry. In this way, for example, the significance of trust (McDermott et al. 2005) and cooperation (Phua and Rowlinson 2004) in the construction process have long been known.

The Means-End Model defined by Woodruff not only conceptualizes the customer value, it also serves as a basis for a definition of this term (Woodruff 1996). This approach and definition, can be adapted slightly to include the construction process as well:

"Customer Value is the result of a customer's perceived judgement of those product or process attributes, attribute performances, and consequences arising from those that facilitate (or block) achieving the customer's goals and purposes in a product's use situation or in a process."

According to this, it is not goals that define Customer Value, but rather the attributes, attribute performances, and consequences that lead to achieving the goals of the customer.

CONCLUSION & DISCUSSION

The basis of this research is the emergence of customer-oriented management approaches in the construction industry. There are currently significant weaknesses in how this topic is dealt with (Bertelsen 2004). The model developed in this paper provides an approach to provide a deeper understanding of Customer Value. Using existing considerations for process-oriented Customer Value (Emmitt, 2005; Binningeret al. 2017) it extends the currently predominant product-oriented perspective on Customer Value. Furthermore, it uses the Means-End approach - widely used in scientific customer studies outside the Lean Construction context - as a basis for determining Customer Value (Salem Khalifa 2004). Making it possible to incorporate existing knowledge from other specialist fields.

While many project participants can be labelled as the customer, in this case the building owner is considered as the central figure in the construction process. Further research is required to understand to what extend additional goals and consequences influence Customer Value and what priorities are set by other customers in the construction process. Moreover, the question remains of how suitable Means-End Models are for describing product-oriented Customer Value (e.g. buildings) and if additional goals, consequences and attributes need to be considered.

The model should also serve as a basis for targeted and consistent use of terminology for describing Customer Value. Currently it is most frequently defined as related to fulfilling requirements (Koskela 2000). Other authors discuss fulfilling demands and reaching strategic goals (Haddadi et al. 2016) or define Customer Value as “what the customer wants” (Orrechia and Howell 1999). For a common understanding of Customer Value these inconsistencies must be minimized in future.

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USING DESIGN SCIENCE RESEARCH AND ACTION RESEARCH TO BRIDGE THE GAP BETWEEN THEORY AND PRACTICE IN LEAN CONSTRUCTION RESEARCH

Sheriz Khan[1] and Patricia Tzortzopoulos[2]

ABSTRACT

The descriptive approaches, like case study, interview, survey, observation and document analysis, widely used by the lean construction community to investigate managerial problems in the construction industry, typically provide explanations of problems and not solutions to them, leaving a gap between theory and practice. Two prescriptive approaches—design science research and action research—are therefore recommended. Design science research and action research offer alternative approaches for studying, understanding and solving practical problems and testing innovative solutions in design and construction management, for bridging the gap between theory and practice and for making academic research more relevant to practice.They can be used to develop and/or test solutions to managerial problems in the construction industry and generate new knowledge and/or theory.The purpose of this paper is to describe design science research and action research and discuss three cases of lean construction research in which these approaches were used effectively.

KEYWORDS

Design Science Research (DSR), Action Research (AR), Lean Construction (LC), the Last Planner System (LPS), Benefit Realization.

INTRODUCTION

The descriptive research approaches that have traditionally been used to investigate managerial problems in the construction industry have typically placed investigators in the position of observers, rather than solvers of problems and agents of change, thus producing results that are of marginal value to practice (Holmström et al., 2009).

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Prescriptive research approaches, like DSR and AR, "could be more beneficial for the construction industry and may lead to better management practices, more effective field procedures, and improved levels of productivity." (Azhar et al., 2010, p. 87). These two approaches make it possible for practitioners themselves to become involved with researchers in studying their work (Stenhouse, 1975) and becoming co-researchers, co-problem-solvers and co-agents of change. However, DSR and A Rare rarely considered when investigating and solving managerial problems in the construction industry, including lean construction research.

Daniel et al. (2015) found that the vast majority of studies with defined methods published by the International Group for Lean Construction (IGLC) on the implementation of LPS in building projects used descriptive research methods like case study, interview, survey, observation and document analysis (see Figure 1). According to Daniel et al. (2015, p. 159):

> *…this should be a point of concern to the IGLC research community that is seeking to build lean construction on sound theories and principles for better practice. Sound theories can only be developed from sound methods and methodologies…*

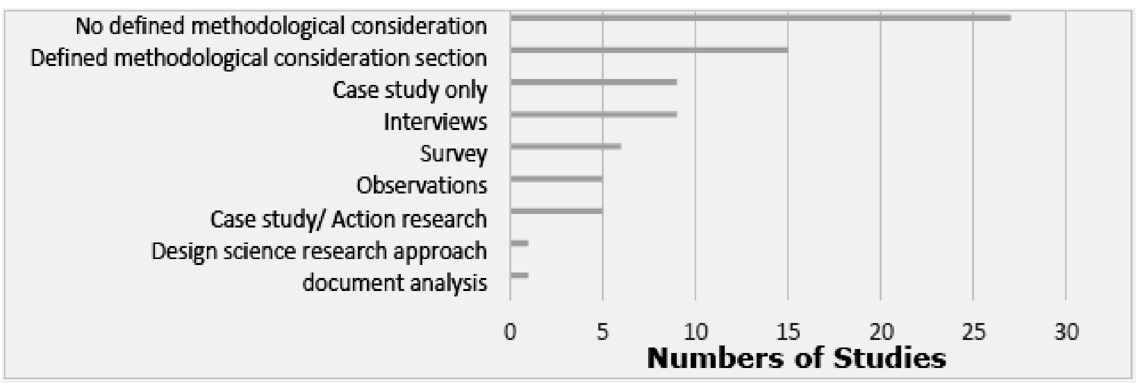

Figure 1: Research methods used in LPS implementation reported in fifty-seven IGLC conference papers (Source: Daniel et al., 2015, p. 159)

Below, the authors briefly describe DSR and AR, argue that LPS is a good example of an output of what may be considered design science research and demonstrate how action research was used in two PhD investigations to implement LPS in two building projects and evaluate its effectiveness in increasing production planning reliability.

DESIGN SCIENCE RESEARCH

DSR has its origin in engineering and the sciences of the artificial (Simon 1996). According to Lukka (2003), DSR "focuses on developing and evaluating innovative artifacts, intended to solve real-world problems and to make a contribution to the theory of the discipline in which it is applied." March and Smith (1995) proposed four artifacts that can be developed and evaluated in DSR: constructs, models, methods and instantiations (see Table 1).

Table 1: Artifacts of DSR as defined by March and Smith, 1995

Artifact/Outputs	Definition
Constructs	Concepts forming the vocabulary of a domain. They constitute a conceptualization used to describe problems within the domain and to specify their solutions.
Model	A set of propositions or statements expressing relationships among constructs. In design activities models represent situations as problem and solution statements.
Method	A set of steps (an algorithm or guideline) used toper form a task. Methods are based on a set of underlying constructs (language) and a representation (model) of the solution space.
Instantiation	The realization of an artifact in its environment, that is, the implementation(s) of constructs, models and methods, demonstrating the feasibility of the conceptual elements that the solution contains.

ACTION RESEARCH

AR is a strategy for implementing and evaluating an existing solution to a practical problem in its organizational context, with the knowledge acquired from the implementation and evaluation used to make recommendations for future implementation of the solution (Iivari and Venable, 2009)and to produce guidelines for best practice (Denscombe, 2010). Lewin (1946) is credited with pioneering AR. According to him, social practices can only be understood and changed by involving and being involved with the practitioners themselves throughout an inquiry. He portrayed AR as a spiral of learning cycles consisting of planning action, taking action, evaluating action and amending the plan based on what was learned.

PARADIGMATIC ASSUMPTIONS OF DSR AND AR

According to Vaishnaviand Kuechler (2008), DSR makes certain ontological (concerned with the nature of reality, what is real and what is not, what is fundamental and what is derivative) and epistemological (concerned with the nature of knowledge and how we can be sure of what we know) assumptions that set it apart from the positivist and interpretative theoretical perspectives. For example, DSR advocates creative manipulation and control of phenomena through the development and application of solutions while the positivist theoretical perspective is mainly concerned with the pursuit of truth (Vaishnaviand Kuechler, 2008). Based on the foregoing, it may be argued that DSR is more than just a research approach; it is a whole new way of looking and thinking about research (Manson, 2006). The procedures for conducting and the criteria for assessing DSR are therefore different from procedures for conducting and the criteria for assessing natural science research and formal science research. DSR aims to construct new and innovative ways to solve a class or classes of problems, thus creating new reality. AR differs from DSR in that it does not necessarily aim to construct new and innovative solutions for a class or classes of problems. Much of AR is conducted to understand existing reality, such as the complex workings of organizational situations and human behavior (Iivari and Venable,2009).

THE LAST PLANNER SYSTEM

Glenn Ballard and Greg Howell developed LPS as an innovative pull production control system that is needed to supplement the traditional push project management system in order to increase production planning reliability in design and construction projects(Ballard, 2000), using an approach similar to DSR (see Table 2). The output of their work may be regarded a method (or system), as defined in Table 1.

Table 2: Similarity between the approach adopted by Ballard and Howell and the DSR steps proposed by Kasanen et al. (1993)

Step	Kasanen et al. (1993)	Approach adopted by Ballard and Howell
1	Find a problem with practical relevance and that also has research potential	Ballard and Howell found a problem with practical relevance and that also had research potential: low production planning reliability associated with traditional the project management systems.
2	Obtain an understanding of the topic	Ballard and Howell obtained an understanding of the topic. Through literature review, they gained an understanding of production and production control, traditional project management, previous applications of production control concepts to the AEC industry, principles for a production control system proposed by Koskela (1999) and criteria for a design production
3	Innovate, namely, construct a solution	Ballardand Howell innovated, i.e., they constructed, a solution. They developed LPS as a solution to low planning reliability associated with the push project management system traditionally used in design and construction. They added “a production control component to the traditional project management system” (Ballard, 2000, p. 3-14).
4	Demonstrate that the solution works	To demonstrate that the solution works, Ballard (2000) analyzed data collected during the implementation of LPS or elements of it in five design as well as construction projects. The methods he used to collect data included direct observations, interviews, questionnaires and document reviews. He relied on PPCs (Percent Plan Complete), RNCs (Reason for Non-Completion of tasks) and “team member assessments” (Ballard, 2000, p. 4-10) to measure the performance of his system.

5	Present its connection to theory and its contribution to research	Ballard (2000) presented the connection of LPS to theories on the application of lean production principles to construction by Koskela (1992) and on production control in construction by Melles & Wamelink (1993). He presented the contribution of LPS to research by demonstrating that LPS combines practice with theory through research.
6	Assess the scope of application of the solution	Ballard (2000) assessed the scope of application of the solution. He found out that LPS improved workflow in construction (prime as well as subcontracted) projects and in design projects.

USING AR TO IMPLEMENT AND EVALUATE THE EFFECTIVENESS OFLPS IN CONSTRUCTION PROJECTS

The construction industry in Saudi Arabia suffers from acute managerial problems, including poor planning, low productivity, mistakes and rework (MOP, 1997; Al-Saqer, 2001), which cause costly delays. Traditional construction planning practices lack a mechanism to manage workflow (Ballard, 2000; Howell, 2003). Studies have shown that LPS reduces workflow variability during the construction stage of building projects by increasing planning reliability through greater collaboration in the planning of construction tasks and better coordination of work between the building trades.

LPS has four planning levels: Master Planning, Phase Planning, Look-ahead Planning andWeekly Work Planning(WWP). For his PhD research, AlSehaimi (2011) adopted an AR approach to facilitate the implementation of LPS Phase Planning, Look-ahead Planning and WWP in two large construction projects in Saudi Arabia over an eighteen-week period and evaluate its effectiveness in improving the construction planning and control process and reducing delay. Figure 2 summarizes the procedure AlSehaimi (2011) followed.

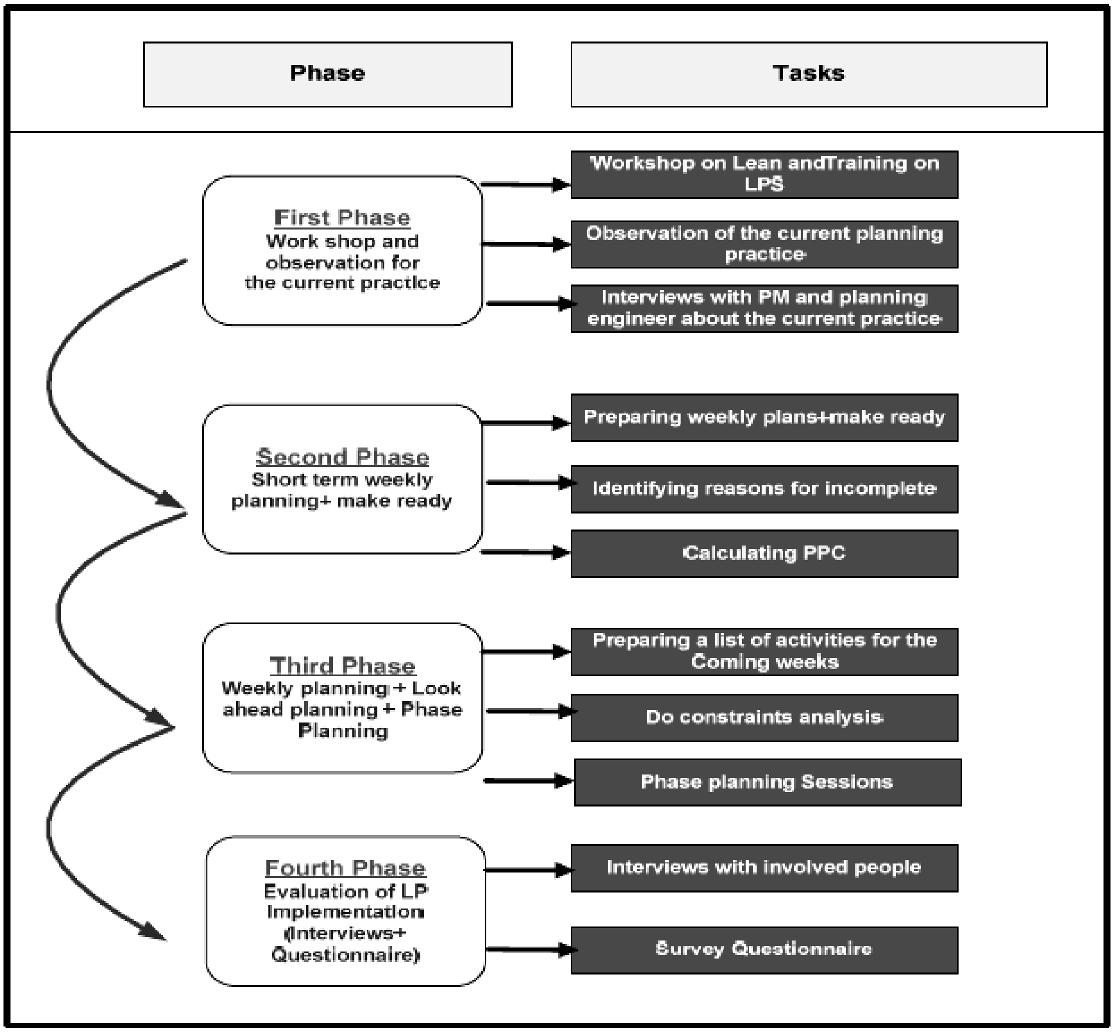

Figure 2: The LPS implementation procedure followed by AlSehaimi (2011)

AlSehaimi (2011) referred to one of the construction projects as B12 and the other as B16. He collected data for his research through interviews, observation, document review and a survey questionnaire. He synthesized, analyzed and discussed the data he collected, and he compared his findings with those of earlier studies on LPS in other countries. He reported PPC in Project B12 rising from 69% in Week 1 to as high as 100% in Week 6 (see Figure 3) and PPC in Project B16 rising from 42% in Week 2 to as high as 84% in the Week 10 and Week 13(see Figure 4), although “the project was always struggling to keep pace with the weekly and look-ahead plans, because the available workforce was insufficient to meet needs” (AlSehaimi, 2011, p. 226). The responses to his survey questionnaire revealed that LPS provided many advantages over traditional methods of project management to both the contractor and the owner. Based on the lessons learned and knowledge gained in his research, AlSehaimi (2011) made four recommendations for the implementation of the LPS in the Saudi Construction industry.

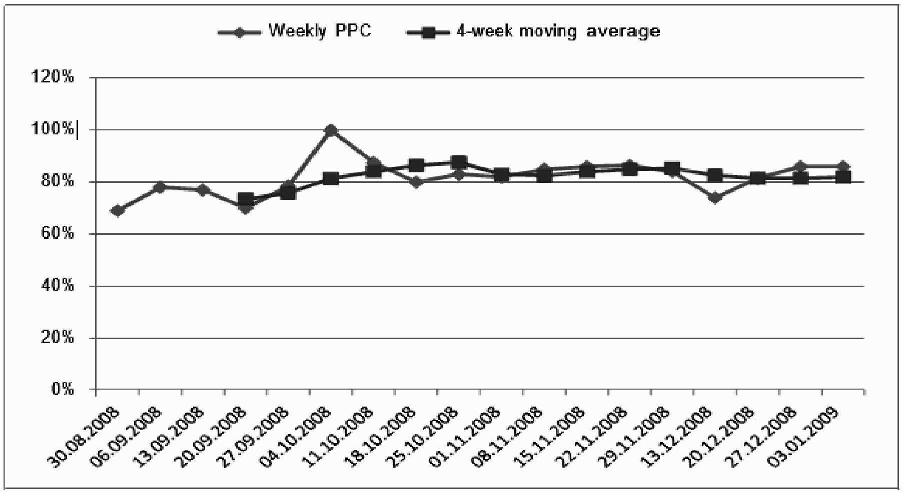

Figure 3: Trend in PPC values for Project B12 (AlSehaimi, 2011: 162)

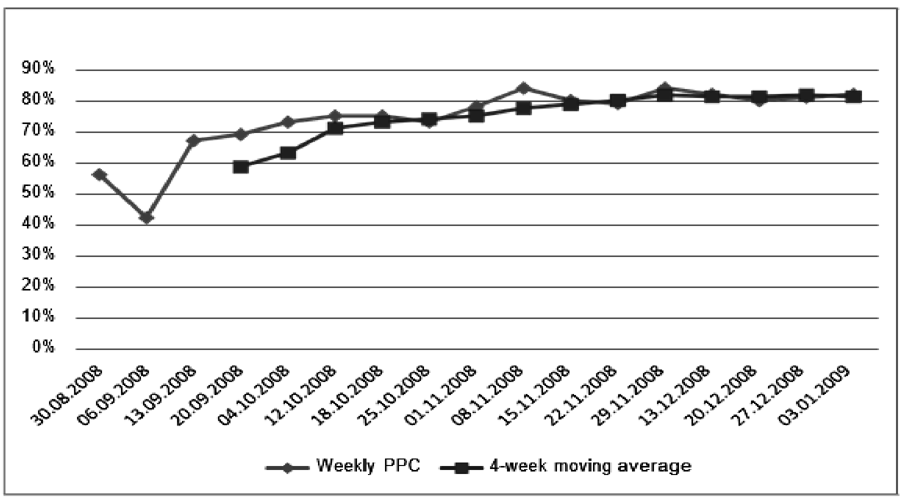

Figure 4: Trend in PPC values for Project B16 (AlSehaimi, 2011: 227)

USING AR TO IMPLEMENT AND EVALUATE THE EFFECTIVENESS OFLPS IN DESIGN PROJECTS

At the WWP level of LPS, the right sequence of work and the right amount of work that can be done are selected (Ballard & Howell, 1994). It is therefore believed that LPSWWP can be used as a production control mechanism toreduce workflow variability during the design stage of building projects by increasingplanning reliability through greater collaboration in the planning of tasks and better coordination of work between the design disciplines. For his PhD research, Khan (2016)adopted an AR approach to facilitate the implementation of LPS WWP and short-term make-ready planning during the final twelve weeks of the sixteen-week design development phase of a seven-story hotel and a six-story apartment at two different AE firms in Florida and evaluate their effectiveness in increasing planning reliability and reducing workflow variability. As shown in Figure

5, his research took the form of a flexible spiral process which allowed action (change, improvement) and research (understanding, knowledge) to be achieved at the same time (Dick, 2002).

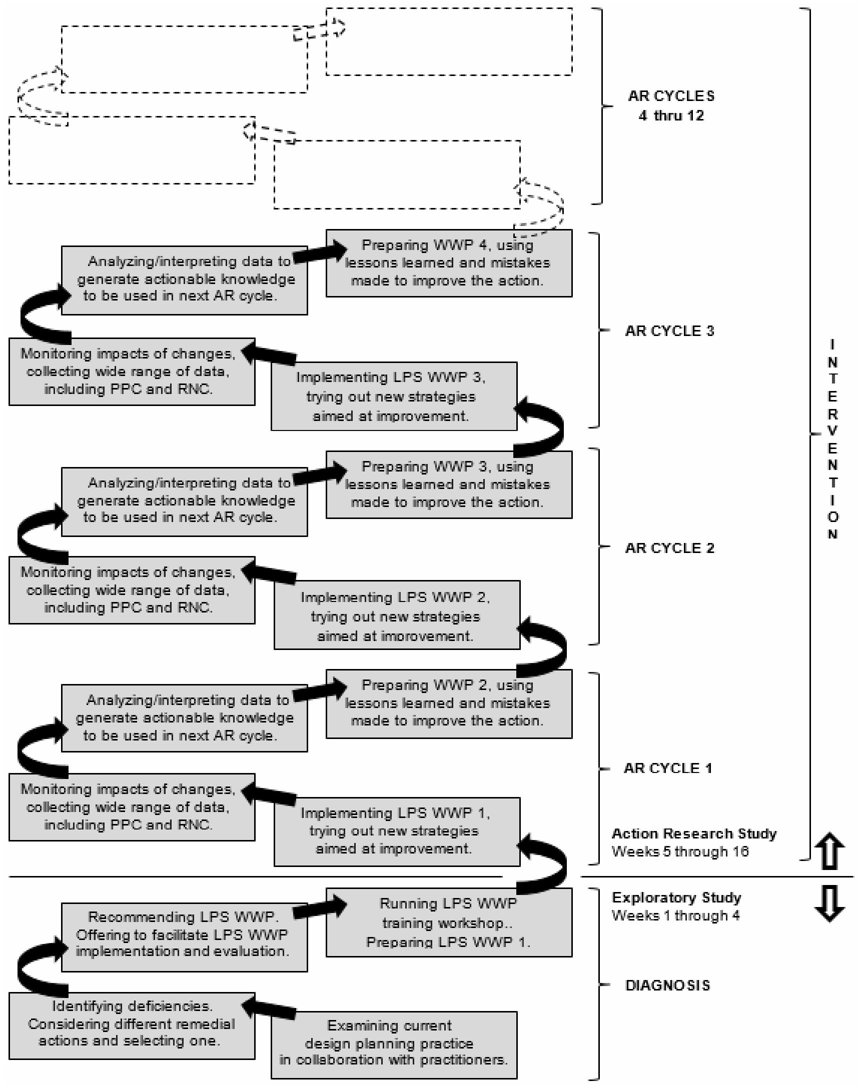

Figure 5: The action research spiral (Khan, 2016)

PPCs were collected at the end of each of the first four weeks of the design development phase to measure planning reliability during this period of traditional weekly task planning (WTP).These PPCs were later compared with LPS WWP PPCs to determine whether there had been any increase or decrease in planning reliability and thus any decrease or increase in workflow variability. Figure 6 show a steady rise in PPCs in both design projects after the fourth week, suggesting that LPS WWP was effective in increasing planning reliability in both design projects and thus improving design workflow.

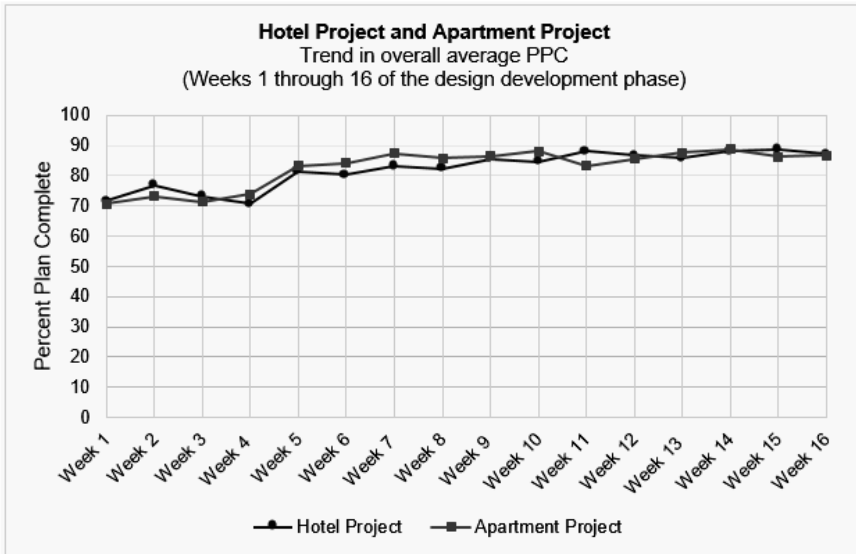

Figure 6: Both design projects—changes in overall average LPS WWP PPC

PPC measurements taken before and after the implementation of LPS WWP increased by an average of 12.1% in the hotel project and by an average of 13.9% in the apartment project after LPS WWP was implemented, representing an upward trend in PPC and continual improvement in design workflow (see Figure 7).

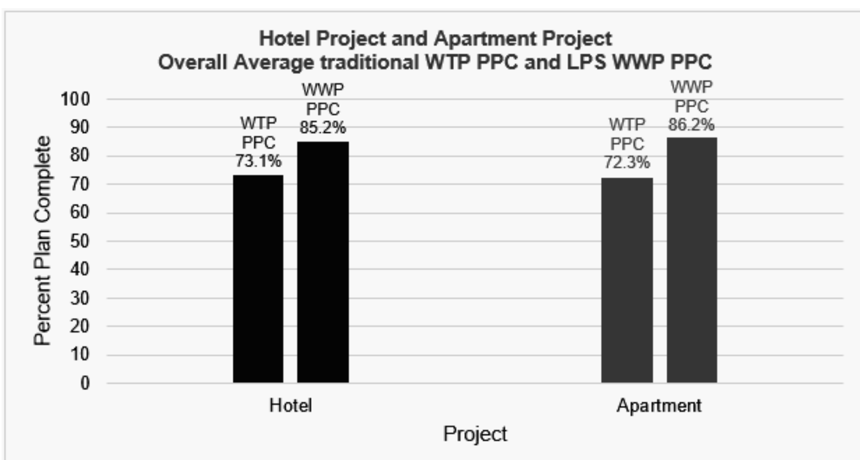

Figure 7: Both design projects—traditional WTP PPC and LPS WWP PPCcompared

Using the knowledge gained and the lessons learned during the implementation and evaluation of the LPS WWP and short-term make-ready planning in the two building design projects, Khan (2016) made twelve recommendations for future implementation of LPS WWP and short-term make-ready planning during the design development phase of similar design projects.

CONCLUSION

Lean construction is the adaptation of lean manufacturing principles to building design and construction processes. Adaptation of lean principles from the manufacturing industry requires the development of valid and reliable knowledge that can be used to create lean solutions to practical problems in the construction industry. DSR can be used to develop such knowledge. Lean solutions to practical problems in the construction industry can be implemented and evaluated in their organizational context using AR. AR is a research approach based on a collaborative solution-testing relationship between researcher and practitioners that can be used to implement and evaluate innovative solutions to practical problems in their organizational context, with the knowledge acquired from the implementation and evaluation used to make recommendations for future implementation of the solution (Iivari and Venable, 2009) and to produce guidelines for best practice (Denscombe, 2010).

The authors strongly recommend DSR and AR as the best research approaches for developing, implementing and evaluating innovative lean solutions.

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DETERMINING BENEFIT-UNDERSTANDING BUILDINGS AS PRODUCTION SYSTEM ASSETS

Frode Drevland[1] and Vicente Gonzalez[2]

ABSTRACT

Maximizing the client value delivered from construction projects is to large degree a matter of maximizing the benefit in use of the built asset. To do so, we must be able to accurately assess the benefits of a proposed solution at the time of design. While some authors have looked at simulation solutions for examining this issue, we believe that this research is putting the proverbial cart before the horse. A more fundamental understanding of what answers we seek is needed before considering how this technically speaking could be done

In this paper, we first develop an understanding of buildings as production assets from a production theoretical point of view by reviwing relevant production theory in the context of buildings. Therafter, we discuss what questions we must be able to answer to optimize building as production assets in light of the previously developed theoretical foundation. Finally, we discuss how these questions can principally be answered through different evaluation approaches.

Keywords: Fitness for purpose, theory, value

INTRODUCTION

Project Management has in the past decade shifted from focusing on delivering a set scope within a given schedule and budget, towards value delivery (Laursen and Svejvig 2016). Value is the relationship between cost and benefit (Drevland and Lohne 2015; Kelly 2007). Thus, delivering value is a matter of reducing costs or increasing benefits compared to some baseline. While reducing costs in a construction project is not necessarily straightforward, it is at least conceptually well understood. Delivering increased benefits, on the other hand, is more elusive.

What are the benefits of buildings? In prehistoric times, humans went from relying on caves to erecting tents and other simple structures to provide protection from the elements.

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While being shielded from sun, wind and rain are still benefits sought from buildings today, the situation is now more complicated.For instance, buildings also provide access to clean water and sanitation.

Buildings can serve many different purposes.According to Blakstad et al. (2008), buildings are either built to serve as residences for human population, or to serve as production assets. While there are commonalities in how buildings provide benefits for these two purposes, we will in this paper focus on buildings as production assets.

As a production asset, the role of a building is to enable the business processes of the organizations that will occupy it (Mahal 2010). According to Mahal, a business process is "*the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a desired result*". The benefits of buildings, that are considered production assets, will therefore be a function of how well the business processes they should support are running. Thus, delivering more benefits, and thereby value, is a matter of ensuring that the business process that the building should support are supported well (Ballard 2008).

In the research literature, when discussing a buildings fitness for purpose, the term usability is often used (Blakstad et al. 2008; Leaman et al. 2010). The term originated in the ICT industry and is defined as the *"extent to which a product can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO 1998). Furthermore, *effectiveness* is the "*accuracy and completeness which users can achieve specified goals"*, *efficiency* is a measure of the *"resources expended in relation to the accuracy and completeness with which users achieve goals"*, and finally, satisfaction is "*freedom from discomfort, and positive attitudes towards the use of the product*". The goals buildings are expected to achieve are related to their functions as productions assets.

There exists a significant body of literature on how building performance can be improved. In the field of facilities management, the most prevalent method described in the literatureis Post-Occupancy Evaluation (POE). The method focuses on evaluating actual building performance and relies heavily on user surveys to map the usability and performance of buildings (Cohen et al. 2001).

Assessing the performance of an existing building can help us to tweak operating parameters such as airflow and lighting, and it can help decide if the building is fit for supporting its current use. Also, the knowledge gained could help inform future projects (Leaman et al. 2010; Rybkowski 2009). However, to have any significant impact on a building's performance, we need to assess the performance of the building before it is built. Buildings are large complex systems that generally have a very long lifespan, and making changes to them are costly. Once a building is built, the processes that will take place within are irrevocably affected for better or for worse for a long period. According to Smith (2009),*"improving the productivity of the people or process that occupy a facility by just 3.8% would pay for the entire facility – design, construction and operations and maintenance"*. If we can accuratelyasses the performance of a building that is still on the drawing board, we can fundamentally improve the design for the better.

Some authors have looked into computer-aided approaches for assessing building performance at the design stage. Both Simeone and Fioravant (2012)and Kalay et al.

(2014)propose an agent-based approach to simulate the building in use. However, we would argue that this research is putting the proverbial cart before the horse. A fundamental tenet of computer simulation is not to make the simulation model more detailed than what is required to answer the questions at hand (Law 2007). Furthermore, simulation might not even be beneficial. Sometimes analytical approaches are more effective.

Additionally, we have found that this research lacks a proper theoretical underpinning for under standing buildings as production system infrastructure. We would argue that such an understanding should be the starting point for any method aimed at assessing the potential benefits of a building in use. In this paper, rather than look at techniques for building simulation, we look at the question of how to develop an understanding of buildings as production assets from a production theoeretical point of view.Furthermore we discuss what questions must be answered if we are to optimize buildings as production system assets, and investigate potential answers to these questions.

From a business perspective, buildings can have both instrumental and symbolic benefits(Drevland and Klakegg 2017). The former coming from directly supporting business process directly, while the latter from providing image and identity for the organization(s) housed by the building. In this paper, we limit ourselves to consider instrumental benefits.

BUSINESS PROCESSES VERSUS PRODUCTION PROCESSES

Ideally, we should measure the performance of the business processes that a building is meant to support. In a POE context, the actual performance of business processes can be measured and benchmarked with similar processes in similar buildings. However, at the design stage, where designers are deciding layouts, room functions and such, they need to consider issues at a more detailed level. Moreover, certain business processes, such as customer acquisition and quality assurance, do not correlate very well to the physical aspects of a building, i.e.rooms and spaces. However, we can instead consider the corresponding production processes that takes place, such as meetings with customers (customer acquisition) and inspections (quality assurance), and evaluate the performance of these. Thus, we would argue that determining performance and usability of a building entails determining how well the production processes that it houses runs.

PRODUCTION SYSTEMS THEORY

We will in this section provide a brief overview of production systems theory that is relevant for understanding and describing buildings as production system infrastructure.

Koskela's seminal work on production theory (Koskela 2000) shows that through the 20th century three different conceptualizations of production have been used. He argues that all three are necessary and synthesises them to one common theory; the Transformation-Flow-Value (TFV) theory. Historically, the predominant conceptualization of production has been that of a Transformation of inputs to outputs. In this perspective, it is thought that the overall transformations can be decomposed into aset of smaller transformations, which in turn can be optimized to improve the whole.

One shortcoming of the transformation conceptualizations is that it only considers value-adding activities, i.e. where processing takes place. Decomposing a production process into smaller transformation activities will also result in many non-value-adding activities that occur in between, such as transportation, inspection and waiting. This is the focus of the second conceptualization, Flow, which considers production processes as flows of materials and resources. Flow activities – or non-value adding activities - are considered waste and are sought to be minimized or eliminated.

Another flaw of the transformation conceptualization is that it is prone to sub-optimization. Neither the consequences on downstream operations nor the quality of the final product are considered when optimizing the smaller tasks. This is the domain of the third conceptualisation, Value, which is concerned with the realization of the customers (internal and external) needs.

In the context of assessing a buildings ability to support production processes, the value aspect is arguably irrelevant. This aspect is concerned with whether or not the right things are done, something that is the domain of production system design. The question we need to answer is whether or not a building allows the right things to be done well, i.e. to what degree are transformation and flow activities supported by the building.

Thus, instead of considering the usability of the building at a macro level, we need to drill down to a relevant level of detail and consider the usability of the constituent transformation and flow activities that the production system design requires. For example, for a hospital, we must consider the usability of activities such as performing surgeries and transporting patients.

With regard to the level of detail required, any activity could be detailed down to very minute operations. Consider a carpenterwho is nailing a board. The act of him taking a nail out of his pocket and moving it into position can be considered flow. The only true transformation taking place is when the nail is being hit on the head and moves further into the board.

Breaking down activities into this level of detail can make sense in some situations. For example, when developing a tool like a nail gun (eliminating the flow of the nail from the carpenter's pocket to the wall). In the context of buildings, an example of this kind of micro-flowis the movement of doctors and nurses within an operating theatre during an surgery. In this paper we do not propose to examine in detail what might be a suitable level of disaggregation.

Assessing the usability for individual transformation and flow activities has an inherent value with regard to improving these activities in isolation. However, at the system level, i.e. the whole building, doing so in-and-of-itself would only be sufficient in production systems with no variability, something that rarely exist in real life. To truly be able to optimize a building as a whole, we have to consider all the activities at once, taking into account *variability* and *buffer* usages in the production system.

Variability in the context of production systems could refer to product variability, either good - e.g. model variants, or bad - e.g. defects (Hopp and Spearman 2011). However, in the context of measuring a buildings ability to support a production system, our primary concern is the variability in time spent performing transformation and flow activities.

The Buffer law tells us that any production system will always be buffered by a combination of capacity, inventory and time(Hopp and Spearman 2011). Hopp and Spearman also refer to this law as the pay-me-now-or-pay-me-later law. If you do not pro-actively place buffers in the production system, you will suffer the consequence of doing so later. Take for example restrooms. There can be a considerable variability in the demandto use them depending on the time of day and the activity in the building. The activity "going to the restroom" must be buffered. Ideally by capacity (more stalls and urinals), but an inventory buffer (people waiting in line) is also possible. If this kind of buffering is not purposely considered at the design phase, buffers could haphazardly form whenever the building is in use to the detriment of overall system performance, e.g. the case of people waiting in line to got to the restroom blocking corridors and slowing transport through the building.

PRODUCTION SYSTEM MODEL

To be able to determine if a proposed building design will properly support the production system that will be housed in the building, we would argue that some model of the production system is needed. We would furthermore argue that the kind of model required here is something vastly different from the outcome of traditional architectural space programming, which is a list of rooms with specific requirements. The problem with that approach is that it entails an early locking of the design space. The production system(s) that are to be housed in the building might be better served by a different configuration of rooms. This, however, is not something that can be considered without taking into consideration the physical layout and characteristics of the building. A good example is the layout of a nursing unit in a hospital. *"The strategic placement of support functions on nursing unit floor plans affects caregivers' movement, as reflected in walking distances, timeliness, fatigue, and exposure to interruptions"*(Zadeh et al. 2012). Thus, a bad layout of a nursing unit could lead to either more nurses being required to do the same job or suboptimal care being provided.

In this paper we conceptually refer to a model containing information about the production activities that will take place in the building as a Building Activity Model (BAM). Furthermore, we refer to any activity directed towards determining how well the BAM is supported by a proposed design as a BAM evaluation. Since nowadays building designs almost inevitably will be expressed in some form of Building Information Model (BIM), a BAM evaluation can also be thought of 'clashing' the BIM and the BAM

The purpose of doing such a BAM-evaluation is to not only do an absolute evaluation of fitness for purpose of a specific desing, but also to provide sufficient information to evaluate design trade-offs to improve the design. At an aggregate level, there are basically two questions that need to be answered: Can the system work? Does it work well? If we are benchmarking two or more designs against each other, having key performance indicators at the system level might be sufficient. However, in order to be able to improve the design, we are not primarily interested in any absolute performance measurements, but rather if and where there is room for improvement. That is, where in the system can ineffectiveness, inefficiency and dissatisfaction be found, and what are the reasons for them. This requires that we acquire information at the activity level. Thus, going back to the usability term, we need to understand to what degree these activities described in the BAM can be performed from the perspectives of *effectiveness, efficiency and satisfaction.*

EVALUATION METHODS

Before considering the specifics of a BAM evaluation, we need to have a notion of the different evaluation approaches that can be used. There are fundamentally two approaches that can be used to examine a system; analysis and simulation (Law 2007). Analytical solutions can be used if the model are simple enough. In this paper, we will separate analytical solutions into verification into two types, verification and calculation

In the Project Management Body of Knowledge, verification is defined as “the evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition”(PMI 2013). In this paper, we define verification somewhat more narrowly. Our definition aligns with what can be found in the systems literature, where the purpose of verification is “showing that all system trajectories satisfy the desired property” (Girard and Pappas 2006). In other words, the answer to a verification question will always be a binary true or false. Further more. “all systems trajectories” entails that uncertainty or variability can be reduced to worst case scenarios.

Some of the answers we want from a BAM evaluation will be numeric. In many cases, this will require the use of computer simulations. However, that is not always the case. Thus, we will define calculation to include any method that yields numericalanswers but does not rely on computer simulation.

Simulation is a ratherbroad term. Law (2007) describes it as ”techniques for using computers to imitate […] the operations of various kinds of real-world facilities or processes”. While we agree with Simeone and Fioravant (2012)and Kalay et al.(2014) that agent-based simulation is likely most beneficial when it comes to simulating building use, we do not here assume any specific simulation method when discussing simulation.

In addition to the types of evaluation that can be used, we must also distinguish between deterministic and stochastic models. A deterministic model is one where all the input variables are known, while a stochastic model is a model where one or more of the input variables are uncertain (Law 2007). Some people mistakenly equate stochastic with simulation and deterministic with analytical solution. However, stochastic models can be solved analytically. E.g. the PERT is a stochastic scheduling method that initially employed analytical methods for evaluation (Clark 1962). Conversely, some deterministic models are simply too complex to be evaluated using analytical solutions and require the use of simulation (Law 2007).

BAM EVALUATION

In the introduction, we referred to Law (2007) who states that modelling should not be done beyond what is necessary to answer the questions one wants to be answered. What are then the questions we want to answer? In the previous discussions we have argued that we need information at the activity level of the production system(s) that will be housed in the building. Therefore, we would argue that there are two main questions that need to be answered. Firstly, can the activities in the BAM can be done. Secondly, how well can these activities be done. Below we discuss how these questions can be answered through a BAM evaluation. Furthermore, while getting information at the activity level is necessary to optimize the buildings design, designers and decisions makers will better be served with aggregate level indicators as an initial result of a BAM evaluation to give them an overall feedback of the quality of the design. Therefore, we also discuss what performance indicators could be usseful at the aggregate level.

Can the activities be done?

The most fundamental type of BAM evaluation is to check if an activity can be carried out in the spaces that should support them, i.e. is the required infrastructure in place, can the required resources, and can materials be transported into the area? This evaluation can be done by relatively simple verification and is already being done today, it then has to be verified against a space program rather than a BAM (Kim et al. 2013).

If we consider the question of whether the required activities can be performed or not more broadly, we are then looking at a far more complicated situation. This entails evaluating whether the building has sufficient capacity to support the needs of the production system, rather than just considering if production activities can be done in the allocated spaces.

Determining if the building will have enough capacity for a specific activity can in some cases be determined by verification. For example, if we have a design for a university building where each of the faculty is supposed to have their own office, then verifying that research activities are sufficiently supported is easily done by comparing the number of offices to the number of faculty resources specified in the BAM. The same with small meetings, if the faculty offices are designed to accommodate this. Determining if there is sufficient space for large meetings, on the other hand, cannot be determined by simple verification. At least not unless the building has been designed with one meeting room per faculty. Verification only yields a yes or no answer. In a situation where the supply of spaces with the required infrastructure might outstrip the demand from activities needing them, we need to move on up to calculation or simulation.

Calculation could be used for simpler scenarios. We can calculate the maximum activity capacity, for example simultaneous meetings, from the BIM, and the total expected meeting room requirements from the BAM. Since there is usually some flexibility as to when meetings are scheduled, this might be sufficient. If, however, we are dealing with activities that cannot be scheduled in advance, the analysis becomes more difficult. Take for example people going to the restroom. This is not something that one would schedule days in advance. Determining sufficient capacity here can be done through calculation, relying on rules of thumbs and averages. However, if some characteristics of the system cause batching to occur, for example people arriving on an airplane at an airport, such average numbers will lack reliability. Thus, in a highly variable setting, we need to simulate circumstancesto get sufficiently relaibleanswers.

How well can the activities be done?

Determining if the activities can be done well, i.e. with high efficiency, effectiveness and satisfaction, is not a trivial matter to determine. The reason for this is the high degree of interdependencies between activities and resources in most productions systems and the inherent variability within these systems.

Hopp and Spearman (2011) distinguish between process variability and flow variability in production systems. Process, or transformation (to use the term of Koskela (2000)) variability originates whollywhit in the process itself. Flow variability is caused by upstream variability. Similarly, we can separate between activities underperforming due to flow issues and due to process issues. Flow issues are those that cause an activity to be starved of some material or input. In this case the activity is not performed at all while waiting for materials or resources to arrive or be released. This could be due to characteristics of the building. For example, staff spending a disproportionate time waiting in line or hunting for bathrooms if the capacity is too low. Process issues, on the other hand, do not cause non-performance but rather degrade performance. Some issues could be purely related to the characteristics of the building, like having suboptimal lighting, while others will be caused by other activities in the system, such as noise in an office landscape.

Some of these aspects could be partially analysed using calculation. For example, consider a case where the HVAC system of an office building is designed to handle outside temperatures of up to 28 degrees Celsius. If the outside temperature rises above this, the inside temperature of the building will fall outside the thermal comfort envelope of its occupants, causing productivity loss to occur (Tham and Ullah 1993). Based on weather statistics and the specifications of the HVAC, designers could determine the mean number of work hours per year where work conditions will be outside of the thermal comfort envelop. Then, with this as a basis, calculate the number of man-hours of productivity impaired or lost each year.

However, such a calculation cannot adequately consider mitigation efforts undertaken by the inhabitants, such as opening doors and windows, and the secondary effects these have on the production activities, like noise. The interdependencies in production systems entails that simulation is required to fully determine how well an activity can be done in a building.

Aggregate performance indicators

At the aggregate level, there are several indicators that could be relevant. The nature of the production system will dictate which indicators are more interesting. Some systems are very flow oriented, and some are more resource oriented. For example, airport terminals are focused on the flow of passengers to and from entrances and gates while office buildings are focused on the production of the people resources working in the building.

In production systems where there is a clear linear flow, such as assembly plants, the parameters that make up Little’s law are of interest. Little’s states that Cycle Time = Work in Progress / Throughput (Hopp and Spearman 2011). For systems with low variability, these parameters could conceivably be determined by employing analytical approaches. However, we would argue most scenarios are more complex and require simulation.

Productions systems that are not flow oriented will typically be knowledge work based and be oriented around immaterial products. For example, academics producing research or architects producing designs. In these cases, the building does not have to provide for the flow of a physical object. Thus, while we could potentially model and simulate the process of the creation of an academic paper, this would be a prime example of taking modelling too far in relation to the questions we want to have answered. Doing high concentration knowledge work is dependent on favourable environmental conditions, such as proper lighting and little ambient noise. So here, a suitable metric would be some measurment of*activity quality*, based on a performance formula with the environmental conditions, at the time of doing the activity,as input variabels.

Whether we are dealing with flow or resource dominant system, having metrics for resource usage is of interest. The most relevant metrics here are the percentage of time spent doing value adding activities and non-value adding activities (waste), and a further drill-down of these categories. The latter is essential to be able to identify inefficiencies in how the building supports the production system. For example, if we see that some resource spends a disproportionate amount of time on transportation, this could mean that the layout of the building is suboptimal. However, it is also important to be aware that in some cases a resource will have a low utilization rate by design to act as a buffer for variability in the system. It is therefore crucial, for example, to be able to distinguish between waiting that is required by an activity or activity sequence or waiting in line for an elevator.

Going back to the situation of the knowledge worker, just tracking the participation of resources in value and non-value adding activities is insufficient in this case. In some scenarios, value-adding could take place in a suboptimal way. Environmental conditions, such as thermal comfort and noise level, being sub-optimal will slow down the work, thus becoming *less* value-adding, however *not* non-value adding. Thus, a productivity index would be a relevant metric for these kinds of resources. The data for which could easily be gathered if some measurement of activity quality, as described above, is undertaken.

CONCLUSION

We have argued that evaluating the benefits of a building at design time should entail an analysis of their ability to support the production system that it will house. To do so there are two fundamental questions that we must be able to answer: Can the activities of the production system be performed? And how well can they be performed?

Answering these questions will require some Building Activity Model (BAM) describing said production systems and its activities. Furthermore, we conclude that while the simpler evaluation methods of verification and calculation can partially answer the questions, to fully determine to which extent a proposed design will support a given BAM, computer simulation will be required.

While previous authors have argued some of the ideas presented in this paper in general terms, we are not aware of anyone who has put them into the same kind of fundamental production theoretical context as we have provided here. We would argue doing so is a prerequisite to properly developing simulation models and other tools.

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CONCEPTUAL FRAMEWORK FOR CAPABILITY AND CAPACITY BUILDING OF SMEs FOR LEAN CONSTRUCTION ADOPTION

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ABSTRACT

Lean construction (LC) is a production system with the potential to deliver exceptional performance within any organisation. LC is possible solution to the many problems faced by construction Small and Medium Enterprises (SMEs). However, Construction SMEs lack the needed resources which constraint their lean implementation efforts. A conceptual framework for capability and capacity building of Construction SMEs is developed based on the Toyota Way model.

This research was conducted using systematic review of literature. The review suggests there is the need to build the capability and capacity of SMEs to fully adopt the LC philosophy. SMEs provide a challenging context for the implementation of LC due to their lack of the needed resources.

The outcome of this study is to focus attention on building the capability and capacity of Construction SMEs to fully adopt LC. This will help reduce the incidence of high failure rates of LC implementation recorded amongst SMEs. Previous works have concentrated on what SMEs can and should do within their limited capacity. However, the use of the isolated tools and practices fail because lean is a system that has to be implemented holistically. A conceptual framework for building the capability and capacity of SMEs for LC adoption is therefore proposed.

KEYWORDS

SMEs, Lean Construction, Capability and Capacity Building, Process, Value.

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INTRODUCTION

SMEs are critical in the structure of the construction industry (Oforiand Toor 2012) as they form majority of the firms (Gyadu-Asiedu 2009; Amoah et al. 2011).In the Ghanaian context, construction SME is a family run domestic contractor with 199 employees as the upper threshold and 10 employees as the lower threshold (Kheni 2008).Small construction firms in Ghana constitute about 95% of contractors, over 90% of the job market, and nearly 80% of all short-term employment (Amoah et al. 2011).Globally, the importance of this critical sector cannot be overemphasized.

In spite of the significant contributions construction SMEs make to the economies of both developed and developing nations, they face a lot of challenges that affect their capacity (Amoah et al. 2011). Accordingly, implementing LC has become a challenge for SMEs (Marasini et al. 2014), as these firms are constrained in terms of the resources (Marasini et al. 2014; Netland 2016). This has led to a concentration on what SMEs can and should do within their available resources. In the work of Rose et al. (2011), the authors argued that SMEs should go in for least costly tools, which is well within their capacity. In other work, such as Matt and Rauch (2013), it was suggested that SMEs should use principles declared to be suitable for them. However, in most cases the use of isolated practices leads to a failure of lean implementation (Lathin and Mitchell 2001). These previous works have fallen short of looking at how SMEs capability and capacity can be built to fully implement the lean philosophy. More so, the benefits of a full implementation cannot be compared with an implementation of just a few tools (Netland 2016; Liker 2004). The study therefore seeks to develop a conceptual framework for capability and capacity building of SMEs for LC adoption.

RESEARCH METHODOLOGY

Systematic literature review was utilized because of the rigorous and transparent form of the review (Okoli and Schabram 2010). This study follows the comprehensive stages for the systematic review developed by Tranfield et al. (2003).

The initial descriptors used for the literature search were “Lean construction,” “construction SMEs,” “Lean and construction SMEs. A total of 114 articles were initially identified from the search. However, not all of the 114 papers presented research arguments on the issue of LC and SMEs. The papers were briefly examined to filter out irrelevant articles. A total of 63 papers were finally selected to be valid for the study. A conceptual framework is developed based on the analysis of these selected papers.

LEAN CONSTRUCTION IMPLEMENTATION WITHIN SMEs

LC techniques offer the potential to minimize, if not entirely eliminate, non-value adding activities (Salem et al. 2005). Thus, LC is about the elimination of all non-value-added steps in a process (Arroyo and Gonzalez 2016). Several studies, such as Cho and Ballard (2011), Bhamuand Sangwan (2014) point to the significant benefits of LC to the incidence of low productivity, low quality of works, increased construction cost, low job satisfaction and waste generation within construction processes. LC is a possible solution to the many problems faced by construction SMEs (Sage et al. 2012; Bhamu and Sangwan 2014).

SMEs are generally constrained by their management, resources and organisational culture and structure that affect their Lean efforts (Achanga et al. 2006; Panizzolo et al. 2012). For instance, human resources in SMEs are weak in terms of their knowledge and skills. There are a number of issues that affect SMEs' ability to recruit, motivate and retain the best of talents (Darkwah 2014). Top management support, commitment and buy-in is a critical success factor in LC implementation (Al-Najem et al. 2012), however top management in SMEs normally will not acknowledge the need for change. It is difficult to succeed in LC without a healthy culture. In UK for instance, only 10% of the firms succeed in their lean implementation efforts. The reasons for such a huge failure are culture and management (Taleghani2010). LC requires a culture of employee empowerment, teamwork and enhanced relationship with suppliers (Al-Najem et al. 2012). This is mostly lacking within SMEs, as employees are not usually empowered and relationship with suppliers is mostly adversarial. Top down leadership style that is a characteristic of Construction SMEs is a cultural barrier that inhibits lean implementation.

A REVIEW OF LEAN FRAMEWORKS

Over the years there have been a number of models that looked into the possible implementation of lean production principles. Anand and Kodali (2010) examined approximately thirty (30) frameworks for lean production. The authors concluded that none was comprehensive. In view of that, they proposed a framework consisting of 65 lean elements, taking into consideration the shortcomings of the previous frameworks. Chay et al. (2015) posit that the framework developed by Anand and Kodali (2010) is too sophisticated and does not address "why" aspect of the implementation of lean principles. The authors also reviewed frameworks developed between 2010-2013. The study discovered that lean production frameworks developed after the work of Anand and Kodali (2010) has disregarded the soft elements of Lean production. Similarly, Gao and Low (2014) reviewed various frameworks for LC. The authors proposed an alternative framework for LC implementation, taking into consideration all aspects of the organisation (both the social and technical).

Consequently, frameworks have been developed specifically for the SME sector (for instance, Amad-Uddin, 2011; Rose et al. 2011; and Belhadi et al. 2016). The strength of these frameworks lies in its consideration of both the soft and hard aspects of lean implementation. These lean production frameworks developed specifically for SMEs overlook the aspects of capacity building, although authors acknowledge the lack of capacity for lean implementation within the SME sector. These frameworks instead propose feasible lean tools that can be implemented within the limited capacity of SMEs, but failed to look at how SMEs can be supported to fully implement the lean system. Similarly, promoting LC to SMEs and developing the capability and capacity of SMEs to deploy LChas received little attention within the LC Community. Considering the capability and capacity challenges of SMEs, any framework which can be successfully adopted by SMEs should take into consideration the capability and capacity needs of these firms and where possible support systems to cushion them to adopt these principles. More so, lean is a system that has to be implemented holistically in principles and techniques, therefore there will there be a need for a framework that takes into consideration capability and capacity building of SMEs to fully adopt the lean system.

DEVELOPMENT OF THE CONCEPTUAL FRAMEWORK

In assessing LC frameworks Gao and Low (2014), posit that 'process-focus' thinking is still the major focus of the LC frameworks reviewed. This is because the implementation of lean principles on the "shop floor" can result in immediate improvements (Liker2004).

In view of the shortcomings of the LC frameworks, the study proposed the "4P Model" of the Toyota Way. This model was proposed to resolve some of the fundamental limitations of the frameworks that are available within the LC domain. The 4P model of the Toyota Way was introduced as an alternative means of interpreting LC (Gao and Low 2014). This study therefore in developing the conceptual framework for SMEs adopts the "4P Model" developed by Liker (2004)and proposed by Gao and Low (2014) for LC implementation.

JUSTIFICATION FOR THE USE OF"4P MODEL"

Many authors have argued that lean is a social and a technical system(Liker 2004; Shah and Ward 2007; Low and Gao 2011). Accordingly, the 4P model would be a suitable choice for LC implementation (Gao and Low 2014). In the application of lean principles, the focus has largely been on the technical aspects of production (Liker 2004), while ignoring the implications for the people related aspects (Green 2002). The technical-aspect fails or underperforms if the social or human related aspects are ignored. This is the case because the real issues during the process are human cantered (Chay et al. 2015). In other words, it is also imperative to create a healthier people system. This assertion is in line with Matsui (2007) who suggests that the effectiveness of technical practices is appreciably increased when equally teamed with the soft practices.

The "technical-focused" thinking significantly restricts the degree of improvement that can be achieved (Emiliani and Stec 2005; Bhasin and Burcher 2006). Accordingly, the "4P model" is a comprehensive model for LC implementation (Liker 2004; Gao 2013; Gao and Low 2014). The "4P model" comprises 14 principles within four layers with each layer serving as an individual model in itself. The next section discusses the "4P model" in detail toward the framework development.

"4P MODEL" OF THE TOYOTA WAY

Liker (2004) used a pyramidal model, which comprises an outline of Toyota's principles. These principles are grouped in four broad categories and each contains important sub-principles:

- Long term Philosophy (Philosophy).
- The right Process will produce the right results (Process).

- Add value to the organization by developing your People and Partners (People/Partners).
- Continuously solving root problems drives organizational learning (Problem Solving).

According to Liker (2004), these four broad categories have fourteen principles. The foundation of the pyramid is the management philosophy, which is based on long-term decisions, even at the expense of short-term financial goals. Following from that are the right processes producing the right results. Ultimately, production flow is standardized and visualized which helps in identifying problems. The next level places respect on people and partners, while challenging and growing them. The last layer of the pyramid is the problem solving philosophy by using various improvement tools such as kaizen and genchigenbutsu (going to see for yourself).

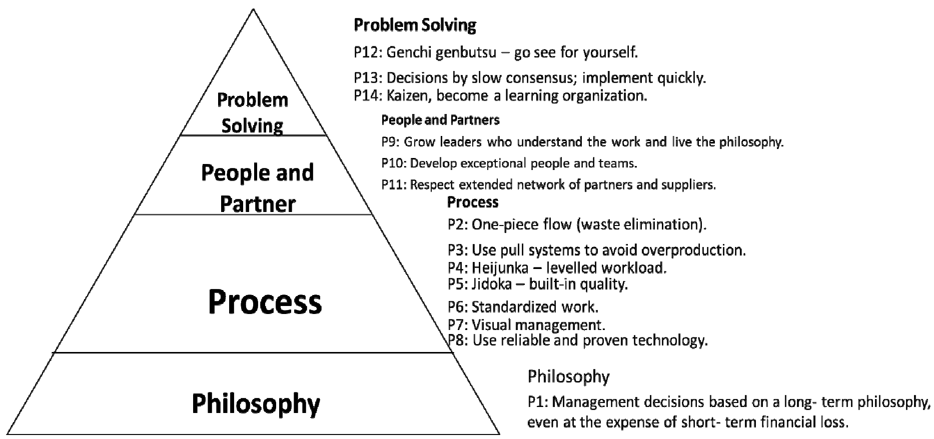

Figure 1: 4P model of the Toyota Way (Source: Liker, 2004)

CONCEPTUAL FRAMEWORKFOR CAPABILITY AND CAPACITYBUILDING OF SMES

In developing the framework as can be seen in Figure 2, the 4P Model was used as the basis for LC implementation. LC tools identified in the literature were linked to the model. The next level assesses the status of implementation and challenges in LC implementation by SMEs. This leads to the capability and capacity needs of these SMEs. Following from these needs is developing intervention for capability and capacity building of SMEs. These interventions are considered from the Systematic Approach. The System Approach consists of four levels; the individual, organizational, industry and state level. In essence, the interventions are taken from the level of the individuals to the organisation, then at the industry and finally at the state level. This leads finally to policies and plans for LC implementation by these SMEs. This framework proposes a strategy for a successful LC implementation by SMEs taking into consideration their capability and capacity needs.

The customer of the framework is the construction industry sector. The conceptual framework eventually leads to policies and plans for building the capability and capacity of SMEs for LC adoption. These policies and plans emanating from the needs of SMEs will act as guidelines to the construction industry sector in building the capability and capacity of individual SMEs for broader application of LC principles. Since this framework incorporates the specific needs of SMES, it will give this important and crucial sector more capabilities and capacity for adopting wider LC principles. Ultimately this intervention will lead to an improvement in the performance of SMEs resulting in a huge impact within the industry and the economy of any country.

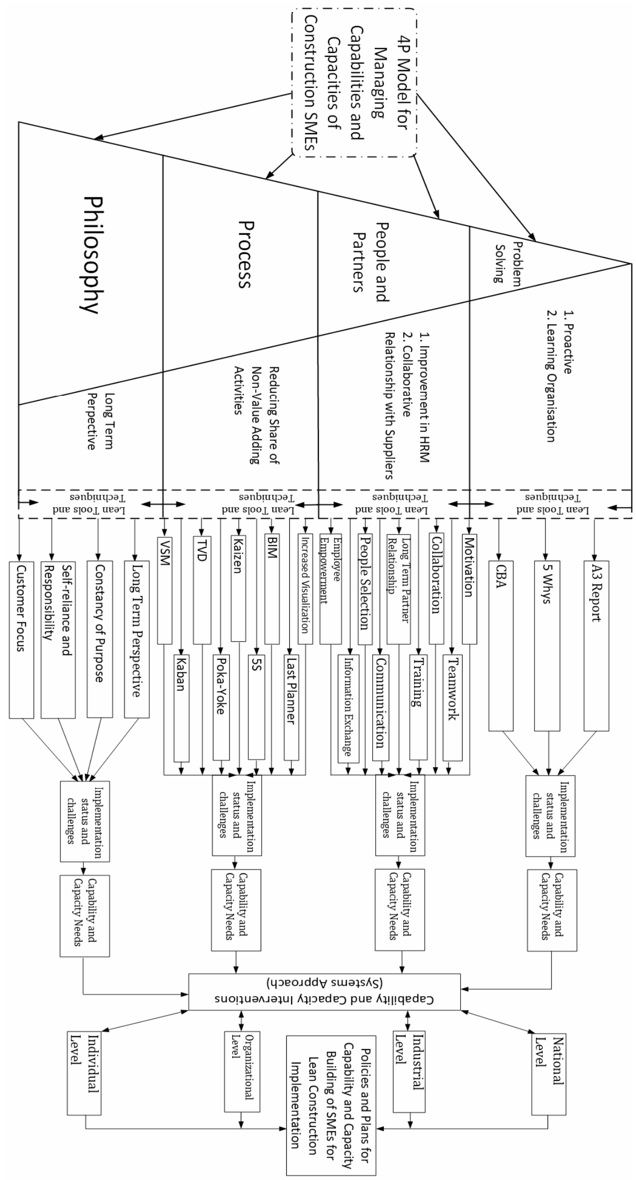

Figure 2: Conceptual framework for Capability and Capacity Building of SMEs

CONCLUSIONS

The growth of the SME sector for any country is of vital significance irrespective of its state of development. SMEs relevance and importance can be seen in all aspects of the socioeconomic lives of countries. Notwithstanding their contributions to the economies of countries worldwide, SMEs are faced with fundamental problems. This, in effect has led to widespread underperformance within this sector and a high attrition rate. LC as a management philosophy is acknowledged as an established set of principles to help organisations to be effective, efficient and maximize value to clients. Therefore, the adoption of LC within the SME sector is an important topic area to examine especially as there is a lower application. LC implementation within this sector is challenging, as these firms lack the needed resources to fully implement this management philosophy.

Several frameworks have been developed for an easy implementation of LC within this sector. Although these frameworks were developed specifically for this critical sector, it has largely overlooked the elements of capability and capacity building. A successful adoption of lean by construction SMEs will heavily depend on their capability and capacity for easy implementation. To overcome this gap this study has developed a conceptual framework for building the capability and capacity of Construction SMEs to fully adopt the LC philosophy. This will help reduce the high incidence of failure recorded in LC implementation. Eventually leading to an improvement in the construction industry as a whole, as SMEs form majority of firms. This study serves as a basis for an on-going PhD that aims at developing a framework for capability and capacity building of Small and Medium Building Contractors for lean adoption to enhance their performance.

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INTEGRATION ENABLED BY VIRTUAL DESIGN & CONSTRUCTION AS A LEAN IMPLEMENTATION STRATEGY

Leonardo Rischmoller[1], Dean Reed[2], Atul Khanzode[3] and Martin Fischer[4]

ABSTRACT

This theory paper probes the intersections of Lean, Mass Production and conventional Construction, Lean Construction, the Simple Framework for Integrating Project Delivery model, and Virtual Design and Construction (VDC). The authors argue that Toyota recognized that integration was necessary to achieve the goal of global optimization in design and production and that this imperative confronts Lean Construction today. They briefly describe the Simple Framework for Integrating Project Delivery as a system model to achieve the high level of integration required to deliver a valuable, high-performing building. Then they focus on how VDC fits within and enables the Simple Framework model, explaining each element of VDC and how project teams can leverage it to consistently deliver high-performing buildings.

KEYWORDS

Theory, production, Lean Construction, Simple Framework for Integrating Project Delivery, Virtual Design &Construction

INTRODUCTION

LEAN PRODUCTION ORIGINSAND THE CONSTRUCTION INDUSTRY

On Ford’s mass-production line, the assembler had only one task and did not understand what the workers on either side of him were doing. Speaking the same language as his fellow assemblers or the foreman was not required for the success of Ford’s system (Womack et al. 1990). There are many construction project sites in which contractors and

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subcontractors do not communicate much better than Ford's mass production assemblers. Furthermore, this fragmented scenario can also be observed to a big extent during the architecture and engineering hours spent designing a new construction project.

While at Ford's plants, the industrial engineer had to think about how all the parts came together as integrated systems, and just what each assembler should do within integrated processes, currently, to a big extent Project Managers and Superintendents play the roles of industrial engineers at construction jobsites, and also during project design stages.

LEAN PRODUCTION AND INTEGRATION

Integration was not explicitly mentioned in *The Machine that Changed the World,* when Jim Womack, and his co-authors argued that the Toyota Production System was really a new "lean" approach to production in which the work of all suppliers was integrated so that value flowed at the pull of the customer (Womack et al.1990). Integration was and is necessary for Toyota to achieve the "global optimization" required to deliver the value their customers were and are seeking. This is a significant leap beyond "local optimization "where individual contributors seek better outcomes for themselves, often at the expense of others (Forbes &Ahmed 2010).

"Lean" uses less of everything compared with mass production: half the human effort in the factory, much less manufacturing space, less investment in tools, many fewer engineering hours to develop a new product in half the time, far less than half the needed inventory on site, and near zero defects; all while producing a greater and ever-growing variety of products. Womack stated that this "less-than" approach calls for different management skills and applying these creatively in a team setting rather than in a rigid hierarchy, with a key objective of lean production to push responsibility far down the organizational ladder(Womack et al. 1990). This resembles the integrated organization idea introduced by Tillmann, Ballard, Tzortzopolous and Formoso (Tillman et al. 2012).

Fischer, Ashcraft, Reed and Khanzode went beyond Tillmann and her co-authors' idea of an integrated organization to the bigger idea of a system model, where each element depends on all the others and can consistently produce a high-performing facility(Fischer et al. 2014; Fischer et al. 2017).

INTEGRATION AS A LEAN STRATEGY

This paper proposes that in addition to the lean construction goal to maximize value and to reduce waste in order to "redefine perfection in construction" (Ballard &Howell 1998; Salem et al. 2005), integration, in this case enabled by Virtual Design & Construction, should be seen as a lean strategy, just as supply-chain integration was originally within the Toyota Production System.

THE SIMPLE FRAMEWORK FOR INTEGRATION

Building on the American Institute of Architects (AIA) "Integrated Project Delivery: A Guide" (2007) and on the organization / commercial terms / operating system model of IPD adopted by the Lean Construction Institute (Thomsen et al. 2009),Fischer, Ashcraft, Reed and Khanzode have explained that process knowledge, organization and information must be integrated to produce the highly integrated systems necessary for a high-performing building, which they define as usable, buildable, operable and sustainable. “A high-performing building can only be achieved through a building with integrated building systems, which can only be produced through an integrated process, which depends on an integrated team with the right people, which need integrated information, to function effectively and efficiently. Simulation and visualization are the primary ways in which BIM informs the integrated team. Collaboration and co-location are the primary ways to allow the integrated team to integrate processes. Production management methods enable the productive design, fabrication, and construction of the integrated building system. Outcome metrics define the performance of the building and validate the integrated building system. All of this is supported by the appropriate agreement or framework (Fischer et al. 2017; Ashcraft 2014).” Figure 1 shows these relationships in what Fischer, Ashcraft, Reed and Khanzode call “The Simple Framework for Integrating Project Delivery (Fischer et al. 2014).”

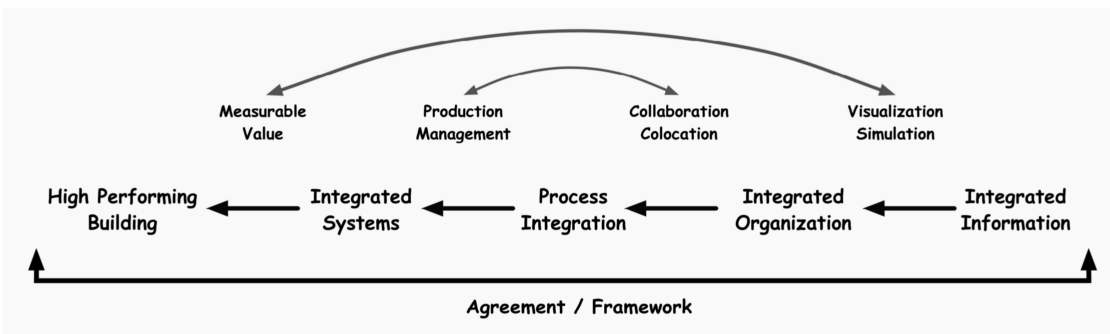

Figure 1: Simple Framework for Integrating Project Delivery(Fischer et al. 2017)

VIRTUAL DESIGN AND CONSTRUCTION (VDC)

VDC AS AN ENABLER OF INTEGRATION

Virtual Design and Construction or VDC was developed through research over the last two decades at Stanford University’s Center for Integrated Facility Engineering (CIFE) (Khanzode et al. 2006; Kunz & Fischer 2012). CIFE defines Virtual Design &Construction (VDC) as “the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organization of the design - construction - operation team in order to support business objectives.”

Based on their own direct observations and reports from practitioners, the authors believe that VDC is a very effective method for project teams to integrate their knowledge and create the information they need to integrate building systems. VDC is the main enabler of the Simple Framework model. The following are the main components of VDC.

BIM+

Building Information Modeling (BIM) has proven to be very useful for validating spatial relationships of components and systems performance (Hardin &McCool 2015). Combining BIM with time to produce 4D models, with cost data to estimate cost, or with lighting and energy data is what VDC researchers call “BIM+.”

Michael Schrage, wrote in 2000 about the rise and benefits of digital modeling media to create prototypes and simulations in companies like Toyota, Chrysler, Boeing, Hewlett Packard, Caterpillar, GE, etc. and how the value of a prototype arises from how much people learn as they create and test models collaboratively over time.(Schrage 2000).Project team members have observed this dynamic with BIM. Like Schrage, VDC states that the value of BIM resides less in the models themselves than in the interactions they invite. Building Information Models often reveal choices people must make, requiring trade-offs not apparent to them initially. Models don’t solve business problems, any more than mathematics solves equations. How models are used determines whether and how problems are solved (Schrage2000).

From the VDC perspective the proper question is not “How will this simulation or model solve the problem?” but rather “How will this simulation or model be used by the project team to solve the problem?” The authors believe there has been too much focus on the quality of the model and not enough on how using the model will change organization’s behavior.

Perfectly good models ignored because no one cares to work with them are underutilized investments that create only marginal value for the enterprise. If models can be made more accessible through techniques of simplification and visualization, without undermining their validity, they stand a better chance of being used by designers and builders rather than a relatively small group of BIM specialists (Rischmoller et al. 2017).

The proliferation of BIM tools can dramatically transform how the construction industry creates value for its customers. A corollary hypothesis is that an organization’s ability to create value now depends on its ability to use these tools effectively. From the VDC perspective, the business issue here is not only the challenge of better information or more effective knowledge management. It is how does the project organization’s way of modelling improve its ability to create value?

Project Production Management (PPM)

PPM is simply the application of operations science to projects by viewing them as temporary production systems. PPM focuses on organization and control of work activities in a project. It provides deeper quantitative and predictive theory on the achievable limits and design of work activities, validated by practice in several settings. The ability to model and simulate work activities to establish the limits of what is and is not theoretically achievable, as well as the ability to infer design criteria to optimize parameters such as throughput, work-in-process, cycle time and use of capacity lead directly to an improvement in cost, schedule and scope performance on projects (Shenoy 2017).

While Lean Construction is not a subset of Project Production Management, neither is Project Production Management a subset of Lean Construction (Shenoy2017), Lean

Construction, as envisaged in 1993, had several similarities with Project Production Management as defined by the Project Production Institute (PPI). Figure 2 below illustrates the historical evolution of PPM and Lean, emphasizing the operations science foundations of both PPM and Lean.

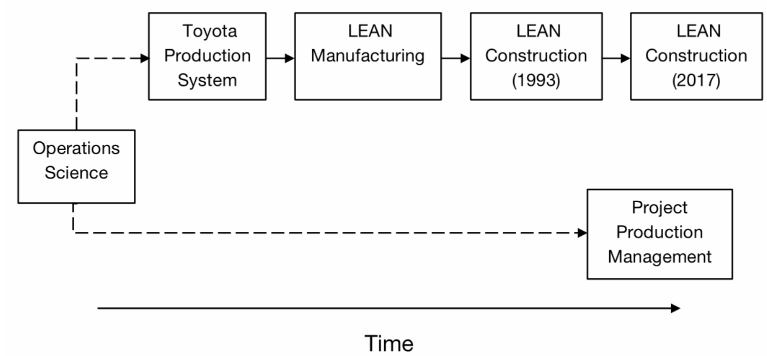

Figure 2 The Operations Science foundation underlying Lean and Project Production Management (Shenoy 2017)

However, over the ensuing 25 years, the concept of Lean Construction and that of PPM, as espoused by the PPI when founded in 2013, followed diverging paths. The core difference can be understood by asking how "system" is defined in "project delivery system" for Lean Construction versus PPM. Lean Construction increasingly focused on human factors, primarily project governance and organization of project stakeholders, whereas Project Production Management focuses on the configuration and organization of the physical work tasks that get performed in a project. Lean Construction has expanded its framework to cover issues of project governance such as contracts, integrated forms of agreement and organization of stakeholders, such as in the Lean Project Delivery System (Seed 2010).

VDC combines the focus on physical work activities in PPM and the human focus of present-day Lean Construction, and enhances both through the introduction of Integrated Concurrent Engineering.

Integrated Concurrent Engineering

Integrated Concurrent Engineering (ICE) is an approach that breaks the decades-long approach of working in isolation and coming together in meetings to report progress and problems. ICE combines engineering analysis and team communication and decision-making. This increases feedback within the design team, shortening design iterations and reducing wasted effort (Coffee 2006).

Based on careful observation of "Extreme Collaboration" methods by the NASA's Jet Propulsion Laboratory (JPL), CIFE faculty and researchers formalized and extended them as ICE, and then incorporated ICE into Virtual Design and Construction (Kunz &Fischer 2012). The productivity of ICE relies on a cycle of convergence in collaborative work sessions to share information, align understandings and coordinate action, followed by divergence for further study and testing, which is repeated until solutions are found for engineering problems. Whereas traditional meetings often suffer from vague meeting agendas, poor participant preparation, unclear logging of decisions made, and haphazard follow-up work, ICE sessions counter these challenges with a clear agenda with explicit objectives, well-prepared participants, and active problem-solving(Fosse et al. 2017).

The term "coordination latency," defined as the elapsed time between a request for information or action and meeting that request, is offered as a unifying, intuitive, descriptive performance metric, intended to reach a near-zero value as a project design goal (Chachere et al.2004). Coordination latency is reduced dramatically during ICE sessions.

ICE sessions use Building Information Models and simulations as instruments for introspection so that participants can learn from the conversations that otherwise wouldn't take place. Precisely because organizations are communities of people and not aggregations of data, the real power of BIM utilized in ICE sessions, comes from changing behavior as participants engage with their models. The transparency introduced by visualization and simulation promotes greater openness, which often forces people to re-examine how they should interact with each other. What should be shared? How safe is it to admit confusion or failure? What are the rules of engagement? Models aren't only essential for designing product and production processes, they enable collaboration (Schrage 2000).

During ICE sessions supported by BIM and the Lean principle of flow, not only is the time to get an answer shorter, participants can ask many more questions earlier. Although further research is needed to validate this intuition, the effect of integration enabled by ICE as a key component of VDC on the timing and number of questions asked, and response latency may be significant. Figure 3 shows a simple two-by-two matrix for evaluating the effectiveness of VDC and Integrated Project Delivery (IPD) compared to traditional practice.

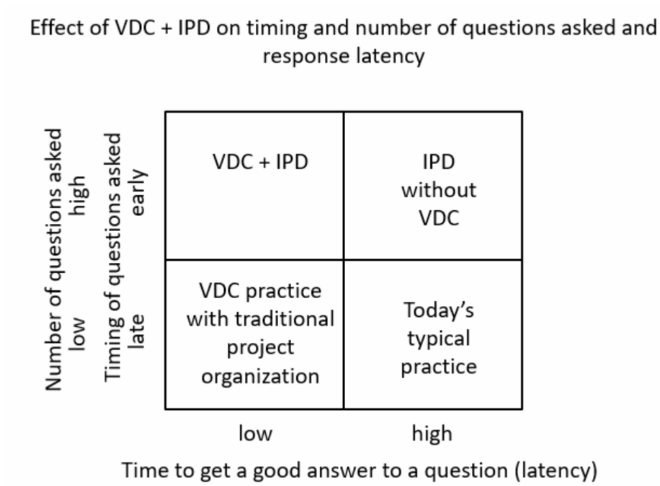

Figure 3: Questions and answers with VDC vs. traditional practice

Client Goals and Project Objectives

Many owners want to optimize use and sustainability while reducing lifecycle operating costs such as building maintenance, building operations, and business operations, along with first cost to construct. However, traditional practice focuses primarily on designing a building primarily for lowest construction cost and fastest delivery. Project objectives and client objectives are not aligned (Evbuomwan & Anumba 1998; Fischer et al. 2017).

The purpose of VDC is to solve business problems. Project objectives must support client goals. If sustainability and lifecycle cost are goals, they must not be left to chance. The Simple Framework model requires project teams to determine objectives where total cost and building performance must always be considered together. The facility must be useable, buildable, operable and sustainable. Figure 4 shows the relationships between client goals and project objectives enabled by VDC within the Simple Framework model(Fischer et al. 2017).

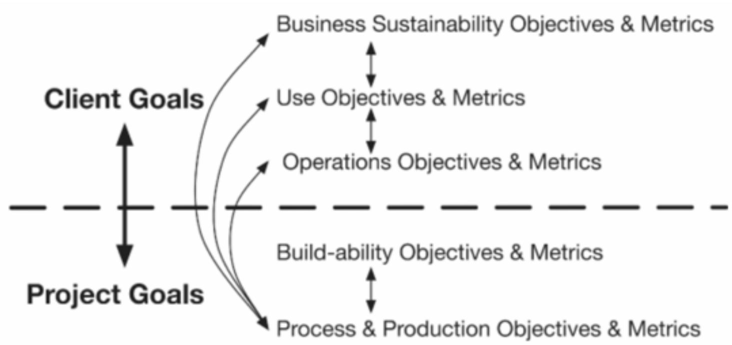

Figure 4: Client and project goals and objectives (Fischer et al. 2017)

The Simple Framework stipulates that a highly valuable building can be created when project objectives support specific, clearly defined client goals for a high-performing building. In this way VDC and Lean intersect at their common starting points of delivering the greatest possible value.

Metrics

Through measurement, a team can gain control over how to achieve the objectives of a project (Shawn et al. 2004). The project team must translate client goals into use, operation and sustainability performance metrics along with those for safety, quality, schedule and cost to measure buildability (Fischer et al. 2017; Rankin et al. 2008).

Economic objectives include metrics for first and lifecycle cost. Environmental goals include metrics like habitat availability for plant and wildlife, storm water retention capacity, carbon dioxide (CO2) emissions over the lifecycle or in a particular project phase, and similar considerations (Kent & Becerik-Gerber 2010). Besides safety during construction, social goals may include development of human capabilities, construction workforce diversity, and community interaction and support. Some objectives can be measured while others are assessments.

VDC practice goes beyond project outcomes, which are lagging reports after the fact. The most useful metrics are leading and focused on factors team leaders believe are important such as meeting participation, number of innovations proposed, the extent of BIM use, and the number of jointly agreed quality acceptance criteria. Establishing metrics is the first order of business once project and work process objectives are decided.

VDC IS INTEGRATED

VDC occurs when its components are part of an integrated approach rather than being used in isolation. For example, it is common to find BIM and Lean areas or departments in projects and companies. If people in these two areas or departments work in isolation from each other, we cannot say that VDC is being applied. Figure 5 shows the relationships between VDC elements, making the point that it is not enough to adopt each of its components in an isolated way. BIM+ and PPM jointly support collaboration during ICE sessions which are intended to achieve metrics aligned with project objectives supporting client goals.

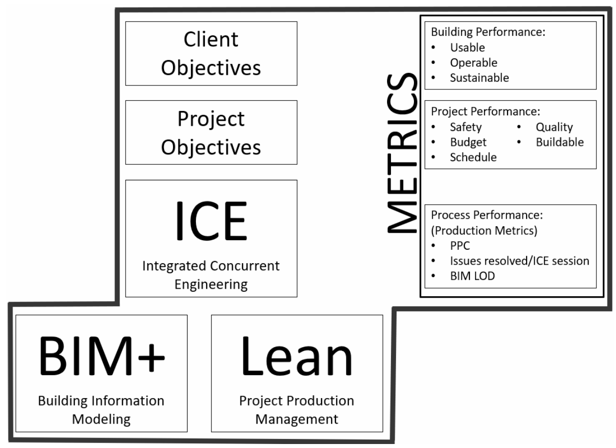

Figure 5: Virtual Design & Construction as a set of integrated elements

VDC AS ENABLER OF THE SIMPLE FRAMEWORK

VDC functions as a subsystem enabling the integration of knowledge, organization and information required to produce the highly integrated system making-up a high-performing building. VDC is the way project teams work to deliver the value their clients are seeking. Figure 6 shows VDC as the enabling upper tier of the Simple Framework.

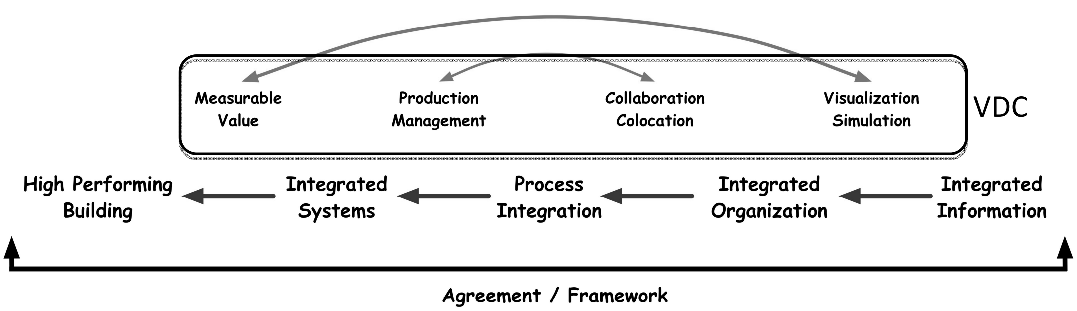

Figure 6: VDC enabling the Simple Framework

CONCLUSIONS

Lean is making value flow at the pull of the customer. This requires global optimization, which requires integration of the supply chain. There is no choice. The Simple Framework for Integrating Project Delivery describes four integrations required for project teams to consistently delivery high-performing buildings, defined as usable, buildable, operable and sustainable. The Simple Framework has two enablers. The first is an agreement of parties on financial terms, responsibilities, and governance that allow them to build trust, so they can collaborate for the good of the project. The second enabler is Virtual Design and Construction, which is a method for solving complex design and construction problems. VDC requires people to collaborate to reach measurable objectives they establish. It is integrative by nature and can be learned and mastered. Everything people do within the VDC framework allows them to integrate systems, processes, their organization and information so they can deliver high-performing buildings.

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WHY VISUAL MANAGEMENT?

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ABSTRACT

From early on, visual management (VM) has been an intrinsic ingredient of the Toyota Production System (TPS) and its derivatives like lean production. Akin to the evolution of most other parts of the TPS, it has been developed through practitioner efforts rather than being propelled by theoretical insights. Recently, scholars have started to create a theoretical knowledge base for VM. Besides taxonomies of visual devices and their functions, there is only one fully fledged theory of VM, based on the concept of affordance. It is contended here that the scholarly field of visual management has been too narrowly defined. In fact, research on (or bearing on) visual devices has been carried out in several other, mostly small fields, often with little mutual awareness. A review on the theoretical explanation of VM is provided, based on this wider literature. The concept of affordance has been used in this context already in early 1990s. This focuses attention especially to the human cognitive capabilities and corresponding features of visual devices. Generally, VM is argued to provide a more rapid and reliable mode of communication in comparison to traditional alternatives. VM is thus compatible with the lean tenets of time compression and variability reduction. This explains its central role in lean production.

KEYWORDS

Visual management, lean production, cognition

INTRODUCTION

From early on, visual management (VM) has been an intrinsic ingredient of the Toyota Production System (TPS) and its derivatives like lean production. Akin to the evolution of most other parts of the TPS, it has been developed through practitioner efforts rather than being propelled by theoretical insights. Recently, scholars have started to create a theoretical knowledge base for VM. One reason for the attention to theory has been the insight that design guidelines for visual devices are badly needed (Valente & al. 2017), and theoretical knowledge is necessary for creating such guidelines.

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Besides taxonomies of visual devices (Galsworth 1997) and their functions (Tezel & al. 2009), there is only one fully fledged theory of VM, developed by Beynon-Davies and Lederman (2017). Thus, it would be tempting to hold their statement true: "there is little theorisation of how the visual device provides value to the wider system of operation". However, this statement can be challenged. It is contended here that the scholarly field of VM has been too narrowly defined. In fact, research on (or bearing on) visual devices has been carried out in several other, mostly small specialized fields, often with little mutual awareness. Insights relevant on VM can be found in Cognitive engineering (Wilson & al. 2013), Human Factors engineering (Wickens & al. 2014), Healthcare informatics (Xiao 2005), Human-Computer Collaborative Work (Maher & al. 1996), Information visualization (Eppler & Bresciani 2013) and management studies into the visual (Bell & Davison 2013).

In this paper, a review on the theoretical explanation of VM is provided, based also on this wider literature. The aim here is neither to build a theory of VMnor to discuss VM in any particular industry, but to pinpoint to phenomena and theories that seem promising and useful, both for theorising and for practical implementation. The paper is structured as follows. The next section introduces the recent affordance theory of VM and presents critical remarks on it. Then, further ingredients for theorising on VM are presented, inspired by the wider literature. The paper is completed by conclusions.

AFFORDANCE THEORY OF VISUAL MANAGEMENT AND ITS CRITIQUE

AFFORDANCE THEORY OF VISUAL MANAGEMENT

As far as it is known, the only major attempt to theorise on VM is the suggestion of Beynon-Davies and Lederman (2017) to use the affordance theory as an explanatory lens. Affordance theory was presented by Gibson in 1977.The basic idea is that an affordance is what the environment provides for a human or an animal[4]. These, in turn, require compatible effectivities, in the form of cognitive or action capabilities. In Beynon-Davies' and Lederman's (2017) encapsulation, "an affordance is an opportunity for action made possible both by the effectivities of the actor and by structures in the environment". Based on an examination of practical cases, they define three layers or domains, i.e. (a) articulation, (b) communication and (c) coordination, connected by the affordances of the visual devices. It is recognised by Beynon-Davies and Lederman (2017) that the definition of affordances by Gibson is not sufficient for covering what happens in VM. Thus, they distinguish between first order affordance, i.e. how the articulation of physical objects allows communication, and second order affordance, which connects communicative action with coordinated work actions.

[4] However, the affordance theory is not the first endeavour to characterize the interaction between living organisms and their environment. Already 1926 von Uexküll presented his theory on the world of living organisms, *Umwelt*. Arguably, the essential ideas of affordances were present.

Beynon-Davies and Lederman (2017) crystallize their explanation of visual devices within wider visual systems into four features: (1) These systems involve the use of material and typically highly visual(tangible) artefacts for information purposes; (2) The physical manipulation of such artefacts in relation to each other is important to informing actors within group work; (3) The overall state of the physical environment in which such manipulation takes place is also important to informing actors; (4) The manipulation of physical and visual artefacts is important to support situated choice.

Based on their theoretical work, Beynon-Davies and Lederman (2017) present five prescriptions for developing VM – unfortunately a short summary cannot convey the full depth of these: (1) Visual devices should be thought as multimodal, thus utilizing all senses; (2) Visual devices should be thought of in terms of facilitating action-taking; (3) Physical structures such as whiteboards should be thought as performative structures (how to communicate and what work would result from such communication; (4) The designer of VM should not consider an individual device but should consider the whole physical environment; (5) Patterns of action should be thought of either *as-is*, *as-if* or *to-be*(this essentially refers to embracing current status, targeted status and change in development of visual management).

CRITICAL DISCUSSION

The affordance theory is a valuable advance in understanding visual management. Unfortunately, it falls short in several respects:

- The discussion is centred around collaborative devices of VM; these are important but leave the similarly important types of visual devices addressing individual work aside.
- The theory does not explain why visual management is preferred in some approaches to management, and not paid attention to in other approaches.
- The term affordance is at a high level of abstraction; according to Gibson (1979), it is "something that refers both to the environment and the animal", "it implies the complementarity of the animal and the environment". It may give an illusion of explanation although it does not detail what precisely is the nature of complementarity, say in terms of characteristics of an artefact and cognitive abilities of the actor.
- The theory is not comparative: as such, it has limited practical use as it does not clearly describe which types of situations or work actions would benefit from VM devices.
- The development of this affordance-based VM theory did not take into account that there has been an approach based on affordances since early 1990's, namely Ecological Interface Design (Vicente & Rasmussen 1990).

FURTHER INGREDIENTS TO THE THEORY OF VISUAL MANAGEMENT

Our starting point is that VM requires a multi-faceted and multi-level theoretical explanation. We do not attempt to present a fully developed theoretical framework here but rather provide examples of viewpoints and domains that will be relevant in the further consolidation of the theory of visual management.

DIRECT AND RAPID ACCESS TO INFORMATION

Beynon-Davies and Lederman (2017) state, without further justification: “Affordances have the potential to be perceived directly by actors without any intermediate, conscious, cognitive processing.” Similar statements can be found from books on VM by practitioners. How can this be explained?

We contend that the question about the existence of two modes of cognition, discussed long since. It is appropriate to start from the discussions on left and brain brain-halves. For example, Springer and Deutsch (1993) give a neurologically justified (in that time) view on these:

- Left Hemisphere: Verbal; sequential; temporal, digital; logical; analytical; rational; Western thought
- Right Hemisphere: Nonverbal; visuospatial; simultaneous; spatial; analogical; Gestalt; synthetic; intuitive; Eastern thought

Afterwards, along with evolving methods to research the brain, it has been realised that this view is too simplified. However, the basic idea of two different modalities of brain functions remains. A popular interpretation is given by Kahneman (2011), who describes two systems of the mind:

- System 1 operates automatically and quickly, with little or no effort and no sense of voluntary control
- System 2 allocates attention to the effortful mental activities that demand it, including complex computations. The operations of System 2 are often associated with the subjective experience of agency, choice, and concentration

The importance of allocating a given information requirement to either of these systems is illustrated through the following quote, where the issue is approached through cognitive engineering (Hettinger, Roth & Bisanz 2017):

> Cognitive work requirements take the form of questions a user must be able to answer ‘at a glance’ without needing to traverse multiple screens, perform mental calculations, or integrate disparate pieces of information […]. Detailed information and display requirements are then specified to satisfy the cognitive work requirements.

Broadly, it can be stated that visual information is captured by System 1 and comprehension of written information by System 2. Images can be recognised in 13milliseconds (Lewis 2014), while an ordinary reader will read 200 – 230 words per minute (3 – 4 words per second). Thus, there is reason to believe that visual management shows sheer superiority in terms of the speed of the capture of a conveyed message in comparison to arrangements where messages are written or oral. However, currently there is hardly any empirical evidence on this performance difference specifically acquired from a VM context. Likewise, there is little research comparing different designs of visual devices regarding speed of capture (which of course is only one of thecriteria to study).

RELIABILITY IN COMPREHENSION

There are many indications showing that reliability of the comprehension of the messages in VM is an important characteristic. For example, visual devices have been classified according to the level at which they constrain action, in other words, reliably lead to the correct action (Galsworth 1997). At the highest level of reliability are fool-proof mechanisms, *poka-yoke*, which usually are not dependent on human senses but operate through physical implements[5]. Further, indirect evidence is provided by the fact that VM has persistently been used in contexts requiring high reliability, such as air traffic control, healthcare and generally in high-reliability organisations.

Again, visual messages can be compared to written messages. Reading is dependent on decoding the written words, and capturing their meaning (comprehension). Regarding both decoding and comprehension, considerable performance variation is reported already in university student population (Landi 2010).As discussed above, capturing the meaning of an image is more direct, which as such reduces the potential for mistakes. In the context where VM is used, the visual images and symbols are well-known (except for novices), which again reduces the proneness to mistakes. The hypothesis that VM leads to higher reliability has broad justification, but specific empirical studies are missing.

PROJECTION OF INTERNAL MENTAL MODELS: SPRACTION

In air traffic control, the controllers have in the past written basic information regarding each flight on a paper strip. Then, for example, the order of approaching flights is indicated by the order of the strips on a rack tailored for this purpose. There have been various attempts to computerise this work process, but the controllers have often persisted with these manual methods. Why so?

In closer examination, it has been found that by organising the strips, an air traffic controller is projecting his internal mental model into a physical artefact. In turn, this physical artefact works then as an aide-memoire for her (MacKay 1999):

> Controllers report that they develop a rich mental image of the traffic during the course of a session. The current strip set up reduces the controller's mental load, allowing them to retain only the important details, since the rest of the information is always instantly accessible in front of them. The physical strips can be viewed as a concrete component of their mental representation, helping them handle more information and successfully deal with interruptions.

However, physical direct action is an indispensable element in this cognitive process; MacKay (1999) describes:

> Most controllers, when taking over a control position, physically touch each strip, rearranging some of them. Reordering the stripshelps controllers mentally register the new traffic

[5] The question arises why*poka-yoke* should be discussed as part of visual management. The terminology is not settled in this area. The term “visual controls” is often used narrowly, to refer only to visual devices. However, in the literature, “visual management” is often used as a short-hand for communication also through visual and other senses (Tezel & al. 2016). Mechanical, electronic and other poka-yoke devices, not based on sensory perception, are also included (Galsworth 1997).

> situation. In each case, it is the act of rearranging the strips, more than the final layout, that is important.

And further (MacKay 1999):

> Controllers sometimes use both hands together, sliding them down both sides of the strip board as they review the set of flights or look for a particular flight. They usually stop, resting a finger on the relevant strip. Student controllers can be observed "thinking out loud with their hands" as they touch each individual strip involved in a particular conflict.

What is happening in this process can be understood through the theory developed by Tversky (2011, 2015).She argues that when thought overwhelms the mind, the mind puts it into the world, in diagrams or gestures; a thought is projected into the world. Thus, human actions organise space to convey abstractions; she calls this *spraction*. Physical action is thus seen as a direct extension of thinking. Thus, creating or interacting with a model through the computer cannot substitute this integrated mental-physical act of spraction.

Other examples of spraction include the physical boards used in healthcare to plan the occupation of beds in a ward (Xiao 2005). In the sphere of construction, the practice of collaborative planning, with stakeholders positioning tasks marked on Post-it notes into a timeline on a paper attached to the wall, represents likewise this phenomenon. Also sketching and model-making in design arguably represent spraction.

MATCHING VISUAL DEVICES WITH DIFFERENT COGNITIVE/ACTION CAPABILITIES

The SRK taxonomy, developed by Rasmussen (Vicente & Rasmussen 1992) in terms of an affordance based approach called Ecological Interface Design, originally for industrial process plant control, refers to skill, rule and knowledge based response of operatives in a work situation. A skill based response is automatic, triggered by the perception of a need for action. A rule based response requires a selection of a rule compatible with the situation, and its implementation. A knowledge based response is needed in a surprising/rare situation, where the background knowledge of the operative on the process needs to be mobilised for problem solving.

The SRK-model contains design guidelines on the user interface of process control regarding the different responses. One design rule is to encourage the use of skill and rule based behaviour when possible, to save on scarce cognitive resources.

Arguably, in the practice of visual management systems, it has been possible to create support to all three types of responses: (1) For skill based responses, visual devices that directly trigger the needed action (like a reflex) are preferred; (2) For rule based responses, the relevant rules are provided for immediate inspection, say through One Point Lesson displays; (3) For knowledge based responses, standardized problem solving methods, such as the A3 method, are utilised.

COMMON GROUND, SITUATIONAL AWARENESS AND SHARED UNDERSTANDING

Common ground

A widely-knownpiece of classical rhetorical knowledge concerns “common ground”, the shared values, facts and presumptions between the orator and the audience. This concept, seminally presented by Aristotle, has been re-discovered and generalised several times in more recent times.

Clark and Brennan (1991) contend that in communication, common ground cannot be properly updated without a process they call grounding. For example, grounding can take the form of referring to objects and their identities, through say, indicative gestures, such as pinpointing. Klein et al. (2005) extend the discussion on common ground to joint activity and related team coordination. The mentioned authors have further studied the loss of common ground, and list a number of mechanisms leading to that. One type, confusion on who knows what, is occurring so frequently that it has been named as Fundamental Common Ground Breakdown (Klein et al. 2005).

Situational awareness

Situational awareness can be defined as the capacity to perceive and comprehend the characteristics of an environment within time and space supporting the realisation of predicted futures aligned with a task or project (Koskela & al. 2016).

Shared understanding

Shared understanding of the problem is a concept emerging from studies on design teams (Cross and Cross 1996, Maher et al. 1996). It has been found that design teams spend a lot of effort to reach shared understanding of the problem, and to manage conflicts based on different interpretations of ideas, concepts and representations.

Visual management supporting common ground, situational awareness and shared understanding

The relation of visual information and common ground has recently started to be studied (Kraut et al. 2002). Research shows that visual information supports conversational grounding (Gergle et al. 2013). Methods of VM seem often to be geared towards the creation of common ground. Especially, the practice of the Big Room (*obeya*) seems to be a paramount means towards creating a broad and solid common ground in product development or facility design.

Especially, public displays seem effective for avoiding the Fundamental Common Ground Breakdown and creating situational awareness (Xiao 2005):

> …the public display of assignments provides a way for individuals or teams to visualize current team activities and resource availability, so that everyone knows what everyone else knows about resource status.

In the area of (general) management, business model canvas, a standardized visual way of presenting a business model has recently been advanced (Osterwalder & Pigneur 2010). Based on this idea, templates for project model canvas and life cycle canvas have recently been developed (Medeiros 2017). All these canvases seem to promote the creation of common ground and shared understanding.

The role of Building Information Models (BIM)in creating common ground and shared understanding has recently been addressed[6]in the literature. Miettinen and Paavola (2016) comment on one-day design meetings where the model has been projected on a screen on the wall – this can be compared to the description of grounding above:

> They discussed the design problems in various places in the building to be constructed by zooming in and out of the combined model and pointing at locations on it. A prominent feature of these meetings was the frequent use of indexical signs during the discussions. The participants indicated those places in the plans that were problematic using the cursor, with indexical utterances, with their hands andby zooming in and out and moving the model.

AVOIDING VISUAL OVERBURDENING

The method of 5S has been presented as part of visual controls. This Japanese method achieves organisation of the workplace through cleanliness, rejection of unneeded items, and order. How can this be explained?

Based on their review of literature, Jackson and Calvillo (2013) conclude that high perceptual load increases response time, narrows attention, and increases error rates. Johnson-Laird (2010), a leading scholar in psychology, claims that irrelevant visual detail impedes reasoning: “Images impede reasoning, almost certainly because they call for the processing of irrelevant visual detail.” Spagnol, de Campos and Li (2015) report a study on brain activation during different levels of 5S application. The findings show significant increased brain activation in the last task (at the highest level of application) when compared to the first, suggesting that 5S facilitates brain pathways for information processing. Maeda’s (2006) call for simplicity resonates with the views and results just presented.

Thus, there is evidence suggesting that absence of irrelevant visual detail, resulting from the application of 5S, facilitates the direct capture of relevant visual information and reasoning involving visual data.

CREATING ADHERENCE

In VM, the abstract concept of discipline is transformed into directly observable concrete practices (Mann, 2005). In view of this, VM can be seen as visual rhetoric, targeting adherence by the audience (Koskela 2015).

The theory of production shows that the reduction of variability (uncertainty) is, at the end, the single most important means against waste. Thus, adherence to standards for work and its outputs is paramount. The objective of rhetoric is precisely to create adherence. This connection offers the opportunity of making the rich legacy of rhetoric to bear on understanding and designing VM. What is needed is research identifying, trying out and evaluating rhetorical principles and their efficiency in VM.

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[6] Visual management is usually based on tangible artefacts. BIM represents the new trend towards information technology based visual management (Tezel & Aziz 2017).

WHY IS VISUAL MANAGEMENT PREFERRED IN SOME MANAGERIAL APPROACHES AND NOT IN OTHERS?

VM is much associated to lean production. There are instances of VM in other fields, such as healthcare and air traffic control, but they are seen as exceptions and there has been a long-standing tendency to replace tangible visual devices by computer systems and displays and screens. How can these split views be explained?

Lean production is an approach that puts production to be at the centre of the organisation; organising is structured to facilitate the achievement of goals related to production. Reduction of waste requires reduction of cycle times and variability. Mental operations, such as communication and decision-making are strictly seen waste in production; they are not adding value to the customer. Through VM, communication and decision-making can be sped up. On the other hand, the higher reliability of VM translates into lower variability. Thus, VM has emerged as an intrinsic part of lean production as it is compatible with its first principles.

Regarding then the mainstream approach to management and organization, the crucial factor is that since the 1960s, production as a phenomenon has been pushed outside these fields (Koskela 2017), and thus the operational benefits of VM remain invisible. This might explain the lack of interest in these fields.

CONCLUSIONS

If anything, the reported explorations towards theoretical foundations show that visual management is at a fascinating crossroads of different phenomena, and of disciplines, old and new, addressing them. Several angles and levels will probably be needed for creating a practically complete theoretical account of visual management. However, already the existing crumbles of insight are useful and pinpoint direction, both for empirical research, development of design guidelines, and practical development.

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VALUE FOR WHOM?

Frode Drevland[1] and Patricia A. Tillmann[2]

ABSTRACT

Designing, building and optimising projects as production systems producing value can be said to be the aim of construction management from an engineering perspective. However, the question is whose value are we optimising the system for? The lean philosophy tells we should deliver value to all the projects customers. However, here anyone that is impacted by the project is considered a customer, not just the paying client. Do all customers matter and is delivering value for all of them of equal importance?

In this paper, we explore this matter by first looking into the literature on stakeholder management. Finding no suitable answers there we attack the question by considering the motivations for delivering value by a literature review and interviews with industry professionals. Finally, we discuss the implications that considering the perspective of multiple stakeholders brings to project management.

The paper argues that the key to deciding whose value matter lies in understanding the motivation for why valueis delivered. However, to what degrees different factors motivates someone will be highly dependent on their philosophical outlook, thus making the matter of value for whom a philosophical question.

THE CONCEPT OF VALUE

KEYWORDS

Lean construction, value, theory, value philosophy, stakeholder management

INTRODUCTION

Engineering can be said to befocused on systems, how to design, build and optimise them. Within the lean construction community, projects are consideredproduction systems (Koskela and Ballard 2006) and that the goal of these production systems is to deliver value (Emmitt et al. 2005). Thus, we would argue the natural focus of construction management is to support the delivery of value from projects. However, there is acritical question that needsan answered in this context: if valueis subjective or particular

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(Bertelsen and Emmitt 2005; Drevl and and Lohne 2015; Holbrook 1998), then whose value are we considering when optimising the system?

The standard answer in lean is that we should deliver value to the customer. Here, however, customermay refer not only to the paying client but also to everyone who is in any way impacted by the project. In other words, the term *customer*is closely related to what the general project management literature refers to as a *stakeholder*. According to the Project Management Body of Knowledge, a stakeholder is "an individual, group, or organisation, who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project"(PMI 2013).

Construction projects produce massive land bound products. On these projects, many stakeholders are involved, including different local, state and federal government departments, non-governmental organizations, private companies, and the community. This intricate network of stakeholders often results in requirement conflicts and need to spend some effort managing trade-offs and the expectations of different groups of stakeholders involved (Tillmann et al. 2011). Even though past research has identified that stakeholders with conflicting requirements are a challenge to project management practices in construction, there is a lack of reflection (with theoretical support) on why these challenges exist and what is the implications for value generation. Whose value matter?Is value for all stakeholders of equal importance? If we want to deliver value through our projects, then answering these questions is a fundamental step.

Whose value matters have been discussed by several authors in the IGLC community(Bertelsen and Emmitt 2005; Drevland and Svalestuen 2013; Pasquire and Salvatierra-Garrido 2011; Salvatierra-Garrido and Pasquire 2011), however, there exists no collective agreement regarding the issue of whose value matter, or even if value for different stakeholders should have the same weight.This paper explores stakeholder theory and motivations for delivering value and present the argument that there is no one prescriptive solution to the matter to be found, as the question of value for whom is at its core matter of philosophy.

THE CONCEPT OF VALUE

Before we address the question of value for whom, we find it necessary to first define value as a term. Value is an ill-definedconcept without any commonly agreed upon definition(Drevland and Lohne 2015; Salvatierra-Garrido et al. 2012; Thyssen et al. 2010).The most common definition of value in the construction project literature is that value the relationship between what you*give* and what you*get*(Kelly et al. 2004). However, many conflate the termvalue with benefits (Drevland and Lohne 2015; Laursen and Svejvig 2016). In this paper, our understanding of value is by Drevland and Lohne (2015). They give a comprehensive, but rather a lengthy definition of value, however, the essence of it is that value is the result of an evaluative judgment of what someone get and what they give. The value will be different for each stakeholder based on their judgment of the get and give factors that matter to them.

METHOD

We have done this research on founded on the pragmatic research paradigm, where truth is notsomething that is entirely objective, like in positivism, or entirely subjective, like in constructivism, but rather a matter of useful belief (Rorty 1999).

Our first step was to do a scoping study, as described by Arksey and O'Malley (2005), to identify relevant literature in the field of stakeholder management. When it became evident that the literature here could not adequately answer questions at hand, we started looking at motivations for why actors deliver value and expanded the scoping study accordingly.

In addition to the scoping study, we supplemented with data from two-case studied that was carried out in research done by the authors parallel to this research. Both cases were hospital projects. One Lean-IPD project located in San-Francisco and one more traditional design-build located in Tromsø, Norway. Data gathering was done using semi-structured interviews according to Robson (2002). We interviewed a total of 14 practitioners serving in different roles on the projects (owners, project managers, architects, engineers and contractors.

STAKEHOLDER GROUPS

Oke and Aigbavboa (2017) reviewed several different construction-related studies that identified stakeholders with direct and indirect links to project construction, and summarised that:

> *"Typical stakeholders in the construction industry include the following, among others: client, owner, sponsor, financier, principal contractor, trade contractor or subcontractor, material supplier, subcontractor, architect, quantity surveyor, employee, engineer, archaeologist, sustainability consultant, development manager, local government, national government, design coordinator, regulatory agency, managing director, technical director, conservationist, environmentalist, project manager, area manager, builder, construction manager, project manager, land surveyor, estate surveyor and other specialist consultants. Others are client's customers, client's employees, client's tenants, client's suppliers, local residents, and local landowners among others."*

Although Oke and Aigbavboa (2017) provide a starting point to understand the stakeholders in a construction project, their classification does not make a distinction among the different levels of influence they might have on defining value. Furthermore, given the way construction projects are organised, such classification does not help us understand how to group these stakeholders. For example, an engineer could be an employee of a contractor, sub-contractor, specialist-consultant and manyothers on that list.

Rather than relying on existing classification of stakeholders, we have chosen to define stakeholder groupings as shown in Table 1.The basis for this has been which groups we have found useful to distinguish between to discuss the matter at hand.

Table 1 Stakeholder groups

Stakeholder groups	**Description**
Owner	Person or company who initiates and finances the facility, and takes ownership of it at the end to useit themselves, renting it out or selling it.
Tenants	Person or company that rents the entire or parts of the facility from the owner
Users	People who in some way interact directly with the building, i.e. people who work in and visit the facility for any purpose
Financial institution	Organizations who have a vested interested in the facility by financed or insured it
Neighbours	Anyone directly affected by the facility in its surrounding areas
Society at large	The general public and society as a whole. Typically represented by government institutions.
Designers	Architectural and engineering firms responsible for the design of the facility
Builders	Contractors and others responsible for the building the physical facility on site
Suppliers	Anyone providing parts or materials

In Mitchell et al. (1997)'s seminal typology of stakeholders, there are three attributes which are used to classify stakeholders

- **Power–**Stakeholders ability to impose on the project
- **Legitimacy-** Legitimate relationship with the project
- **Urgency** - The degree to which stakeholder claims call for immediate attention

In the context of projects and value delivery, we posit that urgency is here a matter of receiving some value from the project, be it positive or negative. I.e. a stakeholder whose value is not impacted has no urgency. Furthermore, we posit that stakeholders with a legitimate relationship are those that have a formal relationship with the project, either contractual or regulatory.

The three binary categories combined yields seven different categories of stakeholder as shown in Figure 1. However, we would argue that in the context of value delivery, only the stakeholders whose value matter are of interest, i.e. stakeholders with urgency. Thus, the stakeholder categories with no urgency can be ignored, leaving us with:

- **Demanding stakeholders**havean urgent claim but no power and legitimacy.
- **Dependent stakeholders** have the urgency and legitimacy but no power.
- **Dangerous stakeholders** lack legitimacy but possess power and urgency.
- **Definitive stakeholders** possess all of the three attributes.

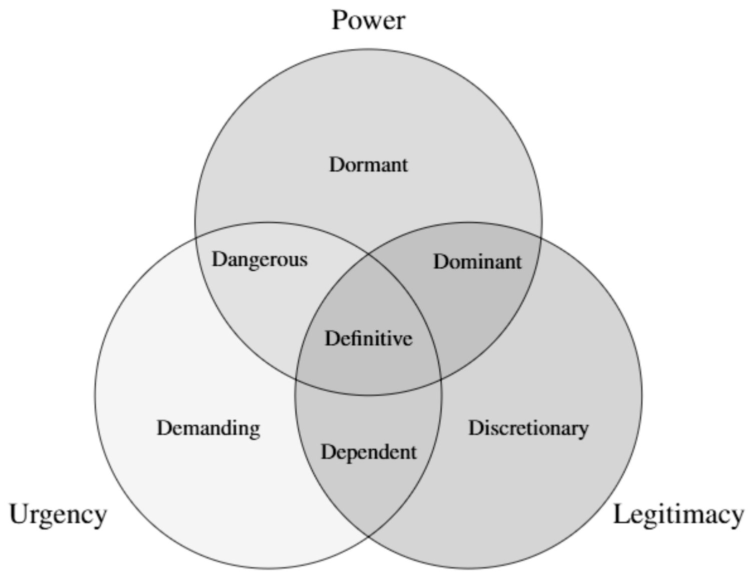

Figure 1: Stakeholder typology (based on Mitchell et al. 1997)

MAPPING STAKEHOLDER GROUPS TO CLASSES

Based on the previously presented stakeholder groups and Mitchell et al. (1997)'s stakeholder typology, we created a mapping between them as shown in Table 2.

Table 2 Stakeholder groups mapped to classes

Stakeholder group	Definitive	Dependent	Dangerous	Demanding
Owner	X			
Tenants		X		
Users		X		
Financial institutions		X		
Neighbours		X		X
Society at large	X			X
Designers	X			
Builders	X			
Suppliers		X		

The owner is arguably *the* definitive stakeholder, being the one who usually would have the most legitimacy and urgency and wields the most power in the project. While tenants, users and financial institutions can all be said to have legitimacy and urgency, yet they cannot impose directly on the project, but instead are dependent on the owner's power.

Neighbours similarly do not have any power on their own, but instead are reliant on the government institutions of society at large. Their legitimacy will depend on what rights they have through laws and regulations, and thus will be either dependent or demanding.

Society atlargeis both a definitive and demanding stakeholder. It has significant legitimacy and wields considerable power in those areas society has decided should be governed by laws and regulations. However, society at large will have interests beyond what is strictly regulated and governed. Arguably, the rules and regulations put in place by societyare to prevent harm to be done to it, not to ensure that good is done. Furthermore, while this might hold true for well-regulated countries in the developed world, the situation in developing countries will be different. Therefore, to which degree society at large is a definitive or demanding stakeholder will vary significantly depending on the context of the project.

Designers and builders, having a contractual agreement will have legitimacy, urgency and power and should, therefore, be considered definitive stakeholders as groups.

Suppliers typically do not have a direct relationship with the project, but rather through the designers and builders and can thus be considered dependent stakeholders.

ARE POWER AND LEGITIMACY ALL THAT MATTERS?

We would argue that stakeholder theory, can be helpful in determining who might want to influence the projects, their ability to do so and their interests. It does, however, little in helping in deciding whose value we should care fore, beyond the need to appease those with power. For example, Mitchell et al. (1997) argue that Demanding stakeholders are pure noise that should be ignored until they acquire either power or legitimacy. However, we do not believe that this sentiment holds true in the construction industry. Architects and engineers tend to have a desire to serve the greater good, and not just the paying client. Therefore, rather than starting by considering who has the power to determine what value to deliver, we argue it is more fruitful to begin by looking at the motivation for *why* different actorsdeliervalue.

WHAT MOTIVATES VALUE DELIVERY

In this section, we reflect based on the findings from data collected through literature study and interviews. We identified different motivations for delivering value and mapped them in a taxonomy shown if Figure 2. Each category is further explained in the following subsections.

TRANSACTIONAL MOTIVATION

The primary motivation for value delivery will typically centre around the formal transaction. That is, two or more parties have a formal agreed-upon exchange of give and get. We define value that is delivered directly to satisfy some condition set forth herein as being related to the *core* of the transaction. Also, the parties to the formal agreement might have to delivervalue to third-partystakeholders to *enable* the transaction. For example, the city will only give out building permits if the design is according to building codes.

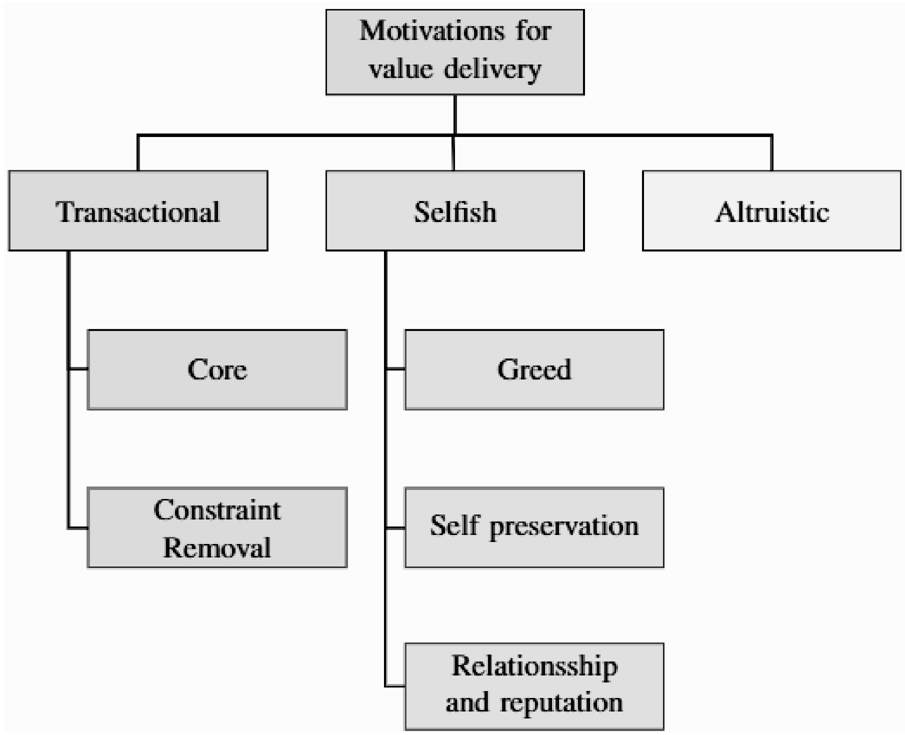

Figure 2: Motivations for value delivery

SELFISH MOTIVATION

No contract is perfect and all-encompassing, and there are always nuances in regards to deliverables and compensation. Any action taken by a party to the contract to exploit any ambiguities in it, where the intent is to increase value for themselves, can be said to be motivated by *greed*. Greed is not necessarily bad. However, greed becomes problematic if it leads to an involuntary value reduction for one or more other parties.

Sometimes, actors will deliver value on a project to protect themselves in some way, labelled as *self-preservation* in Figure 1. For example, Lohne et al. (2017)describe a situation where the contractor in a design-build contract discovered that the fire safety was questionable, and decided on their own accord to upgrade it. The existing solution would pass inspection, and they were not contractually bound to deliver a better solution. However, they choose to do so. While the language of the contract should have exempted the contractor from any future liability from having installed a questionable solution, they did not want to run that risk.

Many designers and builders will have an interest in maintaining a good *relationship* with the owner for the sake of future business, as well as maintaininga good*reputation* in the industry at large. The same holds true for owners vis-à-vis designers and builders. Thus, in many cases, the actors on projects will agree to deliver value to someone else, without being contractually obligated to do so, if this helps their relationship. Alternatively, they might refrain from demanding value,that they rightly would have been entitled to by the contract.

One of the case projects received noise complaints from the neighbours after doing tests runs of the ventilation system. Even though they did not have any formal obligation to mitigate this, the owner decided to do so to avoiding getting a bad reputation with the neighbours, whom they were dependent on for visits and referrals for their business to be profitable.

ALTRUISTIC MOTIVATION

In some situations, value will be delivered, not related to the formal transaction nor done for selfish reasons, but rather for *altruistic* reasons. For example, as part the professional identity, many architects will go above and beyond the minimum requirements laid down by regulations and planning boards related to the urban environment.

OVERLAPPING MOTIVATION

In the real world, actors will have mixed motivation for delivering some specific value. For example, in the business world, altruistic behaviour would fall under the umbrella of Corporate Social responsibility. Jones et al. (2006)points to several potential benefits of such behaviour: *"improved financial performance and profitability; reduced operating costs; long‐term sustainability for companies and their employees; increased staff commitment and involvement; enhanced capacity to innovate; good relations with government and communities; better risk and crisis management; enhanced reputation and brand value; and the development of closer links with customers and greater awareness of their needs."*

VALUE FOR WHOM - A MATTER OF VALUE PHILOSOPHY

Returning to the question of whose value matters, those stakeholders that are considered definitive will always matter, as the motivation for delivering value for them is primarily transactional. Definitive stakeholders are all contract partners or have the power to impose on the project through regulatory constraints. However, to what degree they matter is not a clear-cut matter. Going beyond what is part and parcel of the formal contract and the absolute constraints set forth by regulations and governing bodies, will be done based either on a selfish or an altruistic motivation.

Thus, we would argue that the question of value for whom is at its core a philosophical issue. Both as business philosophy, for example, believing that delivering customer value in the short term is better for long-term gains, as well as more generally, for example wanting to contribute in a positive way to society at large. While a conscious and explicit value philosophy might not exist, any entity involved in the construction industry will necessarily have one, albeit maybe unconscious and implied.

A potential issue, then, that should be addressed in projects, is the matter of diverging philosophy's. Especially in the cases where it can be taken from others, motivated by greed, or giving away value not one’s own, motivated by altruism. An example of the latter would be an architect providing value for a third party, such as a neighbour, in a way that incurs an increased cost but zero benefits for the owner. The issue then becomes very much one of ethics, further discussion of which can be found in Drevland et al. (2017).

We would argue, that the notion that whose value matters is a function of the value philosophy of the project participants is significantly different from the underlying notion of previous research on the matter. Although not explicitly stated, our impression of previous papers is that the authors hold to an underlying notion that whose value matters is something that is more or less absolute and constant across projects, and thus can be explicitly defined once and for all.

CONCLUSION

Having some notion of whose value matters is paramount to being able to optimise projects as production systems aimed at delivering value. The lean construction literature does not provide any clear answer on this subject. Neither does the general literature related to stakeholder management. While the latter can be useful for determining who might want to influence the projects, their ability to do so and their interests, it does little in helping in deciding whose value we should care for, beyond the need to appease those with power

We have argued that the key to deciding whose value matter lies in understanding the motivation for why valueis delivered. However, to what degrees each of the identified factors motivates someone will be highly dependent on their philosophical outlook, thus also making the matter of value for whom a philosophical question. This notion differs significantly from what the views presented by other authors considering this matter.

The main contribution of this paper is that it adds a theoretical discussion that has not been seen in previous studies. Future research will be in the direction of using some of these theoretical models to support teams better understanding how to manage projects with a focus on value generation.

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SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION FROM A PRODUCTION THEORY PERSPECTIVE

Rafaella D. Broft[1], and Lauri Koskela[2]

ABSTRACT

Production management in construction is moving away from conventional construction management. The correctives to this model have been explicitly or implicitly based on flow and value principles. Supply Chain Management (SCM) is often presented as suitable for efficient management of construction production, but its successful implementation in the industry remains limited, particularly at the lower tiers of the construction supply chain. This paper takes a closer look at SCM – an analysis from the production perspective might help to create a better understanding of the concept and the key principles presented could be prescriptive in the further development of SCM in construction.

KEYWORDS

Construction management, supply chain management, production theory, key principles.

INTRODUCTION

Despite the successful examples of Supply Chain Management (SCM) initiatives at the higher tiers of the construction supply chain, relationships at the lower tiers seem to remain traditional and the SC Maturity of construction firms continues to be low (Broft et al., 2016). The quality of a main contractor-supplier relationship affects the main contractors' ability to perform on projects (Kale &Arditi, 2001). The increasing percentage of project turnover which is spent on buying goods and services provides opportunities for contractor-supplier collaboration, and emphasises the importance and significance of managing suppliers (Bemelmans et al., 2012). Main contractors are willing to develop closer relationships, but implementing SCM seems a long-term, complex process and requires a certain level of understanding and therefore learning throughout the supply chain (Broft et al., 2016). In the last decades, various supply chain concepts have emerged in parallel in generic theory and manufacturing practice – all

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highly related, leading to a high ambiguity between the definitions of the different concepts and reflecting the cross-functional nature of SCM (Ellram& Cooper, 2014).

This paper takes a closer look at SCM as an alternative for efficient management of construction production. An analysis from the production perspective might help to create a better understanding of the concept, which is seen as a corrective to the conventional construction management model, dominated by the transformation concept (Koskela, 2000) – discussion exists whether SCM is based on flow or value principles.

CONSTRUCTION FROM A PRODUCTION PERSPECTIVE

"*Production is the action of making or manufacturing from components or raw materials, or the process of being so manufactured*" (Oxford Dictionaries, 2018).

Production has three kinds of goals – besides the general goal of getting intended products produced, there are internal goals related to the characteristics of the production itself (i.e. cost minimisation and level of utilisation) and external goals related to the needs of the customer (i.e. quality, dependability and flexibility) (Koskela, 1999). Production theory and practice has sprung from thinking about repetitive manufacturing – it has essentially been theory about making (Ballard, 2005). Three different conceptualisations of production have been used in practice and conceptually advanced in the 20th century (Table 1) – each of them captures an intrinsic phenomenon of production (Koskela, 2000).

Table 1: Transformation, flow and value views on production (Koskela, 2000)

	Transformation view	**Flow view**	**Value view**
Conceptualisation of production	As a transformation of inputs into outputs	As a flow of material, composed of inspection, moving, waiting and trans-formation	As a process where value for the customer is created through fulfilment of his requirements
Main principles	Getting production realised efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss

THE PRODUCTION-RELATED CHARACTERISTICS OF CONSTRUCTION

In construction, a supply chain shows the following production-related characteristics:

- Converging logistics to a *common and fixed point* in the supply chain: the construction site where the 'construction factory' is located (Luhtala et al., 1994);
- *Temporary and non-repetitive*, or in other words, one-off construction projects that are produced through repeated reconfiguration of project organisations (Vrijhoef & Koskela, 2000) – construction is prototype production;
- *Multiple and concurrent* projects (Souza de Souza, 2015);
- A number of studies have linked construction with the characteristics of the *Engineer-to-order* (ETO) production strategy – ETO-projects are described as

having high levels of customisation and typically managed on a project basis (Gosling et al., 2012).

- Construction is mainly based on two types of processes: *small batch process and job process* (Krajewski et al., 2007);
- One location can be worked on by *several work stations at the same time* and work is carried out in *suboptimal conditions*, with lessened productivity (Koskela, 1999).

THE PECULIARITIES OF CONSTRUCTION

The characteristics of construction are often seen as peculiarities of the industry, preventing the attainment of flows as efficient as in manufacturing (Koskela, 1999).These peculiarities are considered to differentiate between project-based industries and repetitive manufacturing, where SCM was born (Elfving& Ballard, in press). Despite the fact that other types of production also possess one or several of these characteristics, it is the combination of properties that defines construction 'peculiar' (Ballard & Howell, 1998) – construction objects possess two characteristics which together uniquely define them: (1) they belong to the category "fixed position manufacturing", and (2) they are rooted in place. The objects of fixed position manufacturing are wholes assembled from parts. In the assembly process, the parts become too large to move through assembly stations, so the stations move through the emerging wholes, adding pieces as they move. Some degree of site production, at minimum the final assembly, is a necessary aspect of construction. This rootedness-in-place brings with it uncertainty and differentiation (Ballard & Howell, 1998).

The organisation of production and the supply chains is strongly adapted to these basic characteristics (Koskela, 2000; Broft, 2017).

CONSTRUCTION MANAGEMENT FROM A PRODUCTION PERSPECTIVE

The construction industry, both theoretically and in practice, has been dominated by the transformation concept (Koskela, 2000) with three main features: (1) a sequential method of project realisation where design and construction are separated, (2) procurement through bidding; and, (3) segmented control with institutionalised roles and division of work. This conventional model was criticised for its centralised and formal management, as this does not recognise the uncertainty of and interdependence between the operations of the construction process (Tavistock Institute, 1966). The correctives to the conventional model have been explicitly or implicitly based on flow (i.e. Design-Build and lean construction) and value principles (i.e. quality management). One of these correctives, SCM, can be seen as an alternative for realising efficient construction management.

PRODUCTION THEORY: SCM IN CONSTRUCTION

In construction, SCM is often seen as a project-specific approach (Green et al., 2005). Main contractors have a central position in the management of supply chains (Pryke, 2009) – it is believed that main contractors have more influence on the organisation of the project and on the performance and quality of the work of its suppliers. However, implementation of SCM by main contractors is relatively slow (Green et al., 2005). This section analyses the concept from the different production theory perspectives.

FROM A TRANSFORMATION PERSPECTIVE

Production can be seen as a transformation of inputs into outputs, or in other words, as the transformation of one set of resources into a second set (Grubbström, 1995). The total transformation process can be decomposed into subprocesses, which are smaller, more manageable transformation processes (Koskela, 2000) – production management equates to carrying out these 'tasks' as efficiently as possible. Every process exists of any activity or group of activities that takes one of more inputs, transforms them, and provides one or more outputs to its customers (Krajewski et al., 2007).

As a consequence of the uncertainty faced by main contractors in obtaining continuous work and the need to accommodate the different, increasingly specialised and complex, requirements of each project (Tam et al., 2011), most of the subprocesses known in a construction supply chain are outsourced or subcontracted to specialist organisations, suppliers (Broft et al., 2016), focusing on the production of a specific subprocess (Figure 1).As a result, the main contractor, the principal construction organisation that manages a construction project, executes only a small part of the product by its own personnel and its own production facilities (Dubois & Gadde, 2000).

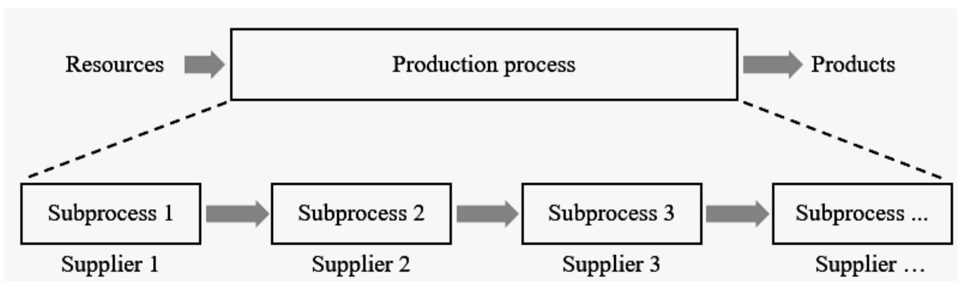

Figure 1: Decomposition of a production process in a supply chain
(adapted from Koskela, 2000; p.42)

From a transformation perspective, subprocesses are considered independent from each other and subsequently, the cost of the total process can be minimised by minimising the cost of each subprocess. In order to get every new construction project executed to the lowest possible cost (Eriksson, 2015), competitive pricing is promoted through procurement strategies often pursued by clients, featuring purchasing transactions (Gadde & Dubois, 2010) and favouring the lowest bidder. Contractually, main contractors are responsible for the construction of projects, but they rely on suppliers to execute the works (Clarke & Herrmann, 2004) – they do this to reduce their overhead and operating costs, improve efficiency, and achieve a more economic delivery of projects (Arditi & Chotibhongs, 2005). As part of task management, all these subprocesses (or effectively suppliers), and the costs involved need to be managed. SCM offers an alternative way for this production management, involving the control and optimisation of decomposed and subcontracted activities, where suppliers are invited to focus on the efficiency of their subprocess (through, i.e., standardisation and prefabrication) and to eliminate unnecessary costs (with the help of the production manager).

Here, a supply chain is defined as a set of three or more entities (organisations or individuals) directly involved in the upstream and downstream focus of products, services, finances and/or information from a to a customer (and in reverse) (Mentzer et al., 2001). SCM, using a process orientation (Ellram & Cooper, 2014), considers the supply chain as a means for linking structured activities designed to produce an output for a particular customer or market, and a means to improve and/or coordinate processes. It looks at activities, where activities could be seen as a single element of a process (Burgess et al., 2006), or processes versus the relationships in supply chains. As a result of the fragmentation and prevalent competitive tendering, construction supply chains are disjointed (Eriksson, 2015). This means that current construction practice, where the relationship with suppliers is considered to be exclusively transactional, with no relational component (Elfving & Ballard, in press), fits the transformation perspective. SCM from the transformation perspective considers these relationships. As opposed to transaction cost economics (TCE) that treats each transaction separately (make-or-buy), SCM includes the systems benefits of organising clusters of related transactions as supply chains are introduced – related transactions are grouped and managed as chains (Williamson, 2008). SCM could then involve elements such as the creation of a more permanent production process through long-term relationships with suppliers. This offers alternative ways of minimising (transaction) costs (Pasquire et al., 2015).

FROM A FLOW PERSPECTIVE

When production is depicted as a flow of material, the flow consists of four stages: processing, inspection, moving and waiting (Gilbreth & Gilbreth, 1922). These transformation and non-transformation activities both consume time from the point of view of the product – the amount of time consumed by the total transformation and its parts or subprocesses plays an important role in the flow conceptualisation (Koskela, 2000). For this reason, production management tries to shorten the total time by eliminating non-value adding phenomena or waste from the production process (Shingo, 1988). In other words, production management involves the management of flow. It minimises the share of non-transformation stages of the production flow, especially by reducing variability as variability increases the lead time. There are two types of variability in flows of production: process-time variability which refers to the time required to process a task at one workstation, and flow variability meaning the variability of the arrival of jobs to a single workstation (Hopp & Spearman, 1996).

From a flow perspective, the object of SCM is "to integrate and manage the sourcing, flow and control of materials using a total system perspective across multiple functions and multiple tiers of suppliers" (Mentzer et al., 2001). A supply chain, encompassing all the subprocesses (as explained and visualised in Section 3.1), is conceptualised as a production flow (rather than a series of transactions or contracts) – it covers the flow of goods from the different suppliers through manufacturing and distribution chains to the end user (Christopher, 2005).

A manufacturing system, which involves the flow of material through a plant – is an objective-oriented network of processes through which entities (the parts to be manufactured) flow (Hopp & Spearman, 1996). Besides the flow of materials, construction knows two other flows: location flow and assembly flow, which are related to the characteristics of construction as described in Section 2.1 and 2.2: Production in construction is of assembly-type, where different material flows are connected to the end product on-site. Due to the size of the product of construction, an intermediate workflow arises where all installation locations proceed through the installation work station (Koskela, 2000). Whilst conventional construction management focuses on the project, SCM emphasises the product and the tasks or subprocesses organised around this product as a network – the realisation of tasks heavily depends on flows, and the progress of flows in turn is dependent on the realisation of tasks (Koskela, 1999). Coordination between subprocesses or supply chain partners is important in order to boost total process efficiency and effectiveness across members of the supply chain (Lambert et al., 1998).

SCM from the flow perspective acknowledges the interdependency between subprocesses and includes integration. The current approach in construction might still be sequential, but SCM in construction should be seen as the management of a network of interconnected organisations that are involved in the different processes and activities that produce products and services to the customer (Dainty et al., 2001; Christopher, 2005). Owing to the still disconnected processes and the large number of suppliers, main contractors are needed to coordinate operations to provide focus and integration of the varied parts (Akintan & Morledge, 2013): SCM is "the task of integrating organisational units along a supply chain and coordinating materials, information and financial flows in order to fulfil customer demand with the aim of improving competitiveness of a supply chain as a whole" (Stadler, 2000).This integration between subprocesses focuses, from the flow perspective, on the overall efficiency of the entire supply chain, through the use of important flow-related principles – the reduction of the lead time of the product through the elimination of waste within the overall production process and the reduction of variability(Berliner & Brimson, 1988; Koskela, 2000). It equals to the synchronisation of a firm's processes with those of its suppliers and customers to match the flow of materials, services, and information with customer demand (Krajewski et al., 2007).

FROM A VALUE PERSPECTIVE

Production can also be seen as a means for the fulfilment of the customer needs. Production management equates to translating these needs accurately into a design solution and then producing products that conform to the specified design. This concept reflects the importance of a focus on value. In construction, the attitude tends to be oriented towards conformance to contractual specifications rather than gaining additional financial benefits or competitive strength from quality improvement (Vrijhoef, 2011). As a result, construction seems oriented more towards production and getting the work done on time and within budget (Lai & Cheng, 2003) – the project success measure is cost, and completing the project by the scheduled date is generally the most important scheduling objective (Tukel & Rom, 1998).

SCM involves the integration of key business processes from the end user through original suppliers that provide products, services, and information that add value for customers and other stakeholders (Lambert et al., 1998).Value creation has become a function of the network of iterative and transient relationships between actors that are connected – construction projects are essentially about the creation of new value in society, delivered by a network of relationships between firms that make up the project coalition (Pryke, 2009).This value includes time, costs and quality. In SCM, all supply chain actors need to be able to make a full contribution to ensure that the client's needs are fulfilled and that value creation is maximised (Broft et al., 2016). This implies a collaborative customer focus and a higher quality of the delivery of each subprocess. SCM also encourages integrated project delivery (IPD) or common product development as suppliers are involved early in the process and play an important role in the design stage, invited to work on target cost (Anderson, 2006) and to contribute to pre-designed solutions. Target costing is an important aspect of SCM – it is an effective inter-organisational management technique that has been used in manufacturing toachieve cost predictability during new product development (Zimina et al., 2012) in a supply chain. It helps to ensure that new products and services meet market-determined prices and provide financial returns (Cooper &Kaplan, 1999).The value perspective also focuses on SCM's main objective to enhance mutual competitive advantage (Pryke, 2009).

SCM IN CONSTRUCTION FROM A TFV-PERSPECTIVE

SCM is considered a way of thinking about management and processes, which includes improved relationships, integrated processes and increased customer focus (Pryke, 2009). Integration (or interdependency) and value creation – important aspects of the F- and V-conceptualisations of the production theory – seem to be essential in SCM. Table 2represents the characteristics of SCM in construction from each production perspective, following from Section 3.1, 3.2 and 3.3. The table is descriptive – it decomposes SCM to its constituents and presents them as key principles.

Table 2: The characteristics of SCM in construction from a TFV-perspective

View on production	**Conceptualisation of SCM**	**Keyprinciples**
Common toall views	Long-term collaborations between supply chain actors to ensure a project-exceeding focus and to create a more permanent organisation.	▪ Long-term collaboration with suppliers.
Transformation	Managing all subprocesses, subcontracted to different suppliers, and logistics needed to perform a production process. Relationships between subprocesses are acknowledged, but remain transactional.	▪ Clusters of related transactions that are managed as chains; ▪ Non-temporary organisation; ▪ Alternative ways for the minimisation of transaction costs.
Flow	A supply chain, encompassing all	▪ Focus on overall efficiency;

	the subprocesses is conceptualised as a production flow. Coordination between subprocesses is important in order to boost total process efficiency and effectiveness across members of the supply chain. This involves the acknowledgement of interdependencies between subprocesses, and includes integration. This integration between subprocesses focuses on the overall efficiency of the entire supply chain.	▪ Lead time reduction through the elimination of waste and the reduction of variability; ▪ Product-focus (including the subprocesses organised around this product).
Value	Ensuring that the client's needs are fulfilled and that value creation is maximised – all supply chain actors need to be able to make a full contribution. This implies a collaborative customer focus and a higher quality of each delivered subprocess.	▪ Fulfilment of customer requirements for the product regarding time, cost and quality; ▪ A higher quality of each delivered sub-product; ▪ Collaborative customer focus; ▪ Common product development; ▪ Supplier prequalification and early supplier involvement; ▪ Mutual competitive advantage.

CONCLUSION

Production management in construction is moving away from conventional construction management. The correctives to this model have been explicitly or implicitly based on flow and value principles. SCM is often presented as suitable for efficient management of construction production. Its successful implementation in the industry, however, remains limited to the improvement of logistics and inventory, whereas in some industries SCM has become a central strategy, dealing with total business excellence.

This paper presents an analysis of SCM in construction from a production perspective. Important aspects of the F- and V-conceptualisations of the production theory have already been implicitly acknowledged in SCM, however, this paper provides the reader with a more descriptive and explicit conceptualisation of SCM from each production perspective and reflects the difference between each view on these conceptualisations.

Despite that all three SCM conceptualisations include long-term collaborations with suppliers, clustering subprocesses around a supply chain, each view on production emphasises a different aspect of SCM. Where transformation focuses on the transactional relationship between subprocesses (or in other words, suppliers) and focuses on cost minimisation accordingly, flow acknowledges the interdependency through the integration of processes and the creation of relationships, and value acknowledges the delivery of quality as a result of each subprocess. The differences have been presented in

Section 3.4 – Table 2 also describes the associated key principles. In this way, the paper creates a better understanding of the SCM concept and suggests that for SCM to succeed in the best possible manner, all three views need to be considered and promoted. This understanding could be used prescriptively in the further development of SCM in construction, and added clarity of the concept might subsequently offer opportunities for successful implementation of SCM at the lower tiers of the construction supply chain.

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IDENTIFYING VALUE ENHANCING FACTORS AND APPLICABILITY OF VISUAL MANAGEMENT TOOLS

Vyoma Vipul Patel[1], Nimitt Karia[2], and Devanshu Pandit[3]

ABSTRACT

A significant amount of capital has been invested in AECO industry for many decades to support public and private initiatives. Therefore, getting reasonable value from the investment is pivotal for any developing nation. Interpretation of the value varies according to the importance and influence of the stakeholders in the project hence knowing its perception is significant. Maximising value is one of the foundations of the lean construction approaches. On the other hand, as Indian construction industry is gearing up for lean construction and its applications, understanding the meaning of the value in local context become significant. Moreover, visual management and its applications in construction have shown promising results. Therefore, how well they can address value maximization in Indian construction context is answered via conducted research.

This paper helps to understand the perception of the value in the Indian construction industry through semi-structured interviews of construction professionals. Additionally, value increasing factors are identified in the construction phase of the project, subsequently; lean visual tools are applied to identify factors. The results demonstrate that the visual management tools have potential to increase value in the construction phase of Indian construction projects.

KEYWORDS

Value, Visual Tools, Construction phase, Factors, Indian construction projects

INTRODUCTION

As defined by Koskela et al (2002), lean construction is the approach to design production system which has minimum wastage to obtain the best value. Therefore, maximizing the value is one of the major philosophy for the lean construction point of

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view. Furthermore, the term value can be defined as the relationship between function, time, cost and quality (Kelly, Male, & Graham, 2004). But, stakeholders from construction projects define the value of the project based on their expectations from the project (Kelly et al., 2009). However, according to Kashiwagi and Savicky (2003), understanding about concept of value among construction projects is lacking.

Therefore, to maximize or increase the value of the construction project it is necessary to understand the perception of the construction clients, internal and external both. Moreover, organizations from Indian construction industry are taking steps forward for lean construction (Anerao, 2016). Thus, this research is carried out with objective to understand the perception of value in Indian construction industry. The study further identifies factors affecting the value of project through qualitative and quantitative approaches.

To enhance communication and to control operations and processes in real time, the visual management and its tool have been developed and used by lean practitioners (Parry & Turner, 2006). Moreover, the successful application of visual management in construction has been proven in the transportation sector, building sector and industrial sectors (Tezel & Aziz, 2017; Tezel et al, 2013, Tezel et al, 2016). The applicability of the visual management tools in Indian construction sector is explored in this research paper using relation matrix. In particular, the matrix shows the relationship between visual management tools and value improvement factors in terms of applicability and ease of implementation.

RESEARCH METHOD

Following the 'research onion' provided by Saunders et al. (2007), this research is classified into various layers which describe research methodology. Consequently, the research falls under 'epistemology' (pragmatism) as research philosophy along with deductive approach and survey strategy is adopted. According to Spector et al. (2014), descriptive research answers "what is" type of research questions. This type of design requires both qualitative and quantitative approaches (AECT, 2018). Therefore, the qualitative research tools such as personal interviews and opinion survey are considered along with quantitative tools such as factor analysis, and matrix rating.The overall research methodology adopted for the study is illustrated in Figure 2.

DATA COLLECTION

Clear definition of the universe, population, unit of analysis, sample frame, sample sizes are essential for determining successful data collection approach design (Tobergte & Curtis, 2013). As this research comprises of three objectives, the data collection method varies accordingly.

VALUE PERCEPTION OF INDIAN CONSTRUCTION INDUSTRY

To determine the perception of value in Indian construction industry, semi-structured interviews were carried out as shown in Figure 2. 10 industry professionals working in different positions including designer, value engineer, project manager, construction manager, client, consultants, and civil engineers were selected. Interviews were conducted to determine value in the construction phase, value influencing parameters, value improving parameters, improvement priorities, and finally to come with recommendations.

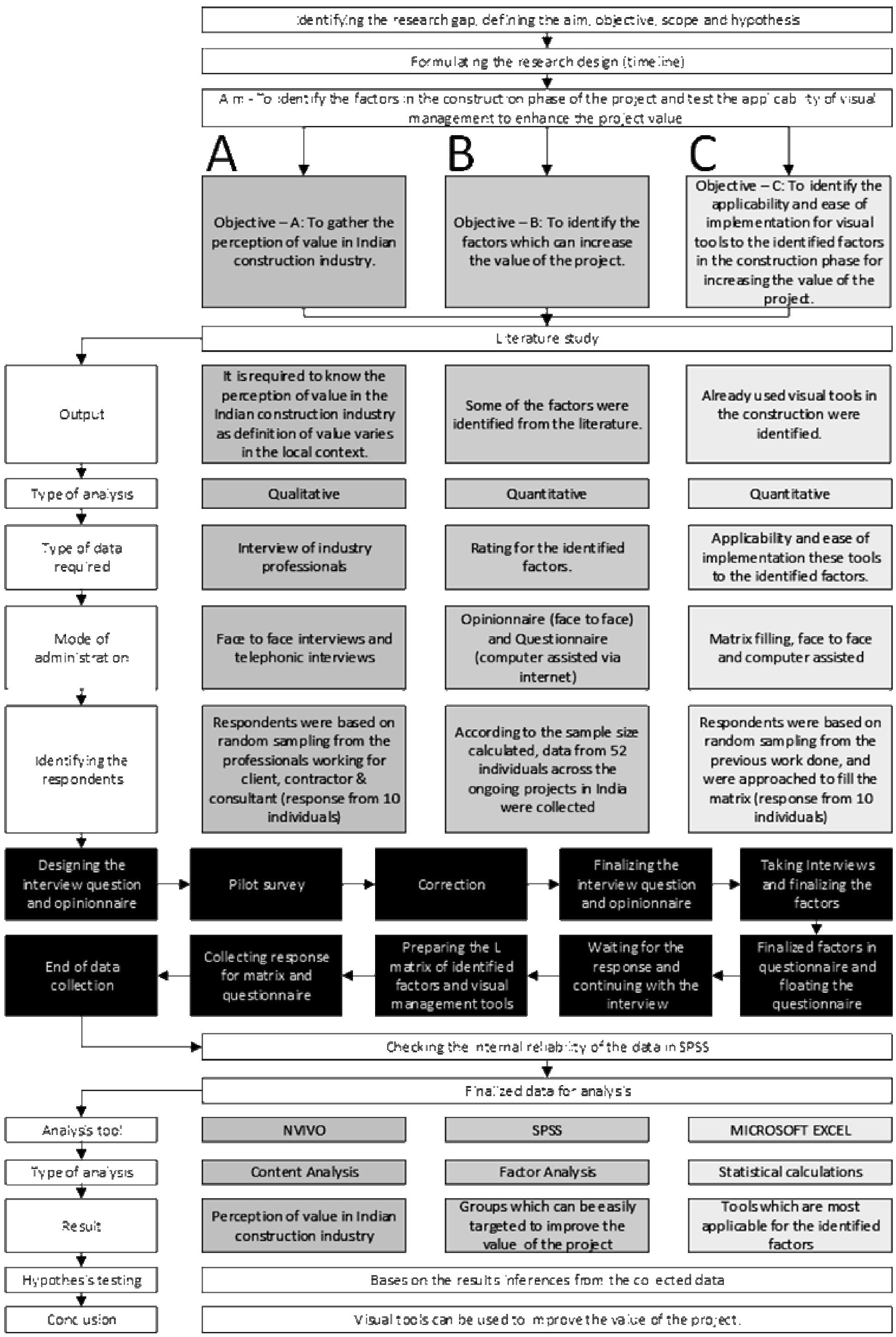

Figure 1: Research Method

DETERMINING FACTORS

Literature study and opinionnaire from industry experts resulted identification of 33 factors that can improve the value of a construction project. A questionnairewas formed comprising of all 33 factors to obtain the response ratings against each factor. Likert scale was used for the importance ranking. On the basis of sample size calculation suggested by Morgan and Krejcie (1970), 52 samples were required. Data collection from 52 individuals across India was received. Additionally, information regarding respondent is captured as - categories of the projects, company's annual turnover, cost of a current project, respondent’s experience in construction industry, education qualification, payment mechanism, designation, type of procurement in the current project, type of organization.

‘FACTOR VS. VISUAL MANAGEMENT TOOLS’ MATRIX

Based on the visual management tools listed by Tezel (2013) and Tezel et al (2011); commonly used visual management tools were plotted on L shaped matrix against identified factors in the constructionphase of a project. This matrix was circulated to the lean experts for determining the relationship between factors and tools based on their applicability and feasibility in Indian construction industry as stated through research methodology in Figure 2.Respondents to this include lean practitioners, professors, directors, lean advisors and managing partners having 20+ years of experience.

DATA ANALYSIS

A different set of methods are utilized to analyzethe collected data. Summary of data analysis can be inferred from Figure 2.

CONTENT ANALYSIS FOR VALUE PERCEPTION OF INDIAN CONSTRUCTION INDUSTRY

The interview scripts are transcribed and further processed in NVIVO qualitative analysis tool. Several nodes and codes are created to carryout content analysis of collected data. Word frequency, text queries and code analysis were performed to interpret collected data describing them under type of analysis in Figure 2.

FACTOR ANALYSIS OF DETERMINED FACTORS AND THEIR RELIABILITY

According to (Trochim and Donnelly, 2006), reliability was used to check the appropriateness of the collected data in SPSS software. The value obtained from the testwas 0.931 (Cronbach's Alpha), 0.855 (Spearman-Brown Coefficient), 0.847 (Guttman Split-Half Coefficient). This result reveals that the collected data is reliable. Further, as said by Johnson and LeBreton (2004) and (Norusis, 1992), Factor analysis(Figure 2) is performed to recognizea small set of groups which can represent the relationships within the set of interrelated variables.Also, some additional test comprising Bartlett test of Sphericity (Approx. Chi-Square = 1129.66), associated significance level (0.000), Kaiser-Meyer-Olkin measure of sampling adequacy value (0.713) has been performed where all results were found satisfactory. The results of totalvarianceis tabulated in Table 1and rotated matrix is tabulated in Table 2.

ANALYSING FOR 'FACTOR VS. VISUAL MANAGEMENT TOOLS' MATRIX

As shown in the Table 3 and 4, the relational matrixes have been prepared from the expert opinion and ratings. Simply, based on the scores they have achieved, the inferences for most addressed factor and the most useful tool is stated in the result section. Conditional formatting and data filtration methods were used to infer the collected data.

RESULT DISCUSSION AND INFERENCES

PERCEPTION OF VALUE IN THE INDIAN CONSTRUCTION INDUSTRY

Value is a very subjective term depending on the perspective of the stakeholders. It is believed that if something more is received for the price paid than that is value. In the construction industry; quality, cost, benefits, etc. are considered the value. In the construction phase, it could be valuedin terms of saving time, reducing misuse of resources – manpower, material and of course value engineering addition for suggesting a specific system which is not going to reduce your quality but it's going to be beneficial either in time or cost. Yes, time and cost are given the utmost importance in our Indian construction industry.

If efforts are made in the correct direction during the construction phase of the project, the value of the project can be increased. With the current practices and different mindsets, individuals are not satisfied with the construction industry. They emphasize for improvement in areas likeproject management, current working systems, quality improvement, detailed planning in the design phase, etc. And a strong belief is shown saying that client is responsible for the smooth completion of the projects. After client comes to the consultants, they play a role by helping the client in taking contractual decisions, convincing the stakeholders for the benefit of the project and a constant observation of consistent performance by the parties involved in the project. Then comes a contractor, who can perform best in parameters like cost, time, quality, satisfaction, function, aesthetics, design, services, money, overall performance, etc. during the construction phase. During this period focus should be on the process and the product, as they are equally important. Most of the respondents agree on that, improving the process automatically improves the product. Measures like planning the tasks properly, using the software for monitoring and tracking the information, analysis related to time, and cost are performed, developing the system in the organization, etc.

FACTOR GROUPING

Factor grouping was done according to the Varimax rotation and nine-factor solution with eigenvalues > 1.000, explaining 75.106% of the variance was formed, as shown in Table 1.It was noticed that the analysis resulted in nine groups for 33 factors and they are interpreted as follows.

Factor grouping – 1 (Administration)

Most factors in this group are managed by the administration department on the site where they look after, legal issues, land acquisition, and traffic plans. If the person having high experience and qualifications are involved, then it becomes easier for them to make decisions and it would result in less number of disputes among the project parties. But, in case of contractors and sub-contractors, the experience of the similar work smoothens the work on projects. Also, there are cases where they have experience and the can add value to the projects yet they being selfish and egoist they add value addition to their organizations only. It also poses risk of quality compromise. Many times, these factors become the reason for the project delay, which ultimately hasnegative impact on the value of the project.

Table 1 Total variance table from factor analysis

Component	Initial Eigen Values			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	11.516	34.896	34.896	4.067	12.323	12.323
2	2.876	8.714	43.610	3.579	10.846	23.169
3	2.008	6.084	49.694	3.503	10.615	33.784
4	1.823	5.523	55.216	2.949	8.935	42.719
5	1.602	4.854	60.070	2.808	8.511	51.230
6	1.432	4.340	64.410	2.705	8.197	59.427
7	1.383	4.192	68.602	1.878	5.690	65.117
8	1.124	3.407	72.009	1.656	5.017	70.134
9	1.022	3.097	75.106	1.641	4.972	75.106
10	0.918	2.781	77.887			
11	0.835	2.531	80.418			
12	0.775	2.347	82.765			
13	0.711	2.155	84.920			
14	0.599	1.816	86.737			
15	0.509	1.542	88.278			

Factor grouping – 2 (Work environment)

In a project, work environment plays a significant role. The less number of interference by the neighborhood, location feasibility, temperature, the space to store the material on site and availability of the design team on site for small clarity and corrections, attitude of the works and the staff, surrounding projects, what procurement strategies are followed for the project, etc. are key areas on which the site environment depends. In many contracting firms, some competitions and celebrations are there for a healthy environment on the site.

Factor grouping – 3 (Culture)

Culture must be developed on site, such that attitude of the individual at managerial level and the workers are good, staff members are taught leadership qualities, attitude for the organization and industry in individual, ethics, and morals followed by the organization, etc. Focusing on these areas unites the individuals working for the project and creates a good rapport on the site.

Factor grouping – 4 (Human resource)

All the project participants should be well coordinated where the communication is very clear and the care for the requirements of the project participants should be taken. Along with this, the training programs and workshops for developing site management skills are required. Experienced leaders can provide motivation to the youth working with them and the atmosphere on the project remains healthy.

Factor grouping – 5 (Compliance)
For the compliance, planning must be a strong and quick response to the activities, such that while execution no difficulties are faced. Subsequently, the planned schedule should be followed without delays and without exceeding buffer time of the activities. During such scenario, the role of project coordinators is very important.

Factor grouping – 6 (Management)
Many times due to the client requirements, variation occurs in the on-going project which needs to be handled carefully. To adopt the changes quickly by accepting the new technologies and systems for the progress of the project – meetings and workshops are arranged, individuals are made aware of the new technologies, safety is taken care of, the status of the projects is evaluated, and difficulties are solved. Resource planning is carried out in advance considering geographical locations. Continuous evaluation of the project is carried out with the planned vs. actual data.

Factor grouping – 7 (Planning)
Precise planning is must to decide the priority. Execution must follow critical path. Constant tracking of the progress is required. Other than planning, distributing the information related to the short-term goalson the site is important. Planning influences the site management.

Table 2 Rotated Component Matrix for Factor Analysis

Factors	Citation	Component								
		1	2	3	4	5	6	7	8	9
Strong cost control systems*	1	0.764								
Fast claim and payment approval*	1	0.737								
Personals with experience and qualification*	1	0.723								
Contractor's experience and capability		0.619								
Frequency of disputes*	1	0.579								0.512
Quality of equipment's and raw materials*	1	0.542								
Level of neighborhood/public interest*	3		0.769							
Local construction market*	3		0.690							
Material Handling & Storage			0.689							
Availability of design team on site			0.623							
Delivery or procurement approach*	2		0.600							
Recycling and reuse of waste*	4			0.778						

Management-worker relationship				0.713						
Leadership skills*	1			0.663						
Employee attitudes in project*	1			0.568						
Communication*	4				0.829					
Availability of trained resources*	2				0.627					
Motivation to perform					0.512					
On time/early completion of project										
Rigid schedule						0.875				
Rigid construction methods						0.861				
Maximum safety										
Environmental management system*	4									
Extent of variations *	3						0.768			
Training*	4						0.622			
Constant evaluation of project value*	4						0.550			
Commitments followed							0.517			
Quality of work*	2						0.506			
Sequencing of work according to schedule*	1							0.685		
On-site Management					0.539			0.565		
Minimum rework									0.864	
Management participation for decision *	1									0.681
Construction productivity*	1									

1 - (Enshassi et al, 2015), 2 - Shabniya, V.), 3 - (Chan, 2012), 4 - (Liu, Wang, & Lin, 2012)

* - Citations are given to only those factors which are taken from the literature, rest of the factors are from opinionnaire

Factor grouping – 8 (Rework)

If any tasks are required to perform again, the amount of resources used will increase which results in more time and cost. Visual tools can help understand tasks easily which would account in less amount of rework and wastage.

Factor grouping – 9 (Transparency)

If people in different levels in hierarchy are involved in the decision making, then the information will be shared with all the participants in the hierarchywhich helps to maintain the transparency. These would result, in less number of disputes internally in the organization and it would smoothen the work throughout the project for all the project participants.

APPLICABILITY AND EASE OF IMPLEMENTATION MATRIX

Applicability Matrix

Table 3 Applicability Matrix

FACTORS	TOOLS												SCORE		
	1	2	3	4	5	6	7	8	9	10	11	12	Obtained	Max.	%
Commitments followed	5	4	4	6	6	6	4	1	6	4	4	4	53	120	44
Communication	5	4	4	4	9	6	7	4	4	4	7	5	63	120	52
Leadership skills	4	2	3	2	3	5	2	3	2	3	3	3	34	120	28
Minimum rework	7	4	4	5	8	6	7	4	4	5	3	8	64	120	54
Motivation to perform	8	3	2	3	6	6	3	3	2	4	3	3	46	120	38
On time/early completion of project	6	5	6	6	6	8	5	4	6	7	5	7	70	120	58
On-site Management	6	7	5	7	9	6	7	3	3	6	7	5	69	120	58
Participation of management	3	5	4	4	5	5	3	4	2	4	4	4	46	120	39
Employee attitudes in project	7	4	3	2	7	6	3	3	3	5	5	5	51	120	43
Delivery or procurement approach	3	5	3	6	4	8	5	3	4	8	4	4	57	120	48
Fast claim and payment approval	4	4	3	3	3	8	4	3	4	4	3	3	43	120	36
Stipulated schedule	5	5	5	4	4	5	4	4	5	7	5	4	56	120	46
Construction productivity	8	7	8	6	5	8	6	7	8	7	6	7	84	120	70
Material Handling & Storage	8	3	3	3	5	5	7	4	4	5	3	4	54	120	45
Quality of equipment's and raw materials	5	3	3	2	3	3	4	4	3	4	4	6	43	120	36
Quality of work	4	4	5	5	4	4	3	5	5	3	4	7	53	120	44
Contractor's experience and capability	3	4	3	3	3	4	3	3	3	3	4	6	42	120	35
Extent of variations	4	5	8	6	6	6	7	8	4	6	4	8	71	120	59
Strong cost control systems	6	5	4	6	4	4	4	4	4	4	4	4	50	120	42
Constant evaluation of project	4	3	5	7	3	6	4	4	3	3	5	3	50	120	42
Frequency of disputes	5	4	5	7	5	7	6	4	5	4	4	4	60	120	50
Level of public interest	3	3	3	3	3	2	2	3	2	2	3	3	30	120	25
Management-worker relationship	6	4	3	4	4	6	4	4	4	4	7	3	50	120	42
Environmental management	4	2	3	4	5	3	4	3	3	2	3	5	39	120	33
Recycling and reuse of waste	4	3	3	3	3	4	4	3	4	4	3	6	42	120	35
Local construction market	3	3	3	3	4	6	4	4	4	3	4	3	42	120	35
Availability of design team on site	3	4	5	5	3	4	4	5	4	3	4	4	47	120	39
Personals with experience and qualification	4	4	4	5	3	4	3	5	4	3	4	5	45	120	38
Availability of trained resources	3	4	4	5	3	5	3	4	3	4	5	4	46	120	38
Maximum safety	8	5	5	5	8	3	6	4	3	3	4	6	59	120	49
Trainings	4	3	6	5	5	3	3	3	4	3	7	4	49	120	41
Obtained score	149	121	125	136	145	160	132	117	117	129	133	145			
Max. Score	310	310	310	310	310	310	310	310	310	310	310	310			
%	48	39	40	44	47	52	43	38	38	42	43	47			

Tools Coding - (1-5S, 2-Andon, 3-Augmented Construction Field Visualization, 4 -BIM, 5-Display Boards, 6-Collobrative Process Mapping /LPS, 7-Color Coding, 8-End Product Samples, 9-Heijunka, 10-Kanban Cards, 11-Obeya Rooms, 12- Poka-Yoke)
Red Colour depicts – minimum applicability of the tool to the factor
Blue Colour depicts – maximum applicability of the tool to the factor

Table 3 shows the matrix comprising of factors and the tools, which represents how relevant is the visual tool, to the identified factors during the construction phase. These factors are relatively graded out of 10, to find out the most useful tools for improving the factors. (Where 0-not applicable, 1-least relevant and 10-most relevant).

When the matrix is read vertically, tool scores highlighted in green colour at bottom of the matrix would be helpful if only one or two tools are being adopted on the site and it has its effect on all the factors according to the obtained score. Here the top five tools which can be used on the site are 5S, BIM, Display boards, Collaborative Process Mapping / LPS, Poke-Yoke.

Whereas if the particular factors are required to be improved on site, than those factors having maximum score in the right side of the matrix, highlighted in green colour can be achieved by all the tools listed in the matrix. The top 10 factors among the identified factors which can be improved with the listed tools are communication, minimum rework, on time/early completion of project, on-site management, delivery or procurement approach, stipulated schedule, construction productivity, extent of variations, frequency of disputes and maximum safety.

Ease of implementation Matrix

Table 4 Ease of implementation Matrix

FACTORS	TOOLS												SCORE		
	1	2	3	4	5	6	7	8	9	10	11	12	Obtained	Max.	%
Commitments followed	3	4	5	7	5	5	5	4	5	4	4	3	52	120	43
Communication	3	4	5	5	5	5	6	5	4	4	6	4	55	120	46
Leadership skills	4	3	3	4	4	5	4	4	3	3	3	3	40	120	34
Minimum rework	5	5	5	6	6	5	5	5	4	5	4	7	61	120	51
Motivation to perform	5	4	4	4	6	5	4	4	3	4	4	3	49	120	41
On time/early completion of project	5	5	7	6	5	7	5	5	6	5	6	6	68	120	57
On-site Management	5	5	5	7	7	5	7	4	4	6	6	4	64	120	53
Participation of management	3	5	4	5	5	5	4	5	4	4	5	4	51	120	42
Employee attitudes in project	5	4	4	4	7	5	5	5	4	3	4	4	53	120	44
Delivery or procurement approach	3	4	3	6	4	6	4	4	4	4	4	4	49	120	41
Fast claim and payment approval	4	3	4	4	4	6	3	4	3	3	4	4	44	120	36
Stipulated schedule	4	4	5	5	5	5	4	5	4	5	5	4	54	120	45
Construction productivity	6	6	8	7	6	7	5	7	7	5	5	6	72	120	60
Material Handling & Storage	6	3	3	4	6	4	6	4	3	4	3	3	49	120	41
Quality of equipment's and raw materials	5	3	3	3	5	4	4	5	3	3	3	5	42	120	35
Quality of work	4	4	4	6	6	4	4	5	5	3	3	4	51	120	42
Contractor's experience and capability	3	4	3	4	5	4	4	4	4	3	3	5	45	120	37
Extent of variations	4	4	8	7	6	5	5	7	4	4	4	6	63	120	52
Strong cost control systems	5	5	3	6	4	4	4	5	3	3	4	4	50	120	41
Constant evaluation of project	2	2	3	6	2	4	2	2	3	2	4	3	33	120	28
Frequency of disputes	4	4	4	6	5	7	4	4	4	3	3	4	51	120	43
Level of public interest	3	3	3	3	3	4	3	4	2	2	2	2	34	120	28
Management-worker relationship	5	5	3	3	4	6	4	3	3	3	5	3	46	120	38
Environmental management	4	3	3	4	5	4	4	4	3	3	3	6	44	120	37
Recycling and reuse of waste	4	3	3	3	4	4	3	4	2	3	4	6	42	120	35
Local construction market	3	3	3	3	3	5	3	4	3	2	3	3	36	120	30
Availability of design team on site	3	3	4	4	3	4	4	5	3	3	4	3	40	120	33
Personals with experience and qualification	3	3	3	4	3	5	4	5	2	3	4	3	39	120	33
Availability of trained resources	2	3	3	4	4	5	4	4	2	3	4	3	41	120	34
Maximum safety	5	4	4	4	5	4	5	4	2	3	4	5	48	120	40
Trainings	2	3	6	5	4	3	3	6	3	3	5	3	45	120	37
Obtained score	119	111	125	148	143	148	130	136	106	105	120	121			
Max. Score	310	310	310	310	310	310	310	310	310	310	310	310			
%	38	36	40	48	46	48	42	44	34	34	39	39			

Tools Coding - (1-5S, 2-Andon, 3-Augmented Construction Field Visualization, 4-BIM, 5-Display Boards, 6-Collobrative Process Mapping /LPS, 7-Color Coding, 8-End Product Samples, 9-Heijunka, 10-Kanban Cards, 11-Obeya Rooms, 12- Poka-Yoke)
Red Colour depicts – difficulty to implement tool on the construction project
Blue Colour depicts – easiness for implementing the tool on the construction project

Table 4 shows the matrix of factors and tools, which represents how easy the tools are for the factors to implement on the site during the construction phase. These factors are relatively graded out of 10, that which is the most useful tools for improving the factors. (0-not applicable, 1-difficult to implement and 10-easy to implement).

When the matrix is read vertically, tool scores highlighted in green colour at bottom of the matrix would be helpful if only one or two tools are being adopted on the site, and it has its effect on all the factors according to the obtained score. Here the top five tools which can be used on the site are BIM, display boards, collaborative process mapping / LPS, colour coding, end sample products.

Whereas if the particular factors are required to be improved on site, than those factors having maximum score in the right side of the matrix, highlighted in green colour can be achieved by all the tools listed in the matrix. The top 10 factors among the identified factors which can be improved are Commitments followed, communication, minimum rework, on time/early completion of project, on-site management, Employee attitudes in project, stipulated schedule, construction productivity, extent of variations, frequency of disputes and maximum safety.

CONCLUSION

In India, construction industry professional believes that equal efforts in process and product both for the value enhancement. Authorities responsible for improving the project value in sequence are: client, consultant, and contractor. The value in the construction industry revolves around cost, time, and quality. Maximum emphasis is given to cost. Safety and environment are also considered vital.

Total 33 factors are identified that can increase the value of the project and they are distributed into nine groups using factor analysis as: administration, work environment, culture, human resource, compliance, management, planning, rework, and transparency.

Visual tools can be used on the construction projects and they can help to improve the value. Most relevant tools to enhance the value of construction project include 5S, display boards, collaborative process mapping /LPS, Kanban cards, Obeya rooms, Poke-yoke. Whereas BIM, display boards, collaborative process mapping / LPS, colour coding, end product samples are easy to implement on-site for improving the value.

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KAIZEN - ANALYSIS OF THE IMPLEMENTATION OF THE A3 REPORTING TOOL IN A STEEL STRUCTURE COMPANY

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ABSTRACT

The A3 report is a Kaizen tool that must contain, on one side of an A3 paper sheet, a context, the current situation, the objective, an analysis, countermeasures, an action plan, the monitoring and an upgrade regarding the situation to be improved. This study seeks to analyze the post-implementation effects of the A3 tool, which is part of the Kaizen method. The research method consisted in the collection and evaluation of A3 reports produced in the past seven years in a company of pre-fabricated steel structures. Among the 154 developed A3 reports, it was observed that 76% were drafted by the engineering and manufacturing departments, which converged on the improvement of processes, services and innovative solutions. The manufacturing and assembly sectors had 60% of the improvements implemented by the A3 tool, but the impacts with the greatest economic significance for the company were found in other sectors, such as sales and logistics. The conclusion is drawn that the A3 report was effective in the deployment of Kaizen, resulting in the improvement of services and processes, and consequently in the direct reduction of the cost of the finished product. In addition, it influenced market and business expansion strategies throughout the company.

KEYWORDS

Kaizen, A3 report, Optimization of Services and Processes.

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INTRODUCTION

The impositions of the global market regarding inventory reduction, time and process optimization, product quality and price reduction tend to directly drive the adoption of the lean production model. Lean Production is more than the complex set of tools that make up the system, dealing in a more in-depth manner with practical activities and processes. The core of these Lean Production practices has its origin in the Kaizen philosophy, developed during World War II. This philosophy is based on the elimination of waste based on solutions with a low implementation cost (Singh and Singh, 2009). In 1930, Walter Shewhart defined four steps for the deployment of Kaizen, forming a cycle known as: Plan-Do-Check-Act (PDCA) (Durward et al, 2010).

The PDCA method exceeds the simplified definition of an improvement cycle, but deals mainly with the management method of companies. The management method has become a commercial barrier to companies since the revision of ISO 9000 (Quality management systems by International Organization for Standardization) in 1994, directly implicating the company's management process in the audit processes (Lobodová, 2003). The PDCA is a process and system management method that works by adding quality to the final product. The management method in the PDCA cycle has repercussions not only for process improvements, but also for the evolution of products and business expansion.

The PDCA cycle begins in the Plan stage, in which analyses from the most varied points of view are made regarding a particular product. The goal is to identify possible points of failure and improvement in the implementation process. In the next step, called Do, the actions and metrics established in the Plan phase are carried out in practice. With the practical process in progress, the Check step emerges, where measurements produce performance indicators that are compared to those predicted in the planning phase. Finally, the Act step intervenes in the process in order to propose corrective and/or improvement actions in the cycle, even recommending the creation of a new cycle, if necessary (Womack et al, 1992).

The implementation of the PDCA management method can be incorporated to companies by making use of techniques and methodologies that facilitate its development. The A3 report is one of these tools. It regularizes and systematizes the collected data, presenting the main causes, the actions taken and the proposed solution to eliminate problems and defects in both products and services on one side of an A3 sheet (42x29.7cm). The results presented by this report enable not only the detailed analysis of causes, actions and solutions, but also a record of the occurrences and measures adopted on each A3, forming a history of data for future reference, accelerating decision making (Durward et al, 2010).

The Kaizen philosophy has been adopted across the world for more than 60 years and comes for the Japanese word meaning "good change". Its principle is the quick analysis of the smaller components of a problem, in addition to quick and continuous implementation (Knechtges and Decker, 2014). A variety of A3 reporting structures can be found in the scientific literature (Lenort et al, 2017). Even though the information is summarized, the A3 report should seek to be clear in the presentation of data. As such, the typical sections of an A3 report include: 1-Context, why is this work being done?

How important is it to the company? 2-Current situation, what is the current context? What current aspects are being analyzed? 3-Objective, what are the objectives of the work? What is the expected result? 4-Analysis, what are the causes of the current scenario? What causes this condition and why does it exist? 5-Countermeasures, what is the analyzed basis for defining what must be done to improve the current situation and meet the goal or target? What needs to be done for the A3 document to have positive results? 6-Plan of Action, how will the countermeasures be put into practice? Description of the operationalization of the countermeasures. 7-Follow-up, work status, proof that the expected results have been achieved. In this section, a decision is made based on the developed analysis: if the expected result is obtained, the improvement is progressed to other areas, otherwise the cycle is resumed with improvement of the studies obtained so far. 8-Upgrade, expansion of the work to other areas of the company.

Even though it is a summarized document, the A3 tool mainly promotes the learning of all those involved in the development of each document, making the comprehension and understanding easier for those who did not participate in the construction of the reports. In addition to being an informative report, the A3 tool promotes and develops practices that structure ideas and practices for successful Kaizen implementation (Durward et al, 2010).

The concepts of the A3 report have been deployed in the automotive sector, improving and facilitating the implementation of the Kaizen philosophy, obtaining remarkably successful results in the application of Lean Production, which explains the tool's choice in the approach of this study. The main objective of this article was therefore to analyze the impacts on the implementation of the Kaizen philosophy of the use of the A3 tool in a steel structure prefabrication and assembly company in Brazil.

HISTORY OF THE APPLICATION

A case study was applied to a construction company that implemented the Kaizen philosophy, seeking results through the commitment of all involved in all areas and processes of the company. The Kaizen deployment process used the A3 reporting tool to support improvements, providing for the interaction of several people from a wide range of areas in the company. The improvement of a particular area or process did not depend only on the internal decisions of the sector, but on all those involved, including customers and suppliers. The company's internal productivity gains should be significant as long as the input and output processes were not changed (customers and suppliers), regardless of whether the process is pulled or pushed. The improvement would only be accepted by the managers of the company when all the members of the group were in agreement with the proposal.

Subsequently, costs were gathered and a schedule was developed for a feasibility study of the changes proposed by the A3 reports, which would then either be approved or rejected by the company's senior management. When the group of collaborators didn't have sufficient know-how about some aspect of the process or product, the company would summon at least one representative from each area involved to participate in the discussion. Most of the time, the guests were qualified people, specialists/coordinators in their areas with an up-to-date understanding of a particular product or process.

Continuing with the implementation of the A3 tool, a pilot report was prepared to present the changes to senior management and all coordinators and representatives of the company. The report consisted of a single sheet prepared and printed in the standard ISO 216 format, size A3, printed on only one side. Afterwards, the report was presented to senior management so it could validate and approve the changes as well as the necessary investment, if applicable. With this, the sectors involved were tasked with developing a collective task force for change, with targets set by senior management so that the project could be deployed in the shortest possible time, avoiding any production stops that would result in delays in relation to the schedules already defined with the customers, considering the large portfolio of works (more than 20) performed simultaneously.

The company also devised a procedure in which all improvements presented and implemented by the A3 reports were displayed in an auditorium through printed boards. The objective of this action was to expose to the employees all factors involving the changes, processes, barriers, challenges and, especially, the gains that the company would have based on the development of the documents. In addition to this display, the company held a commemoratory meeting with the employees to promote the reports in order to congratulate and recognize the commitment of those involved so as to encourage the continuity of the A3 report practice.

The company records showed that the production sector was the first area to implement the A3 reports, as requested by the presidency. The results were significant even after the first implementations in the productive process, including a reduction of the lead time, which resulted in the creation of a specific sector within the company called Continuous Improvement, which was responsible for managing and implementing Kaizen. The Continuous Improvement sector was therefore in charge of mediating, recruiting, managing schedules and conducting matters that involved improvements for the company, such as the standardization of products and processes. The standardization of products and processes was one of the first approaches implemented in the company by this sector. This is a characteristic process when it comes to continuous improvement, because as the standard is improved, the new standard becomes the foundation for further improvements, creating an infinite cycle (MÍkva, 2016). Kaizen was the focus of the company in the pursuit of the stabilization and improvement of processes and products, making departments train employees, who were always guided by a more specialized leader following the proposal by Hambach, Kümmel and Metternich (2017).

With the consolidation of the A3 tool in the factory line, the practice spread to the other areas, including logistics, engineering, sales, quality and assembly. The A3 report is created with the information laid out in a compact and clear manner. It works with such tools as Pareto charts, Cause-effect diagrams, Five whys method, graphs to express the obtained data or results and statistical analyses to get an accurate overview of all the information. As such, a standard was created for the report, which can be seen in Fig. 1.

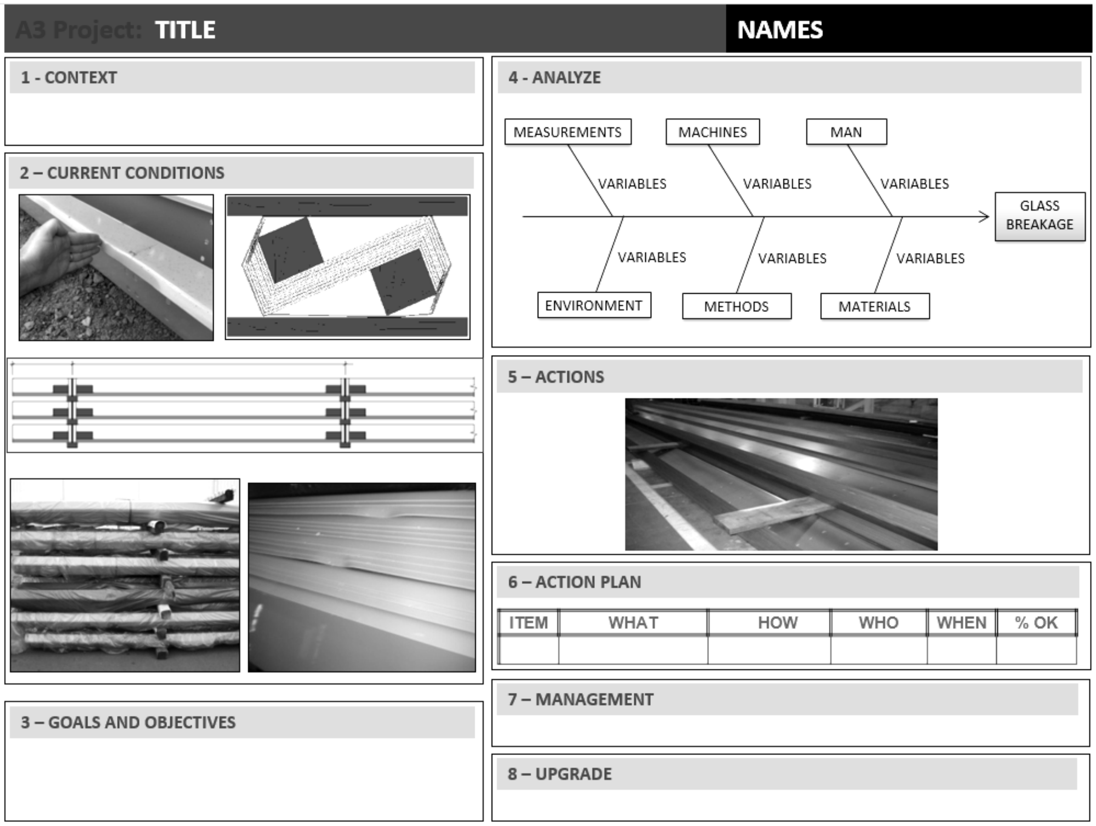

Figure 1: A3 standard developed by the company

RESEARCH METHOD

This study was developed in a Brazilian prefabricated steel structure company that has been operating in the market for forty years. Its specialty is constructive systems made of steel structures and it is active in both the national and international civil construction sector. The company has sales, engineering, factory, logistics and assembly sectors for the development of its products, including: industrial warehouses, multi-story warehouses, factories, malls and distribution centers. Designs are developed and parts are manufactured simultaneously, which means the adopted solutions must be compatible with the factory's limitations. The company has an average portfolio of 20 works being designed and manufactured simultaneously, which tends to increase the complexity of the management, taking into account the variability of the product and the volume of demand. Because of these aspects, the company sought to implement techniques and tools that could promote the development of an adequate management of all its sectors, adding value to the final product and improving the company's market competitiveness.

As such, the A3 reports developments by the company over the course of seven years, during which the Kaizen approach was used, was studied. The plan and sequence of the employed research can be observed in Figure 2.

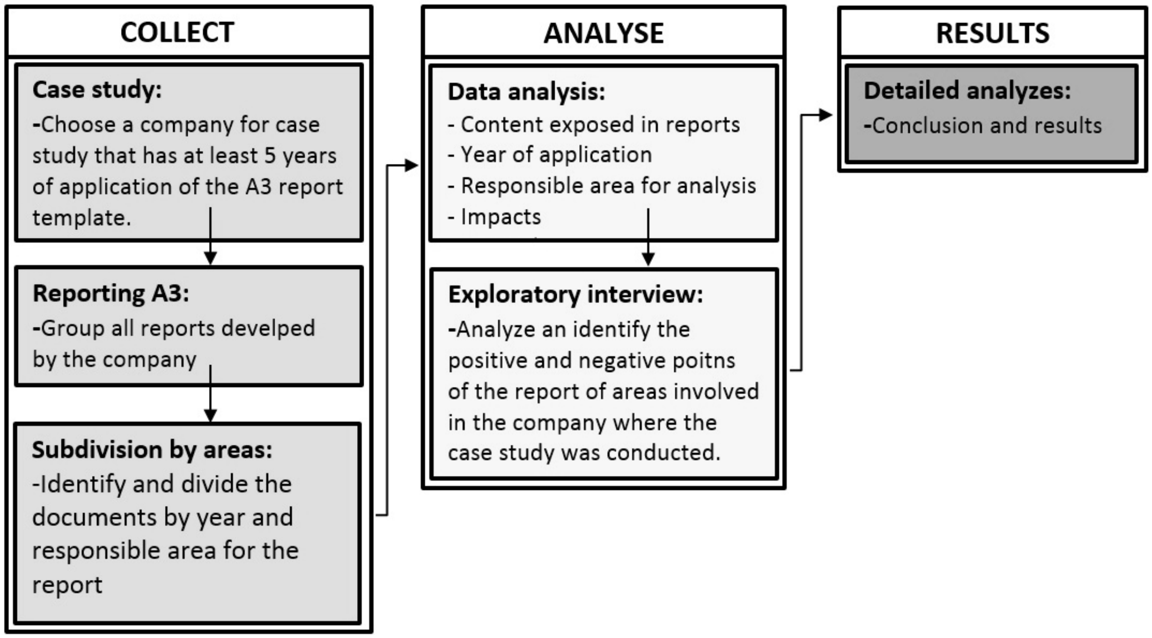

Figure 2: Research steps

The first step of the case study consisted in collecting all the files and reports developed by the company over the seven years. The company's IT manager made the files available, which were archived throughout the development as part of the company's process. The next step was to subdivide these reports according to the year and sector responsible for implementing the measures proposed in each report. The gathering of A3 reports resulted in a detailed analysis of the content of each document found, which sought to identify those that were most significant for each segment of the company using criteria such as time reduction, cost reduction, safety improvements and product innovation. The reports were classified as product, process and market strategy improvements, with each document receiving a score (from 0 to 10, with 0 being low impact and 10 high impact) regarding the results obtained with its implementation.

The third step of the study consisted of an exploratory interview with the coordinators of each sector of the company with questions focused on the characterization of the positive and negative points in the application of the A3 reporting method. The questions were of a discursive nature, giving total freedom to the respondents in their answers and comments on the subject. Finally, with the information collected, the five reports with the greatest impact on the company were selected based on the classification described above, which were developed with the intent of addressing the biggest problem pointed out by the industrial direction, high time to prepare the machine configuration to start production.

RESULTS

From 2010, when Kaizen was first implemented, until the end of 2017, a total of 154 A3 reports were compiled by the manufacturing, engineering, sales, logistics and assembly sectors. Figure 3 shows the progress and formulation of the A3 reports, dividing them by area and year of development.

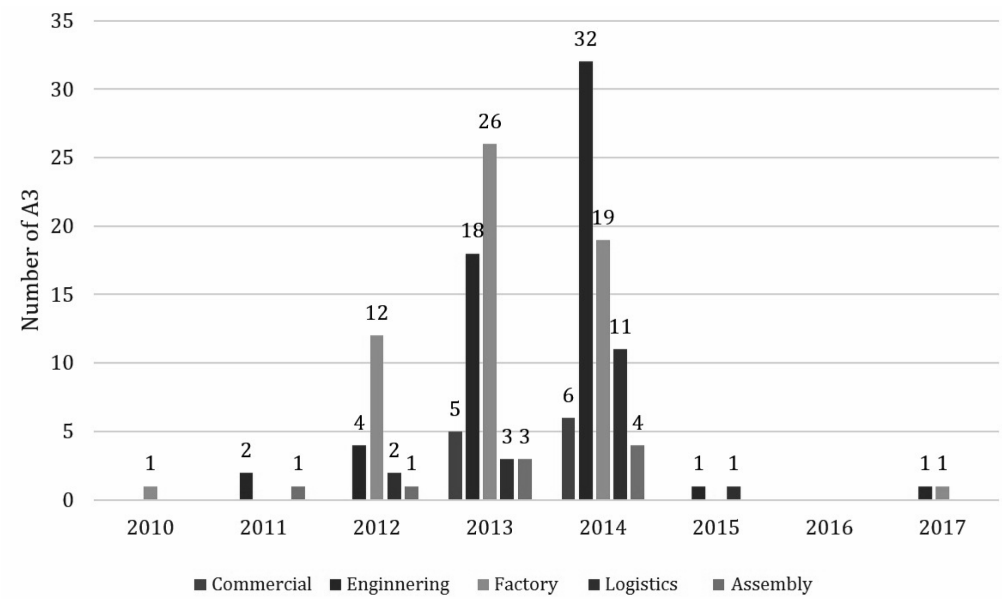

Figure 3: Number of A3 copies developed in each sector of the company

In 2010, only one A3 report was developed, considering that this was the pilot project for the implementation of the Kaizen philosophy in the company. Between 2012 and 2014, the largest volume of A3 reports was produced, which was also when the project underwent its greatest development in the company. After 2015, a significant drop in the creation of reports can be observed, which can be explained by the reduction of investments made by the company in the areas of innovation, standardization and continuous improvement (Kaizen) because of the recession in the construction sector.

With regard to the sectors, the engineering and manufacturing sectors were identified as being responsible for 76% of the generated A3 reports as shown in Figure 4, which could be explained by the fact that the engineering director was the greatest promoter of the improvements, creating A3 reports with more complex criteria related to the standardization of engineering processes and manufacturing projects. As for the factory, the reports had less complex criteria, linked directly to the actual problems faced by workers in their day-to-day work.

The A3 reports were also classified according to the type of solution, observing the criteria used by the company to divide the main areas of focus: services, innovation and processes, as can be seen in Figure 5. Services refer specifically to improvements in the quality of services provided by the company. The A3 service reports are mainly focused on the assembly area, on flow and cost management. Innovation, on the other hand, was a fundamental pillar in the sales area, especially regarding customer retention, market prospecting, competitiveness and portfolio management. The reports were also developed by the Engineering and Production sectors, with engineering creating new constructive solutions and improving product designs, while in the factory innovative tools were created based on the lean production concepts. The processes were the ones that stood out most in the engineering, production and logistics sectors, staying considerably above the average line due to the adjustment of production processes according to, once again, the Lean Production concept. The average line is composed of the total of A3, divided by the number of sectors of the company analyzed, showing the focus of the actions developed, through a medium line.

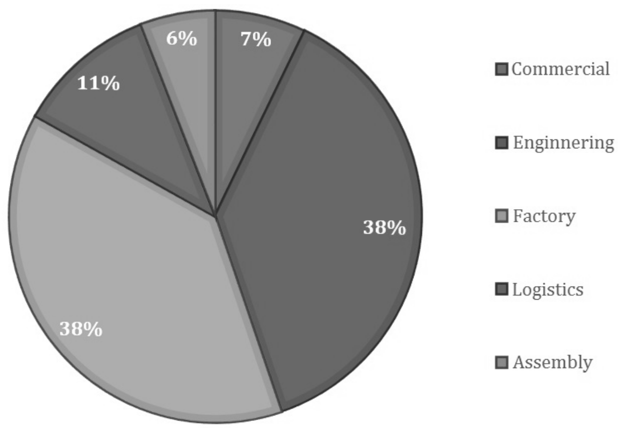

Figure 4: Participation of the areas in the development of Kaizen management

The increasing use of A3 reports between 2012 and 2014 can be associated with the acceptance and incorporation of this practice by all employees in the different areas of the company.

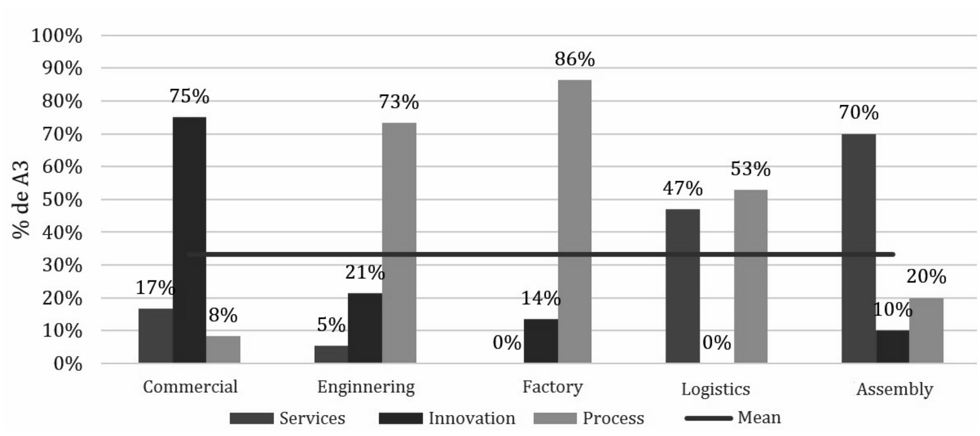

Figure 5: Percentage of A3 reports per solution type

Regarding the degree of impact of the improvements for each sector of the company, Figure 6 divides these impacts into low, medium and high impacts. The scores were ranked from 1 to 10, classifying 0 to 4 points as a low, 4.1 to 6 as average, and 6.1 and over as a high grade. The score was defined by a group of the company's continuous improvement sector in conjunction with the development of this study, based on such factors as the added value of the improvement, deployment cost, improvement benefits, and popular vote (among company employees).

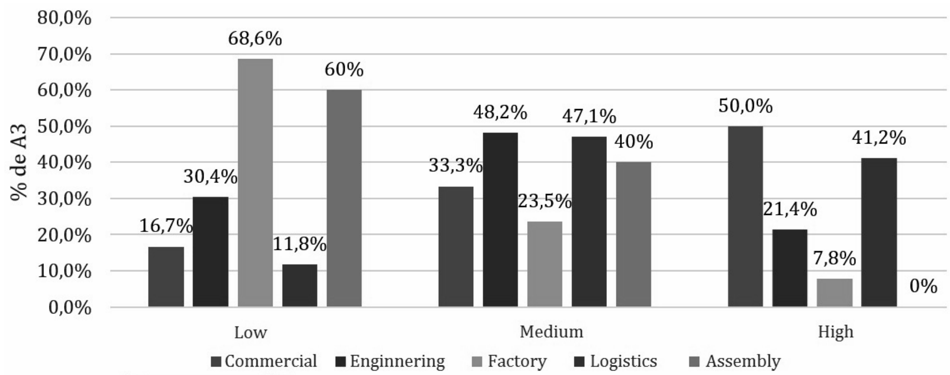

Figure 6: Percentage of A3 reports by sector and degree of impact

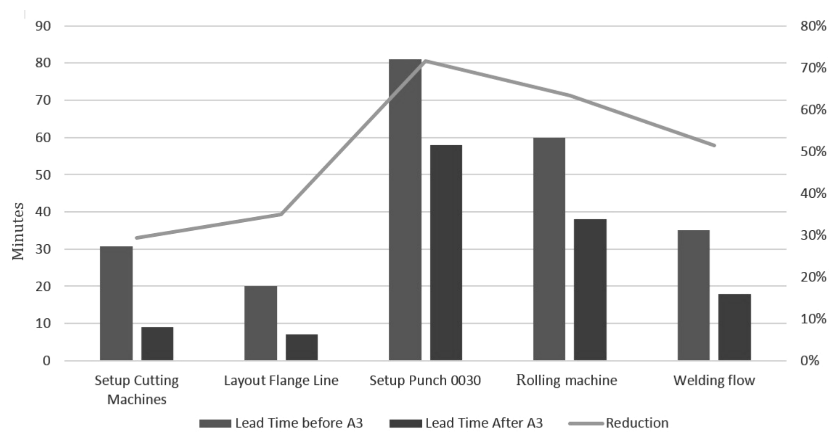

Figure 7: Result of the A3 tool in processes

Five A3 reports of the factory processes were selected in which the obtained results revealed a reduction in lead time in the production of parts in all the sectors where Kaizen was applied with the A3 tool. After applying the A3 report in the machine setup and layout processes, according to Figure 7, satisfactory lead time gains for the company were identified when compared to the previous scenario, in some cases cutting these times by a third of the previous time. The reduction in lead time resulted in such gains as the synchronization of the production process, with a capacity to calculate the productive capacity of the work center and consequently schedule production, reducing buffers or inventories of raw material.

CONCLUSIONS

The implementation of the Kaizen philosophy adopting the A3 reporting tool was effective in making those involved in this study absorb the concepts. The record of the situations addressed and treated by the A3 tool tends to result in an acceleration of decision making in future recurrences, since a database is created with the scenarios of the application of each improvement. Although the development of the A3 tool is feasible for any employee, the involvement of the managers and the commitment of the workers are fundamental for the success of the tool. That is why the recommendations on how to produce effective A3 reports are related to the implementation instead to the A3 tool itself.

The company's recognition of the developed A3 documents motivated employees in the routine identification of improvements in processes and services during their daily work. To the extent that problems were found and resolved and processes organized, the time that was previously spent on unnecessary activities (waste) was now used to solve new problems that emerged, forming a continuous improvement cycle.

The implementation of Kaizen brought gains to the company as a whole, optimizing processes, reducing production lead time, organizing services, standardizing products and contributing to product innovation, leading to the continuous pursuit for quality, error minimization and waste reduction.

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ISO AND LEAN CAN CONTRIBUTE TO A CULTURE OF CONTINUOUS IMPROVEMENT

Christy P. Gomez[1] and Hashima Hamid[2]

ABSTRACT

There is increasing "acceptance" that compliance to International Organization for Standardization (ISO) Quality Management Systems is adequate to secure the full benefits of continuous improvement (CI) practice. This appears to detract construction organizations from developing CI practice that can significantly contribute to a *culture of CI*. This paper proposes that implementation of the Last Planner System® (LPS) for improving construction project planning and scheduling (P&S), based on lean construction's TFV theory, can contribute to CI culture within an ISO QMS compliance framework. It is argued that claims regarding lean construction as being amongst one of the many construction improvement 'panaceas' that are non-contextual, generic solutions that are reductionist 'bolt-on' models of change are rather unfounded.

In order to substantiate the above argument a CI maturity model was developed based on CI critical success factors based on a Delphi survey, and the CI maturity level of ISO-certified and non-ISO certified construction contracting organizations in the P&S process was compared. 39 ISO-certified and 57 non-ISO certified contractor's CI maturity was analyzed using independent t-test. Although the ISO-certified organizations' CI maturity level was higher, the general maturity level was low, warranting serious consideration for the application of LPS.

KEYWORDS

Lean construction, continuous improvement, Last Planner System, ISO-certified organizations.

INTRODUCTION

The construction industry has often been "singled out" for not having taken on board improvement initiatives in an industry-wide and consistent manner to iron out key problematic areas such as timely delivery of projects, poor safety and quality standards and its adverse impact to the environment. There has been strong criticism from some quarters stating that the construction industry seems to be very much in an adversarial position in comparison to other major industries like manufacturing in embracing best

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practice, especially that of process improvement initiatives. However, of recent, there is evidence of increasing uptake by the construction industry.

Within the construction industry there is a general ‘acceptance’ regarding the notion of best practice. Practice is predominantly explained using objective terms, although it is a context-specific and transient concept and subjective in nature. In acknowledging the subjective nature of practice, and for want of amore appropriate term Gomez (n.d.) refers to “excellent practice” to imply better practice based on benchmarking. Green (2001) vehemently objects to the rhetoric of best practice, considering it to be rather prescriptive to the extent of being proffered universally as a panacea for the construction industry’s problems. He apparently views lean production, partnering and business process engineering as exemplars of the predominant ‘best practice’ agenda, serving the narrow cost efficiency interests of the technocratic elite (Green, 2000) at the expense of broader soft human resource management considerations. Taking on a critical perspective, he argues that lean construction is not a theoretically neutral concept, he describes lean construction as just another improvement recipe that fits with the construction industry’s dominant culture of ‘command and control, and thus conveniently accepted as ‘best practice’.

Green (2001, 2011), views generic best practice as a management fashion, shaped and judged by rhetoric of the marketplace (Green, 2001), and not contextual in nature. According to him the best practice initiatives are most willingly undertaken by a management elite aimed at perpetuating the management regime of command and control. Using a critical analytical lens, he observes that there seems to be an uncritical acceptance of the discourse of best practice, as in the case of Business Process Reengineering (BPR); which is still being highly regarded, although there is convincing research evidence that the majority of BPR initiatives fail. It is additionally claimed by him that lean production shares many of the characteristics of BPR - referring to lean production as a cocktail of ideas that includes the continuous improvement concept (Green, 2011).

This paper is presented as a timely, reflexive response to the critical view on lean construction presented by Green (1999, 2001, 2011) and those whom he cites in support of his arguments. The earlier response provided by Howell and Ballard (1999) dismisses much of the claims made by Green (1999) against lean construction; primarily addressing his disconnect with lean construction’s emphasis on reliable workflow centred around production management. In this paper, the response to much of Green’s lamentations is done in the context of tackling the issue of instituting a culture of CI within construction projects through the implementation of the Last Planner System® (LPS) - as a CI management tool in planning and scheduling of projects.

It appears that Green (2011) seems too casual in his critical analysis of lean construction as a practice, loosely lumping lean construction with most of the other process improvement initiatives –leading him to assume that the so-called “best practice” initiatives such as BPR, Total Quality Management (TQM) and Lean Construction rely on generic reductionist tools and techniques. It is suggested here that by using the same critical lens, but with the benefit of having experiential knowledge, detractors would be able to appreciate that this is clearly not the case with lean construction - taking just the

Last Planner System® (LPS) as a case in point. The lean construction community has forwarded strong criticisms with regard to the traditional monolithic systems view of construction projects resulting in vertical reductionist views and top-down approaches, like the work breakdown structure and the critical path method. Dave (2015) notes that Lean as a process improvement methodology has much to offer; stating that unlike Lean, the other major process improvement approaches do not foster a balance between the key areas of people, process and technology. The criticism levelled by Green (2011) against lean construction to be at best a 'bolt-on' model of change 'transplanted' from manufacturing is additionally disconcerting. It is important to have more than just a single lens to view how knowledge is "transferred" or rather "acquired" from other industries; as is well established with respect to process benchmarking. The technological knowledge of lean construction, as perceived here in terms of the LPS, which is taken to constitute CI practice, is seen as being "acquired" through the efforts of lean construction practitioners, that is best understood in terms of the culture acquisition model.

LPS AS CONTEXTUALIZED CI PRACTICE UNDERSTOOD BASED ON THE CULTURE ACQUISITION MODEL

The view that knowledge requires contextual adaptation, from a social constructivist perspective, is in reference to a community of knowing adopting an idea, information or knowledge from a different community of knowing, as some external ideas may not fit (Fleck, 1935/1979 cited in Tenkasi et al., 1999). Hence, it is proposed by Tenkasi et al. (1999), that the information or knowledge may have to be reconfigured or adapted to fit in with the recipient community's meaning system. They posit three different operating assumptions regarding knowledge:

- knowledge may be subjectively constructed and may be subjectively consumed;
- knowledge requires contextual adaptation;
- knowledge is incomplete.

It is in this sense, that the *culture acquisition model* is seen as relevant to understanding lean construction, in terms of community of practice (CoPs) of lean construction practitioners contextualizing practice that was initially developed for the manufacturing industry and producing knowledge relevant to the construction industry. The "culture acquisition model shifts our attention to the work of individuals who make and remake culture and use it for their own ends" (Henning, 1998: p. 86); rather than according to the culture transmission model, which takes the view of culture as a force that organises people. Central to the concept of the 'culture acquisition model' in the context of learning related to lean construction, is that the learner is not a passive receiver, and there is active participation as well as an emphasis on existing conceptions regarding the area of learning (see Fetherston, 1997).

As such, it is clear that Green's criticism of lean production is rather unfounded as the application of lean construction principles, although rightly acknowledged to have been "borrowed" or adapted from lean manufacturing, have been clearly contextualized. The acquired knowledge invariably supported with relevant theory, in addition to having undergone industry validation. The developments attributed to lean thinking are clearly based on a non-reductionist view of the construction project, with the prime motive of maximizing value and minimizing waste in the widest sense possible (a phrase that implies 'interpretive flexibility'). It cannot be denied that in order to operationalize abstract concepts, mechanisms (structure and organization) have to be relied on. Although lean construction is founded on sound principles and theories that has consistent guidelines for implementing the well-researched lean practices, there is 'interpretive flexibility'. If contextualization is a key feature of the relevance of a practice, then certain amount of interpretive flexibility, if not more, needs to be accommodated to engender more creative and significant applications. In this sense, it is argued here that the criticism accorded Lean as being amenable to interpretive flexibility, as Green (2001) views it, is rather limiting. As it clearly sits well within a constructivist notion of knowledge production, which seems to have escaped Green's consideration.

In enquiring into the nature of construction management theory Seymour et al. (1997)note that research in construction management has tended to underestimate or ignore the importance of the interpretive process. From a methodological perspective, this piece of work relies on the researcher's interpretive sense making of the limitations of ISO management systems to embed CI as a practice, whilst taking on a generative research prospect for implementing CI through the LPS for planning and scheduling to contribute to a culture of CI. In more specific terms, this paper is centred around research work aimed at investigating the extent to which the generic process improvement initiative of ISO 9000:2000 series and onwards, which has been gradually placing greater emphasis on CI, can by itself contribute to a high CI maturity level within an organization. As anticipated, it was found that ISO accredited construction contracting organizations, though having a relatively higher level of CI maturity compared to non-ISO organizations, still did not have a high level of CI maturity. Thus, this paper proposes that the application of the LPS, that is structured based on the concept of transformation, flow and value (TFV) could be key to the implementation of CI with respect to the process of Planning and Scheduling (P&S), and thus can contribute significantly to establishing a culture of CI within construction contracting organizations. The intention is to use the LPS as a moot point to draw attention to some of the false claims forwarded by Green against the practice of lean construction.
To recap: the TFV conceptual framework as proposed by Koskela (2002) supports a variety of different tools and techniques that allow the principles of Lean to be applied to the management of construction projects as part of the Lean Production Delivery System (LPDS) - the best known of these is last planner (see Ballard and Howell, 1998), which is structured on the principle of CI.

REVIEWING CI WITHIN CONSTRUCTION INDUSTRY ISO QMS

Although, there have been recent developments within the industry regarding the implementation of CI, however it is evident that this concept is being incorporated within the many generic organization-wide initiatives, such as TQM, ISO 9001:2015 and business models of organizational excellence assessment. The concept of CI was given serious attention based on the work of Deming. The Deming cycle (Plan, Do, Check, Act - PDCA) is a methodology for continuous improvement. This methodology, originally called the Shewhart cycle (initially was a straight line process) for statistical quality control, was developed by Walter A. Shewhart. It was renamed the Deming wheel or cycle by the Japanese in 1950. W. Edwards Deming suggested that the procedure should be followed for the improvement of any stage of production for finding a special cause of variation indicated by statistical signals (Deming Cycle, 2000). Finally, in 1951 Japanese executives developed the Deming cycle into the current PDCA cycle. By the 1960's the PDCA cycle in Japan had evolved into an improvement cycle, and a management tool. The traditional practice in CI implementation is the standard PDCA process. PDCA is often used as a framework for executing Kaizen, which refers to the process of undertaking small incremental continuous improvements in the workplace.

Based on the current scenario in Malaysia and worldwide, an increasing number of construction organizations are now accredited with ISO 9001:2015 (previously being ISO 9001:2008) Quality Management Systems (QMS) standards. ISO:9000 Quality Management Standards (QMS) is now regarded as one amongst the many business improvement methodologies, although initially thought of as a validation of standard operating procedures that are indicative of having in place processes to assure quality. It is noted by Murphy (2002), that with the release of ISO 9000:2000, an unprecedented emphasis has been placed on customer satisfaction and continual improvement. Based on the statistics provided by the Department of Standards Malaysia, updated to the 3rd Quarter of 2017, there are 1,357 ISO 9000 QMS certified construction organizations, the highest amongst all industries. This is heartening to some extent. However, a related issue that has arisen is the perception amongst industry practitioners that having an emphasis on CI within ISO 9001:2000 series is adequate.

A key point of contention is the general perception that by embodying CI within ISO worldwide, ISO (ISO 9001:2008 recently updated to ISO 9001:2015 Quality management systems-requirements) has opened the door for all types of firms all over the world to begin their journey to excellence performance. However, as stated by Stankard (2002) " ISO … alone is insufficient to achieve durable competitive advantage and high performance.. it's scope is too narrow." ISO is viewed here as structured on a "push" philosophy, primarily an auditing tool aimed at guiding performance and instituting acceptable corrective actions. Whilst business excellence practice takes on a more self-assessment driven approach -however still undertaken within a reflective (reactive) mode, and unable to fully capitalize on the full benefits of CI.

The practice of CI requires an attitude that focuses on a contextualized systemic, ongoing value enhancement process with all implementations having a firm theoretical grounding. In this respect, it is important to differentiate Clause 10.3 of ISO 9001:2015 which primarily aims to impress on the organization to continuously improve the suitability, adequacy and effectiveness of the quality management system (QMS). These generic business improvement methodologies that do not have in place specifically designed-in mechanisms to undertake the practice of CI can be limiting. Additionally, for the construction project team this can be rather more problematic, taking into account the

3 *peculiarities* associated with construction projects, i.e. site production; one-of-a-kind product and temporary production organization (see Koskela, 2000).

CI AND THE LAST PLANNER SYSTEM

CI as a process improvement concept is considered as being fundamental to achieving high performance. One key feature of this would entail measurement. Some key indicators of CI are that of performance in eliminating defects, reducing process and product waste, managing efficient production and thus improving productivity, achieved on a continuous improvement basis. Much work has been undertaken by the lean construction community on planning in design and construction underpinned by the philosophy of CI, especially the work of Ballard (2000) on the Last Planner System® (LPS). However, in general such efforts have not been well received by the wider construction management community.

The LPS is seen here as key to enabling CI within construction projects. Construction organizations intending to embed a culture of CI within their organizations have at their disposal a technique that shapes workflow and addresses project variability in construction. It is noted by Salem (2005) that in the LPS, the sequences of implementation of master schedule, reverse phase schedules (RPS), six-week look ahead, weekly work plan (WWP), percent plan complete (PPC), constraint analysis and variances analysis sets up an efficient schedule planning framework based on a pull technique, to manage work flow, sequence, and rate. The LPS matching work flow and capacity allows for developing stakeholder-devised methods in executing work and improves communication between trades. Hamzeh (2011) describes the LPS as one that challenges the old practice of developing schedules and pushing them from top management down to frontline people to execute. It advocates collaborative planning, performing collaborative constraint analysis, and learning from plan failures. He notes that the LPS institutionalizes coordination and communication by incorporating them into everyday activities and into a managerial structure for project planning and control, team building, and continuous improvement.

Sacks et al. (2010), impress the point that CI needs to be deliberate, institutionalized, and implemented as a systematic form of improvement, wherein CI goes beyond mere learning.Dave (2015) notes that Lean philosophy has gained stronger ground as a process improvement philosophy in organizations. Empowerment of people is significant in Lean as workers are given responsibility to control and improve their own processes. It is also more sustainable as it proposes close integration with suppliers to achieve a long term relationship based on trust and mutual benefit. The fundamental problem facing most improvement methodologies are that they lack a specific theoretical basis. This is not the case with CI based on the Lean theoretical framework.

IS COMPLIANCE TO ISO INDICATIVE OF CI PRACTICE?

Specifically, in construction projects, as stated by Shu-Hui and Ping (2006), one of main problems in planning and scheduling (P&S) is the determination of the project schedule, especially when the resources required are limited, and the traditional schedule estimate often fails in optimizing the project performance. It is imperative that a continuous improvement process needs to be established with a feedback loop embedded within the work process using industry-specific tools and techniques. The key notion is that of ‘improving’. The question to be asked is then, does and can ISO deliver aspects such as these, when ISO has its purpose of meeting generic standards. It is stated by Gomez and Hashima, (2009) that the establishment of CI as a practice for P&S requires more “effort” than what is mandated according to ISO 9001.

It cannot be denied that in order to set in place a CI initiative, specific project-specific measures to enable improvement have to be designed and owned by the specific stakeholders. In this respect, this paper provides a comprehensive set of measures of CI practice for P&S of construction projects based on having in place the particular P&S work process CSFs.

EMPIRICAL RESEARCH METHODOLOGY

ACI maturity model for construction project P&S process was developed as a questionnaire form in order to measure the CI practice of both ISO-certified and non-ISO certified large construction contracting organizations. From the distributed questionnaires, 39 ISO certified and 57 non-ISO certified major contractors belonging to the grade G6 and G7category responded (see Table 2).These two grades of contractors, are viewed here as major contractors. Grade 6 contractor companies are eligible to tender for projects costing not more than RM10 million whilst G7 contractors are eligible for tendering for projects costing RM10 million and above. The CI maturity model was developed based on CI critical success factors (CSFs) identified through a 3-round Delphi survey consisting of P&S CSFs identified from literature. The Delphi expert panel consisted of initially 15 construction industry practitioners, with an average of 8 years working experience on construction projects at management level. The number of experts finally trickled down to 6 experts. A total of 8 main latent CSF constructs (see Table 1) were identified with a total of 38 observable constructs.

Table 1: The eight latent CSF constructs for planning and scheduling

CSF1	Development of Continuous Improvement System for Planning & Scheduling (P&S)
CSF2	Development of Performance Measures for P&S
CSF3	Management Review for P&S
CSF4	Analysis of Processes to Identify Improvement Actions
CSF5	Implementation of Improvement Process for P&S
CSF6	Variation Management (general) for P&S
CSF7	Variation Control Method for P&S
CSF8	Variation Management Activities for P&S

The respondents were asked to mark their organization’s level of CI practice according to a five point Likert-scale for a total of 38 observable constructs of the 8 latent CSFs. SPSS software was used to undertake parametric independent t-test to compare the mean of the two independent samples.The feedback from questionnaires were calculated based on mean score and standard deviation. Average Index (AI) method was used to analyze the data. The scores provided by the respondents for all of the 8 main CI critical success factors for P&S in the questionnaire was summed up. The total score for each of the CSFs was calculated and divided with the total number of elements for each main CSF. The average was multiplied by hundred percent to obtain the level of CI practice. The categorization of the CI maturity levels was adapted from Bessant and Caffyn (1994)and validated by the Delphi experts.

Table 2: ISO and Non-ISO Certified Companies Involved In the Survey

ISO Certified Contracting Construction Organizations	Grade of Contractors		
	G7	**G6**	**Total**
Yes	25	14	39
No	32	25	57
Total	**57**	**39**	**96**

Table 3: Percentage, Grade and Description of CI Maturity Level

LEVEL	CI MATURITY SCORE	DESCRIPTION
5th Level	90<CI≤ 100%	Self-optimized CI practice implementation
4th Level	80<CI≤ 90%	Excellent CI practice implementation
3rd Level	70<CI≤ 80%	Clear structured implementation of CI activities
2th Level	60<CI≤ 70%	Implementation of CI activities at organization level
1st Level	50<CI≤ 60%	Implementation of CI practice at project level
0 Level	CI≤ 50%	No clear indication of CI practice.

RESULTS

The approach taken here is to directly relate the achievement of CSFs as indicative of the practice of CI. Table 4 below indicates the frequency of major contracting construction organizations (G6 and G7) according to the 5 levels of CI maturity. The results show that there are 6 ISO-certified organizations at the highest 5th level CI maturity, 17 companies at level 4, and 16 companies at level 3, out of the total 39 ISO certified organizations. However, for the 57 non-ISO contracting construction organization, there were none at level 5, 3 (5.3%) were confirmed to be at level 4, followed by 20 (35.1%) at level 3; 26 at level 2 (45.6%); 1 at level 1 (1.8%) and 7 at level 0 (12.3%). The findings of this research indicates that ISO certified companies are relatively more inclined towards having a more matured CI practice. Although the results show that ISO organizations have a relatively higher level of CI maturity, the CI maturity levels are still rather low.

Table 4: CI Maturity Level of ISO and non-ISO Certified Contracting Organizations

CI Maturity Level		5th	4th	3rd	2nd	1st	0	Total
ISO certified Organizations	Freq.	6	17	16	0	0	0	39
	Percent	15.4%	43.6%	41.0%	.0%	.0%	.0%	100.0%
Non-ISO certified Organizations	Freq.	0	3	20	26	1	7	57
	Percent	.0%	5.3%	35.1%	45.6%	1.8%	12.3%	100.0%
Total		6	20	36	26	1	7	96
		6.2%	20.8%	37.5%	27.1%	1.0%	7.3%	100.0%

The research hypotheses is as follows:

There is a significant *difference* in CI maturity level in the area of planning and scheduling amongst major ISO and non-ISO of construction contracting organizations.

H_o: $\mu_{ISO} \neq \mu_{non\text{-}ISO}$

With respect to the research hypotheses stated above, the result of independent sample t-test shows that there are 37 correlations at significant level, $\alpha = 0.05$. Whilst, the calculated probability (p values) for 37 CSFs out of 38 are less than 0.05 for ISO certified and non-ISO certified large construction contracting organizations. Hence, there is a significant difference in the CI maturity level between ISO and non-ISO certified construction contracting organizations, although the CI maturity is generally not at a high level, as is evident from the results presented in Table 4.

CONCLUSION AND DISCUSSION

It is clear that many organizations are unaware of the fundamental changes needed to shift from a compliance orientation of ISO9000 standard and its variants to the form of management that places broader emphasis on CI(Cobb, 2003). This is rather disconcerting; in view of the vast amount of evidence-based research on the implementation of lean construction principles and its related contributions to CI practice, however still facing the challenge of slow uptake. It is hoped that this paper to some extent will serve to address the current ‘paradox’ within the Malaysian construction industry that appears to be satisfied with seeking to implement elements of CI practice through the ISO compliance route.

This paper has set out to emphasize the point that just having in place ISO:QMS 9001: 2015 standards is insufficient to develop a culture of CI, using the CI maturity model as an indicator. This paper aptly argues for the implementation of more contextualized theoretically-grounded mechanisms to bring about greater CI maturity that can contribute to a culture of CI. The specific case in point here is that of using the Last Planner® System (LPS) to enable the implementation of CI practice within the construction project planning and scheduling process. Wherein, the TFV conceptual framework as proposed by Koskela (2002) is taken as the theoretical foundation for achieving the full potential benefits of LPS.

The achievements in terms of CIthrough ISO:QMS 9001:2015 standards compliance are seen here as enabling organizations to grab onto the low hanging fruits of CI (to use a phrase borrowed from the sustainable development agenda). Thus, sole reliance on ISO certification is not sufficient for achieving fully the higher levels of CI maturity. In practical terms, it is important to view standards such as ISO 9001:2015 and the its variants as being complementary rather than being a competing approach in the pursuit of continuous improvement. Further research could be undertaken to investigate the level of 'readiness' of ISO 9001:2015 certified organizations compared to non-ISO certified organizations in the implementation of the different lean construction principles.

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STUDYING THE MINDSET OF CORRUPTION IN THE CONSTRUCTION INDUSTRY- A LEAN PERSPECTIVE

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ABSTRACT

Studies have shown that the construction industry practice involves corruption. Several factors such as the complexity of the project and organizations involved coupled with scarce sanctions on corrupt activities are basic hurdles for reducing corruption. Lebanon's construction industry is no exception since it is one of the developing countries that lack anti-corruption processes. The aim of this study is to (1) investigate the mindset behind unethical behavior in construction that has detrimental effects on the community and (2) suggest lean-based frameworks that can impact processes and behavior to reduce corruption. Surveys were conducted to better assess the level of awareness of the Lebanese community with regards to corruption, identify existing mitigation methods, and evaluate the importance and feasibility of integrating lean culture into the construction industry. Respondents do not consider some basic corrupt actions to be a serious problem indicating that there is a need for more efforts to raise the community's awareness to the significance of fighting corruption. An anti-corruption framework was designed using lean principles and tools was suggested to better mitigate and control corrupt acts in the Lebanese construction industry. Results show that the construction industry seems ready to accommodate this change. Nevertheless, it must happen at a low pace.

KEYWORDS

Corruption, Lean, Lebanon, Bribery, Anti-Corruption Tools, Integrity.

INTRODUCTION

Corruption is defined by Transparency International as "the abuse of entrusted power for private gain". The construction industry is known worldwide for corruption. According to

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the Bribe Payers Index in 2011, the amount of corruption in construction surpasses any other sector in the economy (Transparency International, International Secretariat, 2011). Corruption prevails in the construction sector due to many reasons. Specifically, the large funds going into these projects aid in price inflation and hiding huge bribes. The global construction market is estimated to be worth $3,200 billion per year. However, it is stated by the American Society of Civil Engineers that $340 billion per year of construction cost worldwide is accounted for corruption (Sohail & Cavill, 2008). To understand the logic behind these findings, this paper aims at analyzing the mindset of people primarily responsible for the mentioned numbers and propose some lean tools and principles that may promote the reduction of corruption in the construction industry while taking Lebanon as a case study.

CORRUPTION FORMS, CAUSES AND IMPLICATIONS

From literature, many forms of corruption were identified, some of them are major, and others are collateral. Le et al. (2014) identified many forms of corruption mainly: 1) Nepotism which can take the form of political pressure or abuse of power, 2) Bribery as taking either cash payment or non-monetary advantages for unjustifiable reasons, 3) Extortion taking the form of physical or financial threats, and many more forms such as fraud, embezzlement, bid rigging, negligence, conflict of interest, kickback, unfair conduct, dishonesty, and front companies.

Corruption in construction has multiple causes including: intense competition in the tendering process, lack of transparency in the selection criteria for tenderers, inappropriate political interferences in cost decisions, insufficient sanctions, complexity of institutional roles and functions, complexity of the project itself, weak transcription of records, asymmetric information among project parties, and relatively low ethical standards (Le et al. 2014; Tanzi 1998; Bologna & Nord 2010; Dorée 2004; Sohail & Cavill, 2008). Furthermore, the culture of each country plays a major role in advocating corrupt practices where gift-giving is mistaken for bribery (Luo, 2004). Culture also influences one's tendency to carry out corrupt actions so, according to Nordin et al. (2013) who interviewed Malaysian construction practitioners over the matter of corruption, it is safe to assume that such unethical acts are, at least partially, due to human behavior.

In relation to the construction industry and the public at large, these unethical practices result in destructive fallouts with respect to the quality of the built facility, project delivery duration, increasing competition among stakeholders and project prices, criminal prosecution and fines, and much more (Sohail & Cavill, 2006; Murray & Meghji, 2009; Stansbury, 2005). In addition, corruption reduces building lifespan and increases building collapse rates and death toll rates (Lewis, 2003; Ambraseys, 2010). Reports released by OECD (2014) state that corruption is approximated to account for $2.6 trillion dollars annually, which is 5% of the global gross domestic product (GDP), where around $1 trillion is in the form of bribery. Moreover, as stated by Kenny (2009), the construction industry is worth $1.7 trillion on an international level which constitutes 5%-7% of most countries' GDP. Since the greater number of corruption incidents occur in the construction field, it is important to constantly look for innovative measures to prevent global and local harm.

STATUS IN LEBANON

Even though corruption has always existed in Lebanon, its effects increased after the end of the civil war in 1990. Corruption in Lebanon occurs in all its forms including nepotism, patronage, bribery, embezzlement, vote-buying and many other forms (Lebanese Transparency Association, 2011). However, political corruption has been identified as Lebanon's the most serious corruption challenge. This is reinforced by the opinion of the Lebanese citizens about corruption. According to the Transparency International's Global Corruption Barometer 2011, 82% of the surveyed participants acknowledged that corruption has increased in the last 3 years. Moreover, 71% of the participants considered the government's actions against corruption as inefficient, or neither efficient nor inefficient. In addition, 68% of the survey participants did not trust the government as a credible actor in the fight against corruption (Wickberg, 2012).

According to the 2015 Open Budget Index Survey that was produced by the International Budget Partnership (IBP), Lebanon scored 2 out of 100 in transparency; which is substantially lower than the global average score of 45. Thus, Lebanon is categorized as one of the countries that provide least minimal information.

According to the 2009 Global Integrity Index, Lebanon scored 53 out of 100 and is recognized as a "very weak" country in terms of integrity. (Global Integrity, 2009) The low score is due to the absence of anti-corruption legislation and lack of institutions such as Ombudsman. (Lebanese Transparency Association, 2011)

The three major forms of corruption in Lebanon are: political, bureaucratic, and bribery. The sectors most affected by corruption show to be the most crucial sectors and that if corrupted, would affect all other sectors beneath. These sectors are the political parties, public administration, police, parliament and even judiciary (Wickberg, 2012).

When it comes to the Lebanese construction industry, around 50% of the construction firms are expected to "give gifts" to obtain construction permits, and around 20% of the firms do the same for operating license or labor inspection (Kenny, 2009). Moreover, from the owner's perspective, government bureaucracy and corruption in Lebanon are major contributors to the delay of construction project due to their negative effect on project financing (Mezher, Tawil, 1998).

Stifi et al. (2017) defined corruption as core waste that is characterized by producing other types of waste in addition to its own waste. Three main reasons for corruption in construction were also identified: lack of integrity, lack of transparency, and lack of accountability (Stifi et al., 2017). The objective of this research is to study construction professionals' perspective on unethical behavior and suggest lean-based frameworks that can impact processes and behavior to reduce corruption. There is very limited literature covering this subject in Lebanon, making this paper the first to address the issue which is critical for improving the industry.

RESEARCH METHODOLOGY

To better understand the topic at hand, the authors looked at previous contributions on corruption in the construction field. A survey was developed based on a previously designed questionnaire by The Chartered Institute of Building (Tanzi, 1998). It was modified to fit the Lebanese environment and construction industry. The general structure of the survey consists of two parts; demographic related questions as well as questions related to perception towards unethical behavior and the frequency of it happening. The survey included two matrix questions which were recorded in the 4 point Likert Scale to ensure accurate mapping (Marsden & Wright, 2010). Pilot testing was done randomly to make sure the proposed questions are clear and the results were effective.

SAMPLING, RESPONDENT PROFILE, AND ETHICS

Purposive non-probability critical sampling has been done in this study based on the researchers' knowledge of the population and the purpose of the study. Also, snowball sampling was used to fasten the process of finding eligible participants, as suggested by Wilson (2014). Characteristics of participants in the quantitative method include: Lebanese, holder of a Bachelor's degree, and working in the construction industry. Ethical issues regarding a participants' protection and confidentiality was insured by not including any personal identifiers. An informed consent was handled at the beginning of the survey and participants were mindful that they could quit from the study at any time. The research was submitted to an institutional review board to ensure the safety and welfare of the participants.

INSTRUMENTS, DATA SIZES, AND DATA ANALYSIS

An online cross-sectional survey was selected to facilitate the process of sharing to respondents in remote places. The survey included 17 questions (close and open-ended). A link for the survey was disseminated through email and social media. The final sample size was 35 survey respondents (Lebanese 100%, Males 80%). Out of 36 surveys, 1 was discarded due to abandonment. The quantitative data was statistically analyzed and represented as descriptive statistics.

JUSTIFICATION OF METHODS

A cross-sectional unstructured survey is selected for this study since the objective is to collect large amounts of data to understand which factors are behind corruption in construction in Lebanon as well as to understand how unethical management practices are perceived.

RESULTS AND DISCUSSION

RESPONDENT PROFILE

The respondents were all Lebanese, from different age groups (23 - 39), and coming from different work sectors (51.4%onsite construction, 28.6%architecture engineering and design, 17.1%construction management consultant, and 2.9% academics and universities) with males forming 80.6% of the respondents. Work experience was distributed as followed: 77.8% < 5 years, 16.7% with 6 - 10 years, and 5.6% with 11+ years.

FINDINGS

When asked about their perception of how common unethical behavior in the Lebanese construction industry is, 44.4% answered fairly common, 38.9% answered extremely common, and 16.7% answered that it was not common. With 0% saying that it wasn't common at all.

Results also showed that 63.9% have previously uncovered unethical behavior in management practices during regular checkups/auditing, 13.9% by chance, 8.3% tip off, and 2.8% using Building Information Modelling (BIM).

Figure 1 shows the percentage of participants who believe that the mentioned unethical behaviors form a serious problem, in relation to the construction industry. For example, almost 40% of the surveyed participants answered that they find the act of leaking information to a preferential bidder to be a serious problem. It is also interesting to indicate that only 20% of the respondents stated that including false extra cost to a contract claim is a serious problem.

Also referring to figure 1, one can identify at least 5 unethical actions characterized by having 30-35% of their answer that these corrupt actions are considered to be minor problems. Looking at such statistics, where a low percentage of the respondents believe corrupt behavior is a serious problem and a substantial percentage refer to these same activities as minor problems, it can be concluded that there is a lack of awareness about the severe damage caused by these prevalent wrongdoings. The authors were able to identify two main reasons as to why the Lebanese are not aware of the crisis they are in. Practitioners say that corruption is highly common and on all levels is due to the unethical practices and poor contractual setup that allows for dishonest behavior.

Another item in the survey aimed to examine at what level the respondent thinks unethical behavior in management practices are most likely to occur. Options included: individual at operational level, individual at middle management level, individual at senior management level, corporate at operational level, corporate at middle management level, corporate at senior management level, client, local government, national government. The answers varied and basically covered all of the alternatives which indicates that really corruption in Lebanon may occur at any and every level.

DISCUSSIONS

The industry is structured in an adversarial and myopic manner that leads individuals and corporations to deprive others and possibly commit illegal actions in order to get their bigger share of the pie. The above-mentioned reasons are also a result of the weak educational anticorruption campaigns on all levels (childhood, school, college and job education) and the immature environment whereby you can find the same person working with a corporation in Lebanon behave differently than if they were working in a corporation in any other country.

The substantial amount of loses due to bad management practices sheds light on the importance of taking actions towards corruption. Moreover, the significant low percentages of participants who believe that the Lebanese construction industry or the government are battling corruption indicate the need for implementing innovative techniques in order to alter the way corporation and the government function in opposition to corruption. This study proposes lean principles and tools as a methodology to mitigate unethical behaviour particularly in institutions that work in relation to the Lebanese construction industry.

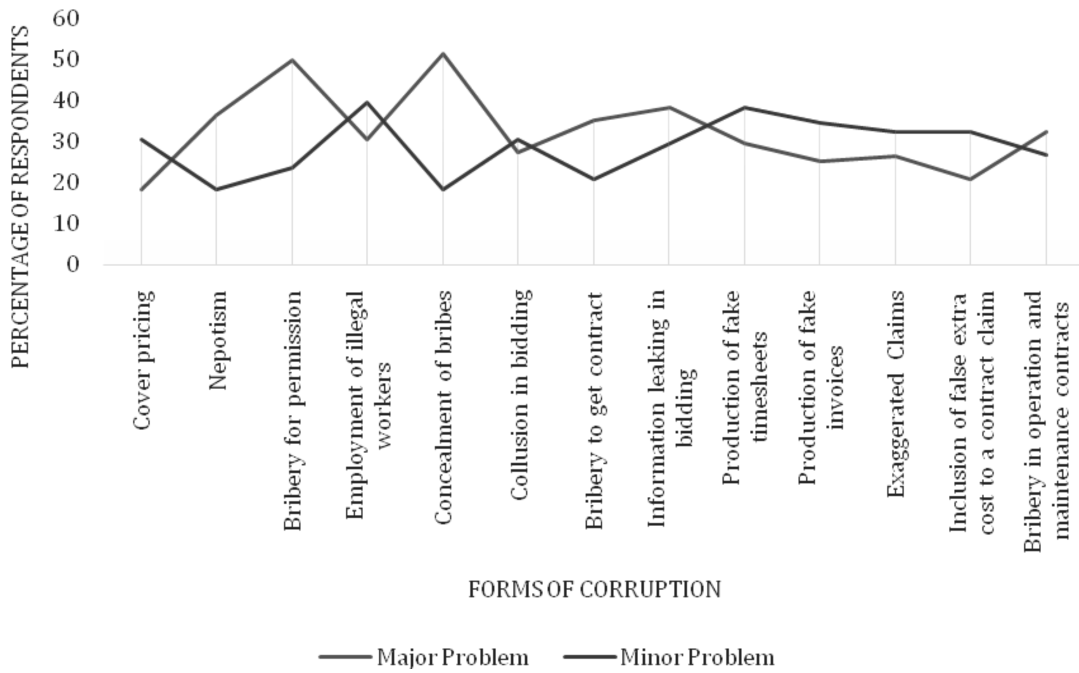

Figure 1: Extent of Corruption

LEAN FRAMEWORK TO ELIMINATE CORRUPTION

From literature, it is prevalent that corruption in Lebanon is prevalent at all levels of the country, starting from governmental officials down to clerks in regulatory offices. A problem that is epidemic and deep rooted needs to be analysed from the systemic level down to the individual level. Although corrupt acts are linked, the study separates corruption in the Lebanese government from corruption in the Lebanese construction industry to address each issue properly.

Using the 14 lean principles of Toyota (Liker, 2004) and lean tools such as Last Planner System, Building Information Modelling and Value Stream Mapping, a framework for eliminating corruption will be introduced.

ANTI-CORRUPTION FRAMEWORK FOR GOVERNMENTAL PRACTICES

The main reason for the wide spread of corruption in Lebanon is nepotism, and to eliminate nepotism, a country wide awareness campaign should be launched showing citizens how much would corruption cost them based on detailed studies. Public awareness is vital in case of Lebanon since it is a democratic country and the politicians are selected based on voting. This would start by nominating parliament members that are fully aware of the impact of corruption on the country and its citizens and have high ethics. When ethical parliament members are present in the government, they can start following lean principles starting by basing management decisions on long term goals. The latter can be translated to action if an anti-corruption strategy is planned. At the core concepts of this strategy should be accountability, integrity and transparency.

The second lean principle states that the right process will produce the right results. The current bureaucratic and hierarchical procedure to get any official documents from governmental offices is a daunting procedure. If change is to happen, the process should be optimized to give short cycle times with high quality. Autonomation using reliable technology would also reduce human intervention hence reduce the possibility of corrupt decisions. One thoroughly tested technology used internationally is e-governance. E-governance is the process of digitization of data used for providing services by governmental agencies. This digitization reduces interaction between humans, and in the process hinders the dissemination of corruption (Andersen, 2009).

Although the Lebanese government has launched an e-governance strategy in 2008 with an expected end date of 2015, it wasn't fully implemented, and no action was taken since 2013 (e-gov, 2013).

Next step in our lean framework is developing people. This can be achieved by paying employees a salary that would ensure they can have a good quality of living. When employees are satisfied with their jobs, they will not look for illegal ways to make more money. This would pave the way for developing a culture that supports anti-corruption.

The last step is to develop and control this framework. This can be achieved by setting and measuring key performance indicators (KPIs) that would monitor performance. These KPIs can be used to assess the current state and continuously develop the framework.

However, it will be challenging to incorporate lean principles into governmental organizations. Even though they are the ones who deal with the publics' money and hence should be extra careful about it, this is not always the case. It requires being proactive and not myopic, so it might not be easy to convince officials with such concepts.

ANTI-CORRUPTION TOOLS FOR THE CONSTRUCTION INDUSTRY

Ohno's famous statement mentions: "Lower the river to reveal the rocks" (Liker, 2004). This is why organizations should be proactive about mitigating corruption. It would be easier to implement lean principles and tools in the privatized sector because they have better control over time and they are profit driven, so every dollar counts. Companies can start by using the toolkits compiled below to deliberately reduce the level of corruption that exists in their projects.

Last Planner System (LPS)

Lean construction requires integrity and corruption poses a lack of integrity. Integrity can play a vital role in changing a corruptive "culture"through striving for reliable promises. According to Erhard et al. (2013), engineers and stakeholders in the construction industry wonder about reasons for projects failure yet never seem to consider lack of integrity as a plausible explanation. The same authors then introduced in their work a model for integrity, referred to as “honouring one’s word”. The “one's word” in Erhard's model of integrity is equal to “promise” in the LPS; therefore, LPS can be considered as a transplantation of integrity into the construction industry. Based on the above, integrity should also reduce corruption. Awareness about the LPS has started to appear in Lebanon (Hamzeh et al., 2016), but more implementations are needed.

Building Information Modelling (BIM)

BIM as described by Janssen et al. (2017) is a complete and differentiated information system, capable of influencing the project design and execution cycle, as well as allowing greater technical and social control over public spending. Janssen et al. (2017) argue that if BIM was adopted on a country level and is responsible for all interactions between people and the exchange of information leading to building and operating publically funded buildings, the common data environment within BIM would be the single source of truth that adds more transparency and accountability, as well as social control over the whole process.

The need for transparency shows how BIM is a necessary tool to prevent and control corruption in the construction industry, not only on the project level, but at the level of a global complex system. Benefits of BIM however, will not be exploited unless the adoption is mandated by the government and becomes a legal requirement for publicly funded projects where corruption is most prevalent.

Value Stream Mapping (VSM)

Value stream mapping (VSM), allows us to analyse the process by developing a map of the initial state. When implemented, an improved state map is established and used to optimize the system (Hines &Taylor, 2000). VSM increases process transparency and enables everyone concerned to understand the status of the system. Increased transparency is necessary for continuous process improvement (Womack &Jones, 2003). By using the VSM technique to document all the value and non-value adding activities required to finish a construction project would make it clear to pinpoint where the waste is occurring. Construction companies would start by identifying what waste is being caused by corruption in their organizations internally and then grow and expand to include other stakeholders in their value stream map. By identifying what is the waste found in their system, they can better implement strategies to mitigate it.

STUDY LIMITATIONS

When it comes to the methodology, it is acknowledged that the study had limitations. The sample used was limited in size due to limited access to professionals in the field.

Some obstructions that one may face when opting to implement lean principles and tools are the classic problems such as resistance to change and not seeing the added value of the process. Some may have misconceptions as to what lean methodologies stand for and that it may require substantial effort to reach beneficial results. Moreover, culture is a huge barrier to implementing lean. According to one of the respondents, unethical behaviour is considered to be the norm in the Lebanese construction industry and part of the process to be able to move forward with the work; unlike other countries where it is hid better and is not as out in the open as it is here. Tools would create tremendous improvement in effective minimization of corruption, but without the right culture, tools would be obsolete.

CONCLUSIONS AND RECOMMENDATIONS

Evidence from the conducted survey shows that first, construction project participants are insufficiently aware of all the unethical behaviour that may lead to corruption in such an industry. Second, their neutral perception, in some cases, towards such malpractices justifies the large number of losses in the construction sector. And third, their consistent belief that there is no vivid action plan that serves to reduce the corruption rate in Lebanon. Therefore, integrity, accountability, and transparency are among the key characteristics of the suggested tools needed to mitigate for corruption. The increased added value to seeing everything early on, capturing problems, and being proactive is essential to the practice of the construction industry without fraudulent acts. The tools are also crucial in terms of reducing waste and doing things in an optimal manner. It would be a step in the right direction. It would reduce the chances of errors and give less incentive for stakeholders to play games and tricks if things are clear from the start of the project. It brings increased visibility and effort in the right place. However, that requires having a concerted effort from all the stakeholders for developing accurate augmented design model. It is a matter of experimenting and starting with one tool at a time starting with simple metrics such a percent plan complete (PPC), tracking, waste minimization, concepts that practitioners and stakeholders can sense and appreciate that could lead to good results with minimal effort. More advanced concepts can be implemented at later stages to hopefully reach a lean Lebanese construction world free of corruption.

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IPD IN NORWAY

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ABSTRACT

As projects become more complex and uncertain, the challenge of increasing productivity and improving project outcome becomes greater. Integrated Project Delivery (IPD) seeks to improve project performance through a high level of collaboration between key participants. Although IPD is a well-known delivery model, only a single project has implemented this approach in the Norwegian construction industry: The Tønsberg Project. The purpose of this study is to identify which theoretical IPD elements are used in this project, document experiences from IPD and provide recommendations for the delivery of future IPD projects in Norway.

This article presents research based on a comprehensive literature review and a case study of the first Norwegian IPD project. The case study consists of a document review and 9 semi-structured interviews with key informants.

The experiences established through this research indicate that a higher level of collaboration facilitates innovative design and effective execution. The interviewees consider IPD to have potential to improve the performance of future projects but describe change in culture to be crucial for project success.

This study presents challenges and benefits experienced in The Tønsberg Project. It provides practitioners with a framework of theoretical IPD elements and first-hand experiences with how these elements can affect project performance.

KEYWORDS

Integrated Project Delivery (IPD), collaboration, trust, case study, recommendations.

INTRODUCTION

Studies show various problems, such as adversarial relationships, low productivity rates and frequent failure to meet the owner’s expectations in the AEC industry(Mitropoulos & Tatum 2000; Thomsen, et al. 2009). A report developed by the Norwegian Ministry of Local Government and Modernization states that the productivity rates in the Norwegian construction industry have declined from the mid-90s (KMD 2012). As projects become

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more complex and uncertain, the challenge of improving the project delivery and optimizing project outcomes becomes greater.

Traditional delivery approaches can often be characterized by fragmented teams, disputes within the project organization and problems related to the interface between design and construction. The parties tend to work in isolated siloes focusing on their own interests (Mei, et al. 2013; Thomsen, et al. 2009). Consequently, the project parties have a low degree of common understanding and a high degree of individual interests in the project, which often results in inefficient project delivery.

There is limited documentation related to IPD in the Norwegian construction industry. By collecting data from Norway's first IPD project, named The Tønsberg Project, this research seeks to fill this gap of knowledge. Consequently, the purpose of this study is to identify which of the theoretical IPD elements that are being used and present the experienced effects and challenges related to the individual elements. Based on these experiences, this article provides a framework with respect to which of the theoretical IPD elements future projects should implement.

The Tønsberg Project is an on-going pilot IPD project in the Norwegian construction industry. A limitation of this study is that the results presented in this article are based solely on this individual project.

METHOD

This study is based on a qualitative research method, with multiple sources of data. The theoretical IPD elements were identified in a literature study, based on the five steps presented by Blumberg, et al. (2014). The search was carried out using internationally acknowledged databases. A systematic search strategy, where key words such as "Integrated Project Delivery", "Relational Contract", "Culture", "Target Value Design" and "Lean" in combination and with various search functions, provided a wide range of relevant literature.

The research presented in this article is established through a comprehensive single-case study. The Tønsberg Project was selected as case seeing that it is the first IPD project in Norway. Yin (2009) describes single-case studies to be rational if they represent "revelatory" cases, where the situation has not been accessible to social science. Because it provides the first experiences with IPD in the Norwegian construction industry, a single-case study is considered to be expedient. The project is a complex building project within the Norwegian health care sector, consisting of a 31,000 m^2 somatic building and a 12,000 m^2 psychiatry building, with an estimated cost of approx. 370 million USD and is set to be completed in 2021.The Lead Contract and Procurement manager in The Tønsberg Project is co-author of this article, which provides a unique insight into the project´s delivery.

The case study started with a review of the project´s IPD agreement, a pre-project report and powerpoint-series previously used by the project participants. This was done in order to get an initial overview of the project. Then 9 semi-structured in-depth interviews with representatives from all major project participants. More specifically,4 interviewees represented the client, 2 represented the main contractor, 2 represented the design team and 1 represented a key sub-contractor. They were selected since they oversee overall project delivery and day-to-day operations.

The research´s validity is considered satisfactory as the findings is based on multiple sources of information, such as literature, documents and interviews. The research´s reliability is assumed to be reduced as a consequence of the face that The Tønsberg Project is considered prestigious for the participants. However, interviewing representatives from all major participants, having informants confirming the transcripted interviews and involving the Lead Contract and Procurement manager is believed to increase the reliability.

THEORETICAL FRAMEWORK

IPD is a delivery model that accommodates the construction industry´s need for more efficient collaboration between project participants. Therefore, the delivery model has similarities to other models based on relational contracts, such as project partnering and project alliancing (Lahdenperä 2012). These delivery models seek to solve some of the problems related to traditional delivery models. Matthews and Howell(2005)present four major problems with traditional and transactional contractual approaches (Table 1):

Table 1: Problems related to traditional delivery approaches (Based on Matthews and Howell (2005))

Problem	Underlying cause	Results
Good ideas are held back	Lack of commitment from trade contractors based on competition. Ideas are held back in the design to keep a competitive advantage	Inefficient design, changes, low degree of innovation
Contracting limits cooperation and innovation	Subcontractors contracts state what each individual trade are responsible to provide	Subcontractors struggle to collaborate, low degree of innovation and common understanding
Inability to coordinate	No formal effort to link the planning systems of the various subcontractors	Inefficient project delivery, potential disputes
Pressure for local optimization	Participants wish to sustain their individual interest	Individual parties interest being prioritized over the project interests

Collaborative delivery models seek to solve these problems by aligning project objectives with the interests of key participants and implementing Lean expediently (Matthews & Howell 2005).

Asmar, et al. (2013) compares the performance of 12 IPD projects with 23 projects delivered with more traditional approaches. Their comprehensive study provides statistical data showing significant superior performance related to quality, communication, change performance, schedule, and environmental sustainability, with no significant cost premium. Their study was generally based on complex building projects, where approximately 50 % of the projects were health care facilities. Furthermore, Cheng (2016) provided research showing examples of projects achieving success with IPD regardless of project type, scope, location or previous experiences with IPD. Her report of ten successful projects in the US and Canada using an integrated form of agreement illustrates how projects using IPD and Lean are more likely to meet owner´s goals and achieve success within costs and schedule.

Thomsen, et al. (2009) defines three basic domains that all project delivery systems operate within: *"commercial terms", * the project´s *"operating system"* and *"project organization"*. Contractual IPD elements, such as early involvement of key participants, mutual benefit and reward and liability waivers, provide *"commercial terms"* that align the project participants' interests with the project objectives. This facilitates collaboration and a much higher level of common understanding between the "major players" of the project (Thomsen, et al. 2009).IPD project´s *"operating system"* seeks to increase efficiency by implementing integrated technology, information systems, and often Lean construction processes and tools, based on collaborative delivery (Thomsen, et al. 2009). Cheng (2016) illustrates the importance of a collaborative "*project organization*" and describes it as being "fostered" by IPD contracts and Lean processes and tools. This leads to an integrated project delivery where the contract and culture provides the framework for collaboration, while processes and technological tools facilitate a more efficient project delivery.

Table 2 illustrates theoretical IPD elements divided into the overall categories of *Contract*, *Technology and Processes* and *Culture*. The categories are based on earlier work, presented by Lee, et al.(2014)and respectively are similar to *"commercial terms"*, *"operating system"* and *"project organization"* presented by Thomsen, et al. (2009).

Table 2: Theoretical IPD elements (Adapted from Lee et al. 2014)

IPD elements	**(AIA 2007)**	**(NASFA, et al. 2010)**	**(Ghassemi & Becerik-Gerber 2011)**	**(Lee, et al. 2014)**	**(Pishdad-Bozorgi & Beliveau 2016)**
Contract					
Multiparty Contract		X	X	X	X
Shared Risk and Reward	X	X	X	X	X
Early Involvement of Key Participants	X	X	X	X	X
Intensified Planning	X	X			X
Collaborative Decision Making	X	X	X	X	X
Collaborative Goal Definition	X	X	X		X
Liability Waivers		X	X	X	X
Financial Transparency				X	X

Technology and Processes					
Lean				X	X
BIM				X	X
Integrated Information	X			X	X
Culture					
Mutual Respect and Trust	X	X		X	X
Willingness to Collaborate				X	
Open Communication	X	X		X	X
Co-location					X

The references presented in Table 2 are considered credible and are frequently cited in relevant literature. By examining the table, it is clear that the focus on cultural elements in literature has increased over recent years. The cultural aspects of IPD have become more relevant in literature, as the industry gains more experiences with the delivery model. This illustrates the importance of a collaborative culture in IPD projects.

FINDINGS AND DISCUSSION

The Tønsberg Project has embraced the IPD methodology and to a certain extent implemented all the theoretical IPD-elements presented in the theoretical framework. The collected data indicates an efficient project delivery system, where most of the desired effects of IPD are achieved. The project has nevertheless experienced some challenges, and the findings indicate that it is possible to learn from the project´s experiences to deliver future IPD projects more efficiently.

EXPERIENCES AND RECOMMENDATIONS RELATED TO THE CONTRACT

As the first IPD project in Norway, the project owner had to examine the procurement process. The lack of experience in the Norwegian industry could potentially lead to scepticism and an unsatisfactory response from the industry. The project owner used a strategy where the procurement of key participants was based on traditional Norwegian contract regulations and supplemented with a letter of intent. This stated that the parties agreed to collaboratively develop a **multiparty contract**, customized for the Norwegian construction industry. The IPD-agreement was developed and signed during the feasibility study. All traditional contract regulations were terminated and replaced with IPD-regulations in the new contract. In the development of the agreement, the legal team based their work on the American multiparty-agreement: *The Integrated Form of Agreement (IFOA).* The interviewees describe that the IPD agreement has worked efficiently and, although it is recommended to make small changes, it would be expedient to use this agreement in future IPD projects in Norway. The changes mentioned by interviewees are related to Norwegian zing the contract to a larger degree than in The Tønsberg Project and customizing the contract to project specific circumstances.

The key project participants have **shared risk and reward**, where the designers, contractor, and three technical subcontractors out their profit at risk. If the project´s actual cost becomes greater than the target cost at completion, the participants´ profit is reduced

by the corresponding amount. Should, on the other hand, the actual cost become lower than target cost, the profit will increase with 50 % of the savings. The owner will in this case receive the remaining 50 %.It is considered important to involve key subcontractors so that a considerable part of the project cost is included in the shared compensation structure. Another benefit of including both the contractor and the technical subcontractors in the shared risk/reward-pool is that they provide relevant competence, and therefore contribute to effective structural and technical solutions. The shared risk and reward in The Tønsberg Project is considered as an important economic incentive to collaborate and has aligned the participants' interests.
There has been **early involvement of key participants** in The Tønsberg Project, where designers, contractor, and three technical subcontractors were involved in the early stages of the feasibility study. This has been an important factor to minimize the project´s costs of change orders. A collaborative project delivery has facilitated effective solutions that are best for the project, based on a high degree of common understanding while there are still substantial opportunities for influence, which makes it likely to assume that the cost of changes has reduced drastically compared to traditional delivery approaches(Figure 1).
Despite the contractor being involved early, key personnel with hands-on experiences in production were working on other projects and did not participate before the production phase. It is likely to assume that potential for positive effects is greater if the project could exploit the competence of this personnel. Future IPD contracts should therefore specify that key personnel from contractors should be involved in design.

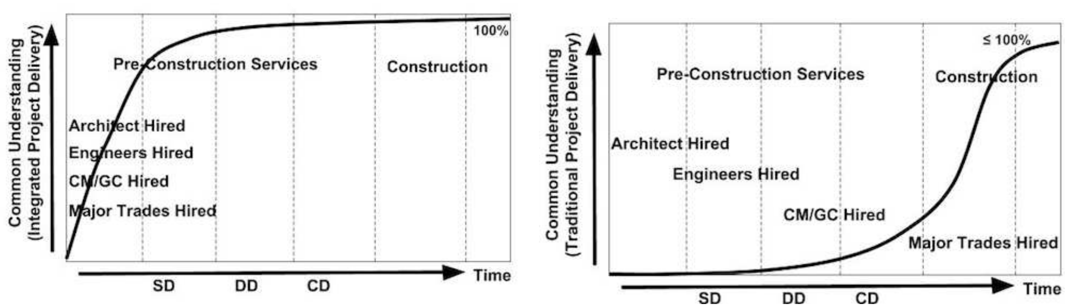

Figure 1: Degree of Common Understanding (Adapted from Lichtig (2008))

The Tønsberg Project did not achieve the desired amount of **intensified planning**. In the closing stages of the feasibility study, the estimated cost became approximately 20 % above the investment budget. This led to some challenging processes, which resulted in less time and resources for planning the project than originally planned. To avoid this in future IPD projects, it is recommended to set sufficient time for intensified planning. It is also important not get too caught up in the project´s concept during the feasibility study, but rather to seek to reduce cost drivers early.

Collaborative decision-making processes have been causing some of the greatest challenges in the project. The project organization has experienced inefficient decision-making processes because of the collaborative "leadership by all" approach, where all the parties must agree upon a decision. As a result of the passive decision-making culture, these processes have become far more time-consuming than with traditional delivery. Future projects need to solve these issues in order to achieve a reasonable decision-making culture. They can benefit by establishing a clear organizational hierarchy, specifying roles and expectations in the IPD agreement or implementing decision-making procedures. Another alternative is to hire external consultants to facilitate the decision-making processes. By combining either of these alternatives with a clear decision-making plan, future projects can facilitate more efficient decision-making.

There has not been a fully **collaborative goal definition** in The Tønsberg project. The project´s target cost and main schedule are project goals that have been developed collaboratively. However, the general project goals were developed by the project owner during the feasibility study. Some of the project participants considered the goals to be somewhat unrealistic and expressed that fully collaborative goal definitions could make project participants feel a greater sense of ownership with respect to the project. It is considered beneficial for future IPD projects to collaboratively develop realistic goals.

Liability waivers have become crucial for participants to alter their traditional approach to deviations. The focus, that is traditionally on who is to blame for deviations, is now on finding solutions that are best for the project. This results in fewer conflicts and facilitates efficient processes to solve deviations.

Financial transparency is described by the interviewees as critical for collaboration, especially considering necessary trust related to compensation structures. Some project participants are competitors and will compete for future projects, which has made it challenging and restrained opportunities for full financial transparency. However, the desired degree of financial transparency has been achieved.

EXPERIENCES AND RECOMMENDATIONS RELATED TO TECHNOLOGY AND PROCESSES

The project can be considered as one of the leading projects in the Norwegian industry using **Lean** design and construction. It has implemented Last Planner, Target Value Design, ICE-meetings, A3-reports, Reliable Promising, and Continuous Improvement. Experiences indicate that Lean design and construction has increased efficiency and reduced waste significantly in The Tønsberg Project.

The Tønsberg project has experienced success using **BIM**. The project implemented virtual design and construction, and won the prize for *"Design using open technology"* at the building SMART International Awards 2017. An interviewee reflected how the selection of technological tools and processes should be based on desired effects, not previous experiences and preferences. Future projects should share BIM models, evaluate desired effects, and consider implementing innovative technology and processes.

Integrated information systems have been implemented in project delivery. This has organized the information and made it more available, while providing all the participants with an accurate representation of the project. The data shows various opinions related to these systems. Some are embracing them, while others find it hard to adapt to new ways of processing information. Future projects could benefit from having someone responsible for sorting the information and making a clear and transparent information structure. E-learning courses, where personnel can learn about the information system, could also help workers find and handle relevant information.

EXPERIENCES AND RECOMMENDATIONS RELATED TO CULTURE

The data collected, indicates that the project has implemented all the theoretical IPD elements related to culture. To achieve the desired effects of IPD, it is described by interviewees as crucial for project organization to base delivery on a collaborative culture. This is the foundation of the delivery, and it is important for all major participants to alter their traditional mind-sets and behaviour to a collaborative approach. Interviewees consider the project´s contractual framework and co-location (3-4 days a week) as important IPD elements to facilitate the collaborative culture. The project organization has, in addition to the mentioned IPD elements, made some specific efforts to facilitate the achievement of cultural IPD elements. These additional efforts are presented in table 3.

Table 3: Efforts made in The Tønsberg Project to facilitate a collaborative project culture

Additional efforts	Description	Desired cultural IPD element
More selection criteria than price in the procurement process	40 % project crew, 40 % delivery and 20 % price	Willingness to collaborate
Initial presentations	Presentations by potential participants in the procurement process	Willingness to collaborate
Focus on social relations across organizational boundaries	Create relations trough social events, shared lunch room, Big Room meetings	Mutual respect and trust
"House rules"	Guidelines for behaviour on co-location	Open communication
Big Room	Meetings to keep the entire project organization keep updatedPresentations for education and training	Open communication
Prepared to replace "rotten apples"	Change personnel or project participants that does not adapt to the collaborative project culture	Willingness to collaborate
Leadership support	Leaders signalizing expectations and attitudes	Willingness to collaborate

The research carried out indicates that the project could benefit from focusing even more on building relationships in order to create a collaborative project culture. In the procurement process of The Tønsberg Project, the project owner focused on experiences with collaborative methods, and potential participants held presentations. To identify participants that are willing to collaborate to an even higher degree, interviews with potential participants in the project procurement are considered expedient.

Training and education are described by interviewees as important and they consider E-learning courses as beneficial for future projects. These courses can provide individual learning and can reduce waste by avoiding excessive educational presentations. E-learning courses can provide informative introductions to the project and teach important IPD methodology focusing on the transition from traditional delivery approaches to IPD.

Another element that can facilitate a collaborative project culture within the project organization is shared values. This is a cultural element that can affect the project positively by aligning participant attitudes and expectations with project objectives.

CONCLUSION

The Tønsberg Project has experienced positive effects using IPD, and the interviewees generally apprised the implementation. The research set out to identify which theoretical IPD elements are being used in the first Norwegian IPD project, to document experiences from the use of IPD, and to provide recommendations for future IPD projects.

The Tønsberg Project has implemented all the theoretical IPD elements presented in this paper. However, the desired degree of intensified planning was not achieved, the general performance goals were not defined collaboratively, and participants are not co-located "full-time" but rather 3-4 days a week.

Experiences from the project, which show various effects with individual elements, reflect how IPD facilitates collaboration and a higher level of common understanding between the key project participants. Several interviewees describe a culture where decisions are being made based on what is considered best for the project, which results in optimal solutions based on a high degree of common understanding and communication between the project participants. Although the research does not provide quantifiable metrics to support these statements, the interviewees described this as aspects that will lead to a drastic reduction in the cost of changes, compared to traditional projects.

All the theoretical IPD elements are recommended in future IPD projects. Table 4 presents specific recommendations related to the project delivery of future IPD projects. In addition to these recommendations, interviewees find shared values for the project organization as a potential cultural element that could benefit future IPD projects.

Table 4: What future IPD projects in Norwayshould pursuefrom The Tønsberg Project

IPD element	Recommendations for future IPD projects in Norway
Contract	
Multiparty Contract	Customize to the Norwegian industry, include key subcontractors
Shared Risk and Reward	Include design team, contractor and key subcontractors
Early Involvement of Key Participants	Involve key personnel (Include hands-on personnel from production)
Intensified Planning	Involve key personnel (Sufficient time)
Collaborative Decision Making	Establish a plan with clear roles and deadlines (Follow it)

Collaborative Goal Definition	Define all goals (Including general performance goals)
Liability Waivers	For the risk-pool parties
Financial Transparency	For the risk-pool parties
Technology and Processes	
Lean	Use to reduce waste
BIM	Shared model for project participant
Integrated Information	Transparent information structure, E-learning courses
Culture	
Mutual Respect and Trust	Build social relations
Willingness to Collaborate	More selection criteria than price, presentations (and interviews), replace “rotten apples”, leadership support, E-learning courses
Open Communication	House rules, Big Room
Co-location	Full-time co-location (More than 3 days per week)

The result of this study is based on a single-case study. In order to provide more representative results, future research should collect data from a wider range of IPD projects in Norway. It is also considered expedient to prioritize the importance of each individual IPD element based on its cost/benefit.

The recommendations presented is this article focus on the owners´ perspective. This offers a comprehensive overview asthe project owner is the party responsible for founding the project and choosing a strategy for the projects delivery.

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ANALYSIS OF THE ACTIVITIES OF SITE AND PROJECT MANAGERS – IMPLICATIONS FROM THE PERSPECTIVE OF CREATING VALUE

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ABSTRACT

Construction projects are complex and include various processes, which have to be managed by a construction team. The position of a site manager or project manager (below we will use the term construction manager (CM)) plays an important role for the success of projects, because this position has the responsibility for the process organisation within the project. Studies show construction managers are typically exposed to a high level of stress. One German study from 1997 shows clearly the degree and effects of a high stress level. A major factor for inefficiency and a catalyst for stress could be a lack of transparency and missing communication inside a construction team.

The paper describes the results of a study of the daily activities of construction managers. Six individuals were accompanied and interviewed. In total 55 hours of observation have been undertaken to analyse the daily routine at this organisational level in projects. Based on the results of this analysis the authors propose improvements for construction managers. The proposal is based on the idea to structure the daily work routine of a construction manager. This helps to reduce the frequent changes and interruptions in activities, so construction managers can concentrate on value creating activities.

KEYWORDS

Site manager, project manager, stress, daily routine, transparency, daily meetings

INTRODUCTION AND STRUCTURE OF THE PAPER

The position of a construction manager plays an important role in the management and coordination of construction projects. This key position has a very wide spectrum of tasks and a high level of responsibility. A high rate of staff turnover and sick leave compared to

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other positions in the construction industry are measurable effects of the high level of stress placed on construction managers (Strobel & Krause 1997). In the first part of this paper the existing situation of the daily activities of a construction manager is described. Additionally information on the fundamentals regarding the study of stress is given.

For this research, six construction managers were accompanied and observed for a total of 55 hours during their daily activities to enable discussion in terms of the current situation, including the influence of digitalization. The data was systematically recorded and validated through interviews. The findings and approach used are discussed in the body of the paper. The goal of this field study is a quantitative analysis of the daily activities of construction managers. A proposed solution to heightened stress levels and overwork is to increase value creation. According to Lean Thinking, waste in construction management must be recognized and eliminated. Various solutions with a focus on increasing the proportion of value generating activities in the daily activities of construction managers will be proposed. Thereby Lean Management approaches for early recognition of waste can be implemented. The result, which will be described in the final part of the paper, is a structured daily routine to serve as the basis for targeted communication and increased transparency within teams.

FOUNDATION AND EXISTING SITUATION

EXISTING SITUATION

Construction projects are dynamic systems characterized by unforeseeable situations and uniqueness. The bespoke character of a project and changing project participants lead to a lack of consistency and uniformity (Koskela 1992, 44-45; Nakagawa and Shimizu 2004, 12-13). The result is a lack of structure and standards. Insufficient transparency and defective communication on the part of the construction managers further intensify the situation and lead to waste in daily activities. Stress occurs if the site manager is not fully informed with respect to problems and their consequences and thereby unable to make decisions. This is an uncomfortable situation and increases the amount of effort needed to obtain information.

A second significant part of construction management is reacting to fluctuating construction processes. Changes at short notice due to disruptions occur on a regular basis. The construction manager must react and implement solutions quickly (Syben 2014, 82–84). In order to still achieve a project’s goals for time, cost and quality, additional management effort is needed. Hence, the success of a project is highly dependent on effective management and therefore the construction manager holds a key position (Rösch 2014, 25). He is the main switchboard of the construction site and progress is highly dependent on his personal project management competencies. Complex tasks and ineffective communication together with changing requirements in daily activities lead to a high level of pressure and stress for construction managers.

The sickness rate in the German construction industry has risen continuously from 4.4% in 2006 to 5.5% in 2014 (Meyer et al. 2015, 412). This lies significantly above the overall average of 5.2% recorded in 2014 (Meyer et al. 2015, 341). Comparatively the number of cases of construction industry workers unfit for work due to psychological illnesses rose by almost 130%[5] from 1995 to 2014.

THEORETICAL BACKGROUND OF STRESS

Rudow (2011, 52)defines stress from a psychological perspective as a short or long-term condition of increased activeness, caused by experiencing danger or a threat which is thereby associated with unpleasant emotions. Stress can also be understood as a process in which a key role is taken by assessing and overcoming burdens (Rudow 2011, 52). As part of this individuals perceive a discrepancy between what is required of them, and the resources at their disposal. Stress is therefore a negative reaction to a (psychological) burden. Chronic incidences of stress can even lead to so called burnout.

It is known from research on stress, that long-term overwork can lead to reduced creativity, wellbeing and motivation to work. Typical effects on day-to-day work include lack of concentration, low tolerance for pressure, irritableness with colleagues, mistakes and unconsidered decisions (Strobel & Krause 1997, 2).

In 1997 Germany's Federal Institute for Occupational Safety and Health (BAuA[6]) commissioned a research project on the topic of "Psychological Strain on Employees with Management Responsibilities in the Construction Area of the Building Industry". The goal of the study was to determine and analyse the main stress factors. Moreover, the effects of psychological stress as well as ways to prevent and reduce these effects were described. These were compiled as a set of guidelines. Based on random surveying of 70 construction managers, responsibilities and stressors were ranked. In addition, they were asked to approximate how frequently specific stressors occurred and what short and long-term effects these had on the affected person. Furthermore, possible strategies and resources for stress prevention and problem solving approaches were recorded from the participants. The five most frequently named stressors were cost pressures, working under time pressure, disruptions to work, disruptions to the construction sites and making decisions based on insufficient information (Strobel & Krause 1997). Due to the fact that the results are 21 years old and do not take into account rapid advances in IT and communication, the applicability of these results is questionable. For a better understanding of the current situation, an investigation of the current situation was carried out.

FIELD-STUDY

METHOD

The results of Germany's Federal Institute for Occupational Safety and Healthresearch serve as the starting point for further investigating and analysing the activities and level of stress of construction managers. For this purpose, six construction managers were observed carrying out their day-to-day tasks for a total of 55 hours. Thereby 371 activities

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5 Own calculations. Data source: Meyer et al. 2015, 417
6 BAuA means Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (Germany's Federal Institute for Occupational Safety and Health)

could be assessed. It should be noted that the entire working day was recorded in order to gain an uninterrupted sample. The study is focused on construction managers for building projects in the areas of turnkey construction, shell construction and industrial buildings. Table 1 shows an overview of the six construction managers.

Table 1: Overview of the different construction managers

CM	**Work experience in [years]**	**Work experience in [number of projects]**	**Total project volume in [Mio €]**	**Description of construction project**
CM 1	4	<5	<25	Turnkey residential houses with over 70 flats
CM 2	23	5-20	25-100	Four turnkey residential houses
CM 3	25	>20	>100	Structural works of Multi-functional education building
CM 4	4	5-20	<25	Industrial building with storage and production hall
CM 5	10	>20	<25	Renovation of retail area
CM 6	3	5-20	<25	Turnkey office building

Table 1 shows the diversity of the experience of the construction managers and the projects. The majority of construction sites were at an advanced stage of execution. All companies of the surveyed construction managers had more than 250 employees.

In the next step a suitable method of observation was defined. As the work of construction manager varies through the day and is characterized by frequent task changes, precise recording of data required a digital solution. The application "Bauleiter Monitoring" freely available in the Apple App Store was selected[7]. Using the app allows passive participation as well as structured and open observation (Atteslander & Cromm 2008, 85–87). Thereby it is possible to separate the researcher and observer. This allows the chance for different persons to review the same observations and compare conclusions. It further allows verifiability of the observations (Atteslander & Cromm 2008, 77).

Before observations took place, a briefing session with each construction manager was held. The exact method was described and a suitable day for observation was agreed to allow the observations to be as representative as possible. Additionally, the construction manager was advised to behave as normal as possible and not to make contact with the observer. The observation allowed each individual process to be observed second by second. In a preliminary stage 160 process types were identified with the help of various literature.

[7]Retrieved on 16.11.2016. No longer accessbile since 2017

After completing the observations, each construction manager was interviewed for approximately 35 minutes. Research hypotheses that could not be tested using the application were discussed in greater detail by conducting a semi-structured interview.

RESULTS OF THE STUDY

The results of the study show that frequent changes between different tasks, long working hours, increased effort for particular tasks and frequent disruptions are characteristic of the working day of construction managers. Figure 1 shows the average duration of a process (one task) per construction manager.

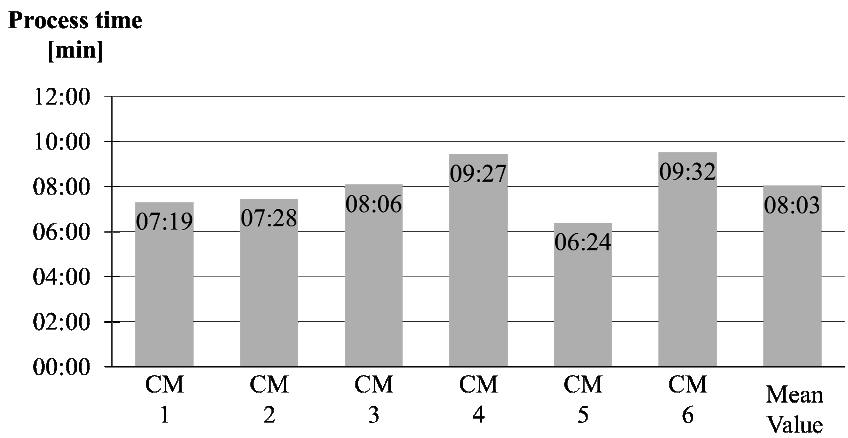

Figure 1: Average process duration CM 1-6

The mean value for all construction managers is 8:03 minutes. Changing processes can also be caused due to interruptions. The construction manager's influence on when to change tasks is therefore limited, and on average he changes tasks 7.6 times per hour. Frequently changing tasks can therefore be seen as a key requirement for construction managers and leads to a situation of increased strain. The construction managers were interrupted due to external factors every 35 minutes. Normalized to an eight-hour working day, this results in 15 interruptions per day. Figure 2 shows the percentage distribution of the causes of interruptions. Phone calls were responsible for almost half (46%) of all interruptions while 36% were caused by personnel. Furthermore, it was investigated whether the same task was continued after each interruption. A mean of 60% of interrupted tasks were continued.

Five of the six construction managers did not agree that the tasks given to them could be achieved within their contractual working hours (without overtime). This is supported by the number of working hours recorded which has a mean of 8:28 hours. This value was lower than expected as CM1 had a significantly reduced working day due to private circumstances. When excluding CM1 the mean value for CM 2-6 is 8:55 hours or five overtime hours per week. Despite the high number of overtime hours, only approximately two thirds of the entitled breaks were actually used.

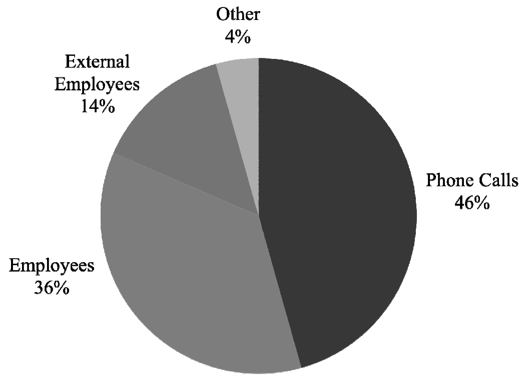

Figure 2: Percentage distribution of causes of interruptions for CM 1-6

Communication by email and (mobile) phone took up approximately 25% of total working time. According to the construction managers, there is an expectation on construction sites that they should be immediately reachable by mobile phone at all times. It is characteristic for all of the construction managers that they complete typical tasks from various project phases at the same point in time.

IMPLICATION OF THE STUDY

The activities of construction managers do not directly generate value but rather support creation of value on construction sites. The results of the observations show that the daily activities of construction managers did not have any structure and the various processes were not standardized. A lack of standardized construction site processes prevents construction management from being more structured. If the construction site is unstructured, so is the organization of the construction manager's work. The work of the construction manager becomes more focused on reacting to situations and less on structured actions. Excessive switching between tasks and interruptions to work cause increased strain and prevent optimal management of the construction site. The following will address these topics in detail from an occupational science perspective. According to the construction managers surveyed, interruptions to work are stressors as these are followed by a phase of getting back into the task at hand. In complex tasks it is particularly difficult to return to the prior train of thought.

Research studies on the topic of disruptions to work show that interruptions lead to increased time needed to complete tasks, higher incidences of errors, forgetting tasks and an increase in negative emotions such as fear and anger (Baethge & Rigotti 2013, 17). In general, multitasking is considered as frequent switching between tasks, and as soon as changing tasks is required, transitional costs occur which are generally expressed as lost time. The result is that multitasking leads to lost time in most cases (Baethge & Rigotti 2013, 14). Researchers from the University of Michigan could demonstrate that the human brain is 20-40% less effective when two tasks are completed at the same time rather than one after the other (Baethge & BAuA 2012, 12). If a person is distracted from a task for more than three minutes or decides to start a new task, approximately two minutes will be needed to return to the same state of the previous task.(Baethge & BAuA 2012, 14). Occupational scientists have already proven a correlation between longer working times and psychological stress (Lohmann-Haislah 2012, 113). Increased weekly working hours lead to an increase in perceived working intensity. Time and performance pressure increase and employees tend to feel overwhelmed by the amount or duration of work (Wöhrmann et al. 2016, 28-29). Furthermore, it could be shown that in the case of longer working hours, a higher number of breaks were skipped.

The cause of the effects described above can be found in the high level of fluctuation in tasks on construction sites as well as in disruptions to the construction process. These can lead to chaos on construction sites. Because of this the construction manager is frequently required to immediately react to seemingly unexpected problems. This requires a higher amount of management and concentration. Often problems are first recognized and eliminated when the consequences have already occurred, and the construction manager takes the role of a 'firefighter' (Hauser 2013, 8). The result is that construction managers have no chance of structuring their tasks and working days. Even smaller disruptions can spread and cause greater disruptions through the so-called bullwhip effect (Sterman 1989, 321-339).

'Firefighting' as a management approach can be effective in specific cases. However, this method cannot be efficient, and the additional effort required disrupts day-to-day tasks negating any gains made. Open and documented communication between project participants is usually lacking in practice. In this situation, the construction manager often functions as the 'main switchboard' of the construction site and coordinates his own team as well as external partners. All information-flows and decisions are managed by the construction manager. As soon as the level of complexity exceeds the competency of the construction manager, the system collapses. A more even sequence of construction, higher transparency between participants and short-cycled target/actual comparisons on-site can minimize these problems.

STRUCTURE AS A SOLUTION FOR VALUE CREATION

Creating value by reducing waste in the everyday activities of construction managers is a significant factor for optimizing their workload. The findings of this study point towards a need for improving the way construction managers' tasks are organized. A conceivable solution would be to arrange each workday into work blocks. The prioritization of the work blocks according to delivering value to the client and interlocking with construction site processes allows unnecessary works to be reduced or eliminated. Through the basic approaches of Lean Construction, the working approach used by construction managers can be planned more efficiently. The structure should reduce disruptions to work, the frequency of task changes and the number of overtime hours and therefore reduce stress on construction managers. The structured daily routine should give specific standards, but also be flexible enough to take into account individual circumstances of each construction manager. This study showed that the beginning of the workday is particularly suited to being structured. One way how this could be achieved is shown in Figure 4. This includes a site walkabout, 15 minutes of clearing e-mails and meetings with people from various levels of hierarchy.

Time	Work	Duration [min]	
7:15	E-Mail	15	Beginning of the Workday
7:30	Construction Site Visit	30	
8:00	Takt Control Meeting	15	
8:15	Internal Meeting	30	
8:45	Morning Break	15	
9:00	**Block of Work 1**	**90**	
10:30	**Block of Work 2**	**90**	
12:00	Lunch Break	45	
12:45	E-Mail	15	
13:00	**Block of Work 3**	**90**	
14:30	**Block of Work 4**	**90**	
16:00	E-Mail	15	
16:45	Daily Planning	30	

Figure 3: Example for Structured Daily Routine consisting of the Beginning of a Workday and of Blocks of Work

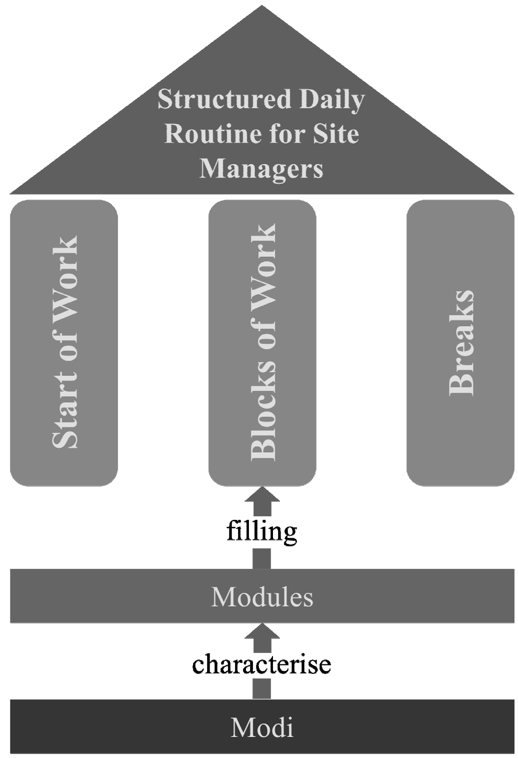

Figure 4: Fundamentals of a Structured Daily Routine

An example of this is the Takt Control meeting according to the method of Lean Construction described in detail by Binninger et al. (2016, 1–13). This is supported by visualizations and universal functionality. It provides an alternative to complex and chaotic systems that are difficult to implement due to language barriers. Possible obstacles and unclarities are identified well in advance and prevented before they are able to cause problems. The rest of the workday can be divided into multiple standard blocks as shown in Figure 3. Every work block is allocated a particular module, which allows a clear separation of construction site planning and construction site management. Different modes are defining the characteristics of each module. This allows an uninterrupted and concentrated working approach and thereby leads to a lower rate of errors and time saved during the workday. Figure 4 shows the stated fundamental requirements for a structured and standardized workday. The work blocks are suited to repeated longer tasks such as meetings or complex tasks that require a high level of concentration. These can be allocated to different modules and flexibly distributed across the day. The blocks are 90 minutes long. This time period is long enough to achieve the majority of a construction manager's tasks within one block (Cichos 2007, 175). Furthermore attention and concentration significantly decline after 90 minutes meaning longer blocks are not feasible (Brendt 2008, 95-96). Eachworking block can include different modules. One module defines construction management activities which have similarly high requirements. Due to modularisation, the daily routine is standardized which nevertheless allows great flexibility. The construction manager has many possible courses of action and the freedom to consider the actual on-site situation or the requirements of his employer.

The modes of each module provide a suitable framework for working conditions. Thereby the construction manager obtains greater control about getting interrupted, for example. This allows a significant reduction in disruptions and task changes as well as greater control over those that do occur. Stressors can be reduced while at the same time increasing the construction manager's working capacity. For example, the 'concentration' module allows for complex tasks to be carried out. These tasks should be carried out continuously and without interruption. A work block with the module 'routine' should be used for more simple tasks. Disruptions and changing tasks are possible, but should be minimized. For detailed descriptions of example modules and modes refer to Schneider (2016). However, the described daily routine is a theoretical approach. The ideal typical structured daily routine is not directly applicable, but rather demonstrates approaches that could be applied as suited.

CONCLUSION AND OUTLOOK

The field study shows a number of reasons for the high level of stress present in the construction management profession and gives a good overview of construction manager's every day activities. To better asses the existing situation, the observations must be carried out on a greater scale and over a longer period. The key to reducing stress on construction managers and an increase in value generated from their day-to-day tasks is particularly dependent on a structured working day. The proposed structured workday as described in this paper should be critically scrutinised and be adapted according to real-life situations. Other industry sectors have already implemented similar methods. The construction industry, in many areas, has not yet gained this level of understanding. Nevertheless, this structure helps with operating methods from Lean Construction such as Line of Balance, Takt Planning and Takt Control, and Last-Planner-System®. Even in such systems, there must be enough time allowed for communication and sustainable approaches to problem solving. The contradiction between a classic construction management style and structured execution with Lean Principles could be determined on many occasions by the authors.

The factors named herein should not be considered in isolation, but rather are all interlinked. In this regard, this paper includes suggestions for possible courses of action to reduce stress on construction managers which in some instances still require testing and validation in practice.

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ASSESSMENT OF ORGANIZATIONAL CULTURE IN CONSTRUCTION –A CASE STUDY APPROACH

S. Manna Simon[1], and Koshy Varghese[2]

ABSTRACT

Recent studies suggest that Lean concepts can be successfully adopted only when it is aligned with the organizational culture (OC). OC can be defined as the shared values and beliefs of people, according to which they perceive, react and act in any situation. For sustained and effective adoption of Lean, it is important to institute Lean philosophy in the core culture of an organization. To enable effective adoption, it is important to analyze and understand the organizational culture and its dimensions before inducing a change management strategy for sustaining Lean. The objective of this study is to understand the impact of prominent cultural dimensions on the different management levels of employees.

The paper presents, results and discussion of an exploratory study conducted using a case study approach. A construction company based in a metropolitan city in India was chosen based on its active program in Lean implementation. To analyze the cultural dimensions of the organization, Competing Values Framework (CVF) was chosen. The key dimensions based on which CVF assess the OC are dominant characteristics, management of employees, organizational leadership, organizational glue, criteria for success and strategic emphases. The data was collected through "Organizational Culture Assessment Instrument (OCAI)" and the target respondents were the top-management and middle-management staff. The data was analyzed by standard scoring mechanisms, to arrive at the particular type of organizational culture. Apart from the questionnaires, views, and opinions from the experts were also taken.

From the study, it was found that the perception of employees about the organizational culture varies with different management levels, which might be a potential threat to sustain Lean philosophy. The study concludes by emphasizing the need for detailed understanding on the impacts of cultural dimensions in an organization.

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KEYWORDS

Change Management, Commitment, Lean Construction, Lean Culture, Organizational Culture.

INTRODUCTION

After the publication of the book "The Machine that Changed the World" in the 1990's, the adoption of Lean practices, that was once confined to the automobile industry expanded to other service sectors.(Matthias Holweg 2007). Many organizations around the globe started to pilot Lean concepts in their projects. However, in the long run, most of these organizations were not able to sustain Lean concepts, as most of them tried to imitate Lean tools and techniques rather than understanding that Lean is a culture-based concept.

Lean concepts have percolated to the construction industry as "Lean Construction". Many large-scale organizations and SME's have tried adopting Lean Construction and has succeeded to some extent. Coming to the Indian context, Lean Construction has picked up in the recent years. Many large companies have tried and adopted Lean Construction. However, in the long run, these organizations are not able to sustain Lean Construction due to many reasons like hierarchical mind-set, cultural issues, lack of top management support, lack of discipline, lack of inclusiveness etc. as mentioned in the literature (Cano et al. 2015; Devaki and Jayanthi 2014; R. Jadhav et al. 2014). One of the key reason mentioned in the literature is "Culture". It can be seen that there is no alignment between the organizational culture and Lean culture. It is therefore important to align these cultures for sustaining Lean.

However, when we see the current state of the construction industry, aligning Organizational culture with Lean culture seems to be a challenge due to the inherent culture of the sector. In addition to the uniqueness of construction projects, unskilled and changing workforce, mindsets of the construction community and organizational structure disables the effective adoption of Lean construction. In this scenario, it is very important to understand the organizational culture of the construction sector and mold it in such a way that Lean construction can sustain and yield long-term benefits.

The overall objective of this paper is to assess the organizational culture and understand the impact of cultural parameters in enabling Lean.

LITERATURE REVIEW

The literature review has been structured in three parts. The first part gives a brief introduction to the organizational culture and different models for its assessment. The second part briefly reviews Lean culture. The third part throws light on the existing literature on organizational culture and Lean implementation and ends by identifying the gaps in the existing literature.

ORGANIZATIONAL CULTURE

The term organizational culture has been defined in many ways by different management scholars. One of the widely accepted definitions of organizational culture is given by

Edgar Schein. He defines Organizational culture as *"a pattern of shared basic assumptions that the group has invented, discovered, or developed in learning to cope with its problem of external adaptation and internal integration and that have worked well enough to be considered valid, and therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems"*. In simple terms, organizational culture can be defined as the sharedbeliefs of a group of people, according to which they perceive, act and react. Researchers have tried to classify organizational culture through different methods and models. Some of the widely known models and methods are described below:

- **Hofstede dimensions of culture:** Hofstede states that an organizational culture and behavior is being influenced by the national and regional culture. He identified six dimensions of national culture which affects organizationalbehavior. Those six dimensions are: *Power distance* (extent to which less powerful members of an organization believe and accept that power is distributed unequally), *Uncertainty avoidance* (extent to which members can accept or avert uncertainties), *Individualism vs. collectivism* (integration of members into groups), *Masculinity vs. femininity* (extent to which members seek heroism, assertiveness or material reward instead of cooperation and quality of life), *Long term vs. short term orientation* (determines focus) and *Indulgence vs. Restraint* (it is generally the measure of happiness/gratification of getting basic needs and desires fulfilled) (Hofstede 2011; Zamanabadi 2017).
- **Daniel Denison Model:** Denison states that four dimension describes organizational culture. Those four dimensions are Mission, Adaptability, Involvement, and Consistency. *Mission*includes strategic direction, objectives, vision, and goals. *Adaptability* focuses on the customer, organizational learning, and creating a change. *Involvement* includes employee empowerment, skill building, and team orientation. *Consistency* deals with the core values, coordination, and integration. (Denison and Neale 1999)
- **Edgar Schein Model:** Schein views an organizational culture as an observer and classifies it into three: Artifacts, espoused values, and basic underlying assumptions. *Artifacts* comprise of the visible part an organization that can be seen at the surface level of an organization like mission statements, slogans, dress codes, rituals etc. *Espoused values* define the core values embedded in the organizational member like norms. *Basic underlying assumptions* comprises of elements that are not visible, nor spoken. These values exist within the organizational members unconsciously and are taken-for-granted. (Schein 2004)
- **Kim Cameron and Robert Quinn Model:** Cameron and Quinn have proposed a framework which determines the organizational culture based on the flexibility, stability, external and internal focus of an organization. This model assesses the characteristics of an organization and distinguishes it into predefined cultural

groups: Clan, Market Adhocracy, andHierarchical culture. (Cameron and Quinn 2006)

Apart from the mentioned models, there are several other models available such as Gerry Johnson's model, Stanley G. Harris model, Charles Handy model etc., that assess and classifies organizational culture. However, the central focus of this study remains on strategy, dominant characteristics, organizational glue, management of employees, leadership style and criteria for success.

LEAN CULTURE

Lean can be defined as a management philosophy of continuous improvement which consists of a set of practices and processes. For effective adoption of Lean philosophy in an organization, it is very important to understand what is "Lean Culture". Liker in his book titled "Toyota Culture" says that every Toyota plant has its own unique culture, based on its locality, leadership, history, and people. However, Toyota has developed certain core principles that have to be followed by every Toyota plant regardless of the location. Toyota actually established its philosophy (Kaizen and respect for people) as the foundation and built its core principle and strategy on it. Moreover, Toyota had methods and tools to enable their principles and strategy in addition to the performance measurement and control systems. It is important to understand that Toyota is able to sustain its practices because the whole "Toyota Way" is established on its philosophy. Liker in his book "The Toyota Way" describes 14 management principles based on the 4P model: Philosophy, Process, People & Partners, and Problem solving. The 4P model emphasizes on adopting a long-term philosophy, process optimization, investing in people & partners and seeking consensus with the team members.

The whole process of adopting Lean philosophy as the building stone of an organization and aligning and sustaining the whole processes and people towards it, is defined as Lean culture. It is very obvious to encounter a Lean failure if an organization tries to imitate the visible Toyota Way. It is very important to understand that the visible Lean tools and practices are just the "*Artifacts*" which can be related to the tip of the iceberg and adopting these tools may yield some short-term benefits but in the long-run, it won't yield. Therefore, it is important for an organization to assess its culture, understand its strength and weakness, and then adopt Lean principles in their Business Excellence Model.

LEAN AND ORGANIZATIONAL CULTURE

This section of the literature review will try to explain: Why and how people resist change? What can make people embrace change? What are the enablers of Lean adoption? How is organizational culture related and important for sustaining Lean?

The literature on Lean implementation barriers states "Resistance to change" as a common hindrance for Lean implementation across the service industries. (Cano et al. 2015; Devaki and Jayanthi 2014; R. Jadhav et al. 2014; Salonitis and Tsinopoulos 2016; Shang and Sui Pheng 2014). Some of the reasons for resistance to change are: culture of distrust (when people are uncertain about the change process), Fear of unknown (lack of clarity about the change process), personality conflicts (conflicts between the Lean expert and the employees), competing commitments, past negative experiences and violation of personal compacts (personal compacts is the relationship between the employees and the management with regard to the mutual obligations and commitments (Strebel 2018)). People resist change by raising vocal opposition, false commitments, poor attitudes, deliberate failures and negative peer pressure. Although there are ways and means by which people resist change, there are certain enablers that can make people embrace change. These enablers are active and visible leadership by senior and middle management, community-based leadership, employee initiative, providing reliable information, training for senior management, positive and strong relationships between workers, employee empowerment and developing employees as an integral part of the organization(Alkhoraif and McLaughlin 2016; Keyser et al. 2016). It can be seen that these enablers are strongly related to the organizational culture. The type of leadership style, the involvement of people in the processes, developing and empowering people are all directly related to the culture of an organization. Few organizations may be able to take these types of initiatives for adopting Lean and few may find it difficult and complicated to cope up with these needed changes. Thus, it calls for an appropriate change management strategy. To implement a change management strategy, it is important to understand, “what you are” and what you should be”. In other words, it is necessary to assess and understand the current organizational culture and should be able to fix a desired organizational culture. The journey from the current state to the desired state should be in incremental steps, analyzing the variations and improvement that take place in every step. There has been a study conducted in Brazil to find out the Ideal Lean Culture (Paro and Gerolamo 2017), which managers can use to benchmark the progress of their own journey. However, the study considered only the desired organizational culture for sustaining Lean.

This study will be focusing on understanding the current organizational culture in the construction sector in the Lean implementation context.

RESEARCH METHODOLOGY

This research has employed an exploratory study to understand and assess the organizational culture and the impact of its dimensions in Lean adoption. A large Indian construction company was chosen based on its active program in Lean implementation. Competing Values Framework (CVF) has been chosen to analyze the organizational culture for this study. This frameworkutilizesOrganizational Culture Assessment Instrument (OCAI) for collecting the data in the form of a questionnaire survey. Details of CVF and OCAI has been shared in the next section of this paper. The basic steps involved in CVF are:

a. Assessment of the current culture
b. Analysis of the current culture
c. Setting and scoring the desired culture
d. Analysing the desired culture
e. Finding the difference between current vs. desired culture

But for this study, the desired culture was not assessed and evaluated. The current culture of the organization was focussed. The questionnaire was distributed to 5 members of top management, and 5 members of the middle level. All the employees were asked to score the statements in the scale of 100, for the six different dimensions (Dominant characteristics, Leadership, Organizational glue, management of employees, strategy, Criteria for success) as per the current culture. The score of the first, second, third and fourth statement of each six dimensions was added together to get the total score for Clan, Adhocracy, Market and Hierarchy Culture respectively. After getting the score for each of the six dimensions, the average has been taken for these cultures.

COMPETING VALUES FRAMEWORK (CVF)

CVF is one of the most used and validated model for organizational culture assessment. CVF is a relevant model to understand, how the organization operates and the values that characterize it. As organizational culture is complex, CVF uses two dimensions as shown in Fig 1. One dimension of CVF emphasizes flexibility and stability. The other dimension differentiates an organization's internal focus with an external focus. These dimensions create four quadrants which define the values of an organization (Cameron and Quinn 2006). OCAI assess organizational culture with six key dimensions which are described below:

a. *Dominant Characteristics:* It defines the level of teamwork, creativity, focus on competition & goals.
b. *Organizational Leadership:* It defines leadership style.
c. *Management of Employees:* It defines the level of participation, consensus etc.
d. *Organizational Glue:* It defines cohesion between people.
e. *Strategic Emphases:* It defines employee development, stability, goal setting etc.
f. *Criteria for Success:* It is defined by how success is evaluated (market share, cost, etc.)

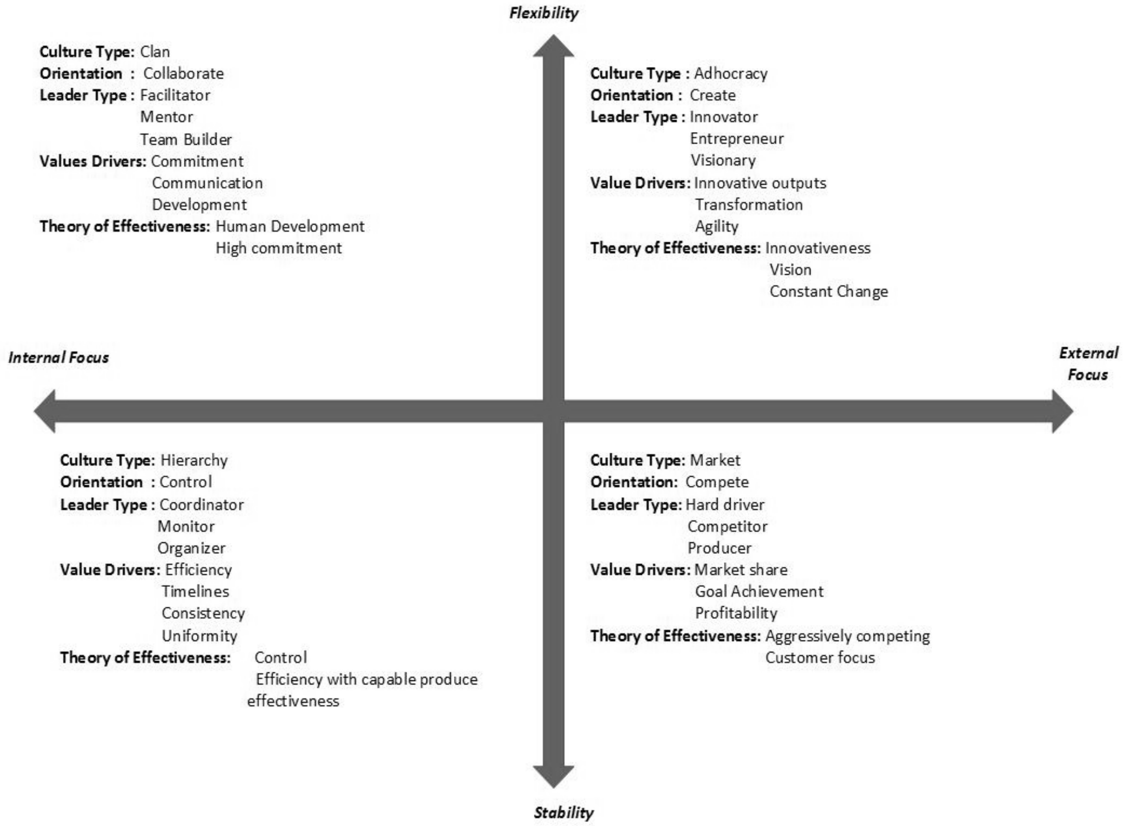

Fig. 1: Competing Values Framework

The scores from the OCAI instrument will help to find out the current organizational culture from the prominent cultures viz. Clan/Adhocracy/Market/Hierarchy culture. The above four organizational cultures are briefly explained below:

a. *Clan Culture:* This organization has a friendly environment. Leaders are mentors or can be called as facilitators. Groups show loyalty and are more traditional. Employee development and cohesion among the groups are given more priority.
b. *Hierarchy Culture:* This organization is formal and highly structured. Employee behavior is governed by rules, procedures, and standards. Leaders try to become good coordinators.
c. *Adhocracy Culture:* This organization is highly dynamic, creative and entrepreneurial. People try to innovate and take risks. Freedom and initiatives are appreciated.
d. *Market Culture:* This organization is focussed on execution. Employees tend to be competitive & goal oriented. Success and reputation are of high priority.

FINDINGS

From the OCAI analysis, the CVF values are found to be: Clan Culture - 25 points, Adhocracy culture - 12 points, Market culture -17 points and Hierarchy culture - 26 points. The resulting CVF model has been shown in Fig. 2.

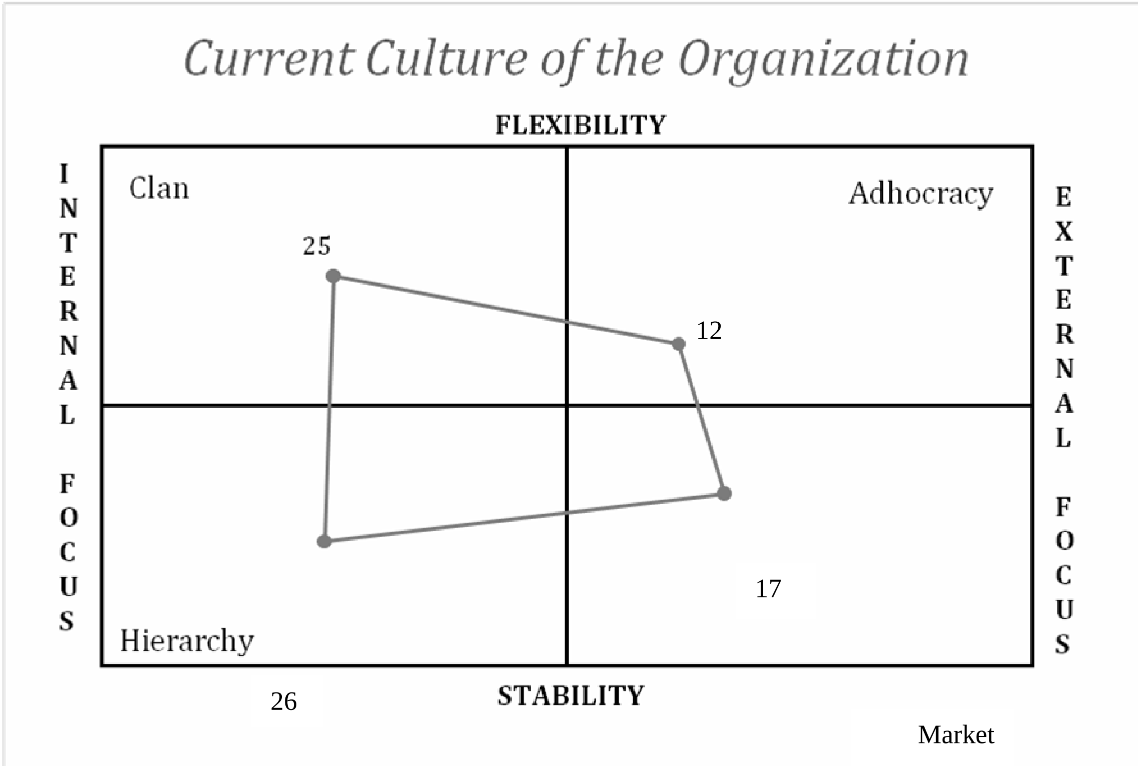

Figure 2: Current culture of the case organization

DISCUSSION

As mentioned earlier, it is important to align Lean culture with the organizational culture in order to sustain effectiveness of Lean implementations. In a study conducted by Delhi et.al in Lean culture, reported that the behaviour of people changed once they realised that they are not under the direct watch of top management (Delhi et al. 2017). This type of behaviour can be related to fat behaviour as mentioned by Emiliani (Emiliani 1998). A fat behaviour can be related to any behavioural action of a person that adds no value to the processes. e.g.wasteful verbal content, confusion, negativity, ambiguity, deception, inaction etc. It is evident from the observation made by Delhi et.al that there are few behaviours in the employees which does not align with the Lean culture which can be linked to resistance of people to change. From the definition of organizational culture by Schein, it can be inferred that if this type of behaviour continues, it can become the norm of the organization. However, fat behaviour is a threat in sustaining Lean philosophy. In order to have a basic understanding of the dynamics of an organizational culture, its assessment at the current scenario is required.

As already discussed in the earlier section, CVF has been used to assess the organizational culture. The organizational culture dimensions considered in the CVF model are dominant characteristics, organizational leadership, management of employees, organizational glue, strategic emphases and criteria for success.

As per the results obtained by the survey, it has been observed that the CVF values for hierarchical and clan culture is approximately equal. On further analysis, it is found that the perception and views of employees of different management levels are different. Top management employees view the organizational culture as clan whereas the middle management employees view it as hierarchical. The top management believesthat the organization is more formal and collaborated, and the procedures and standards govern the working of the organization; whereas the employees of middle management level perceive that the organization is more goal oriented and the leaders are demanding.

Further analysis has been done with respect to the six dimensions of the CVF model, in order to understand the impact of these dimensions on the overall organizational culture. The results of detailed investigation are explained below:

Dominant characteristics: Weightage given to the organization for being a controlled and structured place, governed by formal procedures is very high, compared to the weightage given to the characteristics of clan culture. It is clear that this dimension resembles the characteristics of a hierarchical culture.

Organizational leadership: Weightage given for leadership to exemplify mentoring, facilitating or nurturing is almost equal to the weightage given to leadership that coordinates and organizes the smooth running. So, in this case, it is not possible to differentiate if the organization exhibits the characteristics of clan or hierarchical culture.

Management of employees: From the result, it can be clearly stated that the management style in the organization is characterized by team work, consensus and participation which resembles the characteristics of clan culture.

Organizational glue, Strategic emphases, Criteria for Success: The weightages for the characteristics of hierarchical and clan culture for this dimension are approximately equal to the each other. Thus, further investigation is needed to understand the impact of this parameter.

It is not possible to draw any definitive conclusions in this study. The type of organizational culture required for sustaining lean is not simplistic but a complex multidimensional issue. But, the present study helps to understand that there are different perceptions about organizational culture among the employees. It also highlights the need for detailed research in the area to find the implications of various other cultural dimensions apart from the six dimensions of CVF.

SUMMARY & FURTHER WORK

This study has adopted an exploratory research methodology to understand the organizational culture in the construction sector with respect to Lean adoption. The study helped to understand that the perception of employees regarding the organizational culture at different management levels varies, which is a potential threat to sustain Lean.

The study is limited to a case with less number of respondents for the survey and interviews. Further detailed investigation has to be done to understand the impact of cultural dimensions on the organizational culture.

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INNOVATION WITH CREATIVE COLLABORATIVE PRACTICES

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ABSTRACT

Lean is about solving problems related to reducing waste while maximizing value. The project team of the construction project Bispevika in Norway is working on how creative collaborative practices can be performed in problem-solving processes. This paper considers following research questions: Which creative collaborative practices are implemented in Bispevika? What are the experiences of these practices? How to improve these practices in future projects? In addition to observations on site within design and procurement, interviews of the project managers as well as a document study based on received project material is carried out to identify creative collaborative practices. A literature study on trust in collaboration, creative processes and creativity and innovation in lean is also presented. The engagement of an innovation manager as a facilitator combined with his own research on creative practices contributes to the overall vision of being an innovative project. The executed method is based on a four-phased process leading to the choice of best solution to a case. By using a strategy of creating winning teams and focusing on trust in these collaborations, the project is aiming at innovating the way projects are managed in the future. Identified creative collaborative practices with proposed adjustments are presented.

KEYWORDS

Creativity, collaboration, innovation, trust, problem-solving processes

INTRODUCTION

The goal of planning and executing projects while minimizing waste and maximising value comes from the mindset of lean construction (Ballard and Howell, 2003), and is increasingly implemented in a conservative and traditionally bounded industry, as construction is perceived today. Simultaneously, a complex project design demands uniqueness and higher level of specialization (Lombardo, 2014), yielding a need for interaction and involvement of multidisciplinary stakeholders on another level than before (Bygballe and Swärd, 2014). Problem-solving processes are often carried out as

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mapping of previous solutions and experiences, moving along patterns of existing knowledge (de Bono, 2009), thus limiting the number of possibilities. By using a structured and conscious approach towards creative processes leading to innovative and improved solutions (Amabile et al., 2002), future projects are able to combine the mindset of lean with the demand for complexity and uniqueness. Implementing problem-solving practices of this kind requires close facilitation (Lombardo, 2014; Amabile and Khaire, 2008) with internal as well as external, multidisciplinary stakeholders, and should aim at crossing these established patterns in problem-solving processes. Thus, creative practices demands and yields collaboration, as a partnering relationship requires interaction to reach its full potential (Bygballe et al., 2010). In total, a new approach to problem-solving practices should involve the two elements creativity and collaboration, while emphasizing the development of innovative solutions.

This study aims to discover how creative cooperative practices are used in production of innovative solutions in a multidisciplinary engineering project. More specifically, to identify:

1. Creative collaborative practices concerning procurement and design in a case study,
2. The experiences of these practices from the main contractor's point of view, and
3. The potential for improvement of these practices for future projects.

Regarding limitations, the first step has been to narrow the scope to concern mainly two project activities, whereas procurement and design has been chosen as the most relevant activities. Further, the study is restricted to the view of the main contractor. The research period is limited to a timeframe of six months, which could have an impact on the results regarding the current project phase. The time limitation also makes the follow-up of a specific case through its respective phases of the creative process constraining. The solution has thus been to collect a representative number of observations from each phase, not taking the continuity of each case into consideration.

THEORETICAL FRAMEWORK

Based on the topics presented in the introduction, it appears interesting to take a closer look at research treating topics related to the creation of trust in collaboration, as it is considered a critical element in obtaining a creative collaboration (Swärd, 2016). How creativity and innovation are mediated with the concept of a lean mindset raises some controversies to be treated further on in this chapter. Other topics needing to be explored are creativity by its definition and creative processes in problem solving tasks. The aim of this chapter is primarily to map how these topics have been treated and explored in existing research and secondly to identify lack of knowledge about how mentioned topics interact with and are dependent of each other (Blumberg et al., 2005).

TRUST IN COLLABORATION

Several researchers within creativity and innovation are pointing towards the need for trust, affect and reciprocity as a prerequisite when developing a problem-solving and creative environment (Bygballe et al., 2010; Swärd, 2016). Affect and creativity are linked by positive affect facilitating cognitive variations (Amabile et al., 2005). These variations yield new associations which finally leads to creativity. Reciprocity is defined as a social norm in the shape of an expected repayment for an action between two parties, a behaviour which may lead to increased trust (Swärd, 2016). The response time of a reciprocity increases with the significance or investment of the reciprocity, and will also contribute to a larger sense of trust in a long-term relation. In order to optimize the use of reciprocity and then the development of trust, the necessity of psychological safety in the collaboration between multidisciplinary actors at a workplace or a project needs to be announced and established (Edmondson, 2012). Psychological safety is critical when establishing working teams beyond a business relation. This must imply that when conditions for trust are present, the project is more likely to succeed in implementing change.

CREATIVITY AND INNOVATION IN LEAN

Creativity has been looked upon as an individual and abstract skill, with low ability of measuring effect or size (Klausen, 2010; Kaufmann, 2003). Among other misconceptions are the idea of creativity only being performed as an activity of brainstorming (de Bono, 1995) and that the best creative solutions are achieved under time pressure (Amabile et al., 2002). There are several challenges related to the definition of creativity, and Klausen (2010) reminds us to never confuse novelty alone for being creative. As problem-solving processes traditionally consist of moving along patterns elaborated from previous experiences and existing knowledge, crossing across these patterns can enable serious creativity in the form of *lateral thinking* (de Bono, 1995).

As implementing change in the construction sector is dependent on incorporating new knowledge into existing routines (Bygballe and Swärd, 2014), there is reason to believe that relation and interaction with external stakeholders are critical elements for success in concepts like lean construction. The motivation for change needs to come from a belief of increased competitiveness in the market (Bygballe and Swärd, 2014). In other words believing that change could make the organisation more profitable and attractive to other stakeholders. By bringing creativity and innovation into the concept of lean, an organisation's confidence, attitude towards problems, motivation and engagement are among the requirements for optimal execution (Johnstone et al., 2011). The concept of lean construction emphasizes resource-use and process-flow in optimisation, while creativity is proven to reach its potential when time is an adequate resource (Amabile et al., 2002). Thus, there is a controversial balance to be upheld in uniting creative practices with a lean mindset. One concern is related to workers developing an excellent planning skill while reducing their creative skill, towards neglecting or strangling innovative, creative work (Bygballe and Swärd, 2014). Organisational practices mediate the link between innovation and knowledge-sharing by collaboration and interaction (Foss et al., 2011), and interaction should thus be taken into account when managing creativity and innovation in a lean-environment. One solution must be to facilitate consciousness towards the definition of creativity, and what creative practices are intended to achieve.

CREATIVE PROCESSES

As a possible solution to the challenges regarding problem solving processes in optimization of innovative solutions, lateral thinking should be enabled into practices suited for a given project. A possible practice for creative processes, adjusted to the complexity of multi-disciplinary project teams, is presented in the thesis of Lombardo (2014). The practice consists of four phases; focus, idea generation, assessment and evaluation, and finally choice of solution. Each phase follow a certain layout regarding how they should be carried out. The method emphasizes establishment of a focus rather than a problem, and the use of this as a guide towards creating ideas and further evaluating and choosing possible solutions. The method clearly describes how to facilitate and explore the potential of creative sessions, as well as how ideas and potential solutions should be documented, assessed and evaluated in order to be implemented and executed in real life. Lombardo (2014) also includes experience-based do’s and dont’s along with every phase, preparing the reader for potential pitfalls in a creative session. It is particularly the idea generation-phase which demands creativity, as the creative interaction between the stakeholders is put at the core of the problem-solving process. The practice aims at leveraging the creative resources by stimulating interaction. Within each phase, a number of actions are performed in order to provoke creativity, requiring participants to know the usual approach to a problem in order to be appropriate.Absence of previous knowledge – ignorance - is known to be a potential source to creativity (de Bono, 1995), making the practice unnecessary. This type of generation or exploration of creativity requires having an adequate time frame while avoiding an excessive number of participants in the collaboration (Amabile et al., 2002).

METHODOLOGY

The chosen research methods are based on practice as unit of analysis, consisting of data collaboration and data analysis. Initially, a literature study has been performed in order to map current research on the topic field. Data collaboration in the case study is carried out through initial, qualitative interviews in addition to document studies and observations.

Findings from the literature study are presented in the theoretical framework as the current state of research related to the topic of the study (Blumberg et al., 2005). Recommendations from supervisors and search-engines online are the main source to the findings. Chosen literature spans from published conference articles and journal articles to books and theses.

PRACTICE AS UNIT OF ANALYSIS: A CASE STUDY OF TEAM BISPEVIKA

The context for this research is the case of Team Bispevika in Oslo, Norway, a project aiming to contribute to an innovative change of project management in the industry. In Norway, the interest for continous improvement and Lean Construction is relativelty high (Engebø et al., 2017). All interviewees, documents and observations are related to this case.The project is the first in a long-term goal of the main contractor to use innovation in order toincrease the added project value by 40%. The plan is to reduce costs by implementing innovative solutions and increasing quality for the end-users.The ongoing project has a cost of MNOK 1109, consisting of constructing 11 buildings over 48.000 m^2 at the old harbour of Oslo. Areas of innovation spans from partnering with contractors to contract strategies, and the vision affects all aspects of the project. Towards innovation, the project uses creative processes in problem solving incidents. These practices are prominent within procurement and design as chosen areas of this study, but also in production and end sale. The project management has its main workforce from one of the largest contractors in Norway, and the client is heavily involved in project execution.

INTERVIEWS

Interviews are carried out with a prepared interview guide and semi-structured to allow the interviewer to angle the questions and topics toward the relevance based on answers given by the interviewee (Yin, 2014). There are five interviews in total, and all interviewees hold key roles in the project management. The intention of the interviews has been to unveil the mindset of the project, and how they work differently than traditional construction projects. There have been challenges concerning the coordination of information given in the interviews, as the interviewees perceive different perspectives of the project as important.

DOCUMENT STUDY

There are mainly used three project documents to examine the intentional purpose and framework for the practices, contributing and supporting collected data from interviews and observations. All documents are received from the project management on request. The document related to the tender stage is considered a guideline for every aspect of the project, and there is thus only the chapter concerning innovation which is taken in closer consideration. The document related to creative processes in design is a guideline on how sessions in the optimization process should be carried out. Representing procurement, the chosen document presents an example of how strategies for each discipline are developed and documented for further collaboration.

OBSERVATIONS

Observations consisted of participation in sessions related to procurement and design with the innovation manager operating as the session's facilitator. When planning the observations, the method of Creswell (2012) was used with the intention to follow meetings in procurement and design as a direct link to discover how practice is performed in everyday project life. Published material from the project's innovation manager was used to conduct each meeting, and recording of the observations were made through taking minutes. The phase concerning choice of final solution has been left out, as it is considered to be of less interest to the research questions. A matrix of the observations made within each case, activity and process phase is presented in table 1. The limited time frame made it demanding to follow each case through each process phase, thus a representative number from each phase is chosen.

Table 1: Observations of the case study

Topic for innovation - Activity	**Focus**	**Idea generation**	**Evaluation & assessment**
Waste recycling - Procurement	X	X	
Roof construction - Design		X	X
Concrete: Con Form - Procurement	X	X	
Discipline Strategies - Procurement & Design	X		
Sunblind - Design			X
Timber - Procurement	X		
Logistics - Procurement			X

FINDINGS AND DISCUSSION

This section presents both findings and discussion of each research question under the process phases, with an aim of identifying characteristics and experiences of creative, collaborative practices in Team Bispevika and how they can be improved, as presented by the research questions. The guide for observational studies is based on the method of Lombardo (2014), elaborated in the theory section. A simplified presentation of the phases are shown in figure 1.

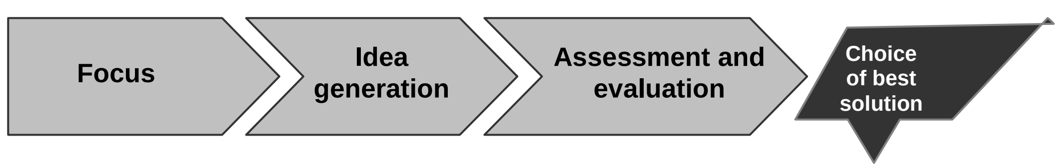

Figure 1: The phases in a creative process, freely based on Lombardo(2014).

FOCUS

Which creative and collaborative practices are identified in the focus phase?

To map the potential of each discipline within the project, the procurement team is developing different strategies for each project area in documents called *Discipline*

Strategies, presenting intention and goal of each collaboration and how to work together towards improved solutions. Through process facilitation and method awareness, the project team aims at meeting increasing project complexity and client demands. This is emphasized through spending resources on engaging qualified personnel such as an innovation manager and an improvement manager to follow up creative processes, collaborative challenges and innovation management. By having these key roles on site as a part of the project management team, the chances increases of creating solutions that are tighter connected with market needs and development in a long-term perspective. Throughout the focus sessions, the innovation manager reminds the participants of the session's intention and desired outcome. This strategy is confirmed through the project documents, aiming to contribute in implementation of the creative process in daily problem-solving work:

The Innovation Manager(IM) is responsible for execution and facilitation of the project's innovation processes. IM will also plan and execute collaborative processes.

What are the experiences of these practices?

The interviews and observations unveil variation from procurement to design regarding the time frame of the focus phase, due to the current project phase and nature of the activity. Findings show that the procurement team spends more time on establishing trust and knowledge towards the project's mindset, while the pressured time-limitation in the design team rather makes the collaboration about "getting the job done". This was especially made clear through focus sessions with the concrete supplier and waste recycling, where the facilitator needed to postpone the delivery of focus criteria to the later meetings, and rather spend time on getting the new partners into the innovative mindset of the project. The final outcome of the focus phase for the two collaborations were the highly ambitious goals of 33% increased productivity for the concrete work compared to similar projects, and 99% recycled material for waste management.The observations of design are done on a more detailed level than procurement, which could explain the difference in time use. As a part of the process towards change of problem-solving practices, creating competitiveness in the market is used as a motivation for development of these practices. The project team uses a visual presentation of their long-term goal of cost reduction and quality increase throughout the focus sessions. The main delivery of the phase is a list of criteria corresponding to the problem-solving issue, mentioned and confirmed orally in sessions as well as written in project documents.

How can these practices be improved in future projects?

A change of attitude and perception takes time, and members of Team Bispevika work every day to change the stakeholders' conception of creativity, collaboration and innovation through their vision. As one of the interviewees pointed out:

None of the elements we use here in Team Bispevika are totally new and never tried out before, but the framework around how we do business gives a new perspective on how projects can be managed and executed in the future.

Preparation of the focus phase should consist of creating knowledge and awareness towards the method itself, as it takes time and effort to realize that creativity not necessarily equals novelty. Interviewees also request a tool to determine deadlines and timeframes related to the creative collaborative practices, and propose a flowchart or timeline as a possible future solution. The tool should cover all project activities, as they are closely intertwined when planning each part and process. In addition, the identification of stakeholders and their interests in the current problem or challenge could be closer examined in the focus phase.

IDEA GENERATION

Which creative and collaborative practices are identified in the idea generation phase?

The traditionally presumed way of executing a creative phase solemnly through a brainstorm determined by individual skills as presented in the theoretical framework, is clearly disproved through observations and interviews of the case study. The project team invites a varied and representative selection of stakeholders to join and collaborate in these sessions, as they believe that different minds spur several associations, yielding more creativity and finally better ideas. Highly skilled and experienced consultants in design emphasizes the need of using constraint-shattering practices, aiming to find new angles to old challenges. This is connected to the concept of crossing established patterns in lateral thinking.

What are the experiences of these practices?

Observations and interviews of sessions in design amplify the impression of a struggle to document each idea as they progress throughout the session. When participants are new to the practice, it seems easy to lose focus and start an immediate evaluation of a presented idea, as opposed to keep focus on preserving the creative aspect of each idea through registration. In the session of designing new solutions to a roof construction, the team used a smart board to register all ideas digital, consecutively and in an organised matter. Regarding idea generation in procurement, all contributions are visibly anchored in the business model of each sub-contractor or collaborative partner. The project team have taken several actions to create a sharing culture where all stakeholders are meant and expected to contribute in creative problem-solving processes. Among the most visible actions are co-location of external design consultants and sub-contractors on site and feedback-surveys to measure the subjective effects and experiences of a session or meeting. These actions aim at creating psychological safety for each and every participant and contribute to a vision of every stakeholder pulling in the same direction. The delivery of the idea generation phase is a list of registered ideas, ready to be further treated and evaluated.

How can these practices be improved in future projects?

High speed and time pressure related to the design process makes it demanding to spend resources on developing creative collaborative practices, and the implementation of the current innovation practice needs adjustments in order to fit the daily workload within design. As the current time frame is limited, new solutions need to justify providing time on implementation. These adjustments should be able to bring out the potential of invested resources in the project and not only become time-consuming.Through focusing on expected preparation from participants ahead of each session, the total creative collaborative contribution can increase, and quality of the ideas could elevate. In addition, challenging participants in expanding their creative space by using techniques for association and value chains should be included in sessions.

IDEA ASSESSMENT AND EVALUATION

Which creative and collaborative practices are identified in the idea assessment and evaluation phase?

The project team have - through stating the practice in tendering documents - chose to focus on creating *winning teams*, aiming to increase the collaborative environment by using an open-minded strategy:

We will work together on a long-term perspective, and time spent on building trust is time well spent. (...) Respect for the skill of one another is another central premise, and not to mention getting acquainted as personal individuals, regardless of position.

This relates to the creation of psychological safety (Edmondson, 2012) as well as affect (Amabile et al., 2002). The project team works from a mindset that implies the following:

I know you →Wehave an established relatedness → I feel safe → I see more solutions

This implication is particularly visible through the procurement strategy, confirmed by the interviewees. In design, using a matrix to evaluate and map ideas according to chosen evaluation criterias creates a basis for the assessment and evaluation phase, a practice relating directly to the findings of Lombardo (2014).

What are the experiences of these practices?

When discussing and evaluating possible solutions during these sessions, the facilitator encourages an open dialogue between stakeholders to unveil biases and avoid anyone feeling bypassed. This mindset is clearly appreciated by external stakeholders, as feedback is given during sessions and through positive reciprocity in a long-term perspective. Reciprocity is shown through taking risk related to resource use as economical contribution, time spent on development of new, collaborative solutions and follow-ups of the chosen practices. Observations and interviews shows how close and careful guidance from the facilitator is necessary when sorting and categorizing generated ideas, as the practice is new to most stakeholders. During the evaluation phase, the facilitator must keep in mind the existing solution as a full-fledged alternative to consider, in order for the new ideas to be realistic alternatives. When the goal – as stated in project documents - is to leverage the creative resources, the innovation manager creates strength and credibility towards the chosen practice by using methodology recovered from his own research. Making it easier to correct unwanted execution of the practices as well as increasing chances for replication in future projects are desired results of using the framework of Lombardo (2014) in combination with engaging him as head of innovation and facilitator. The session's delivery is a complete list of possible and realistic solutions ready to be implemented to the daily work of design or procurement.

How can these practices be improved in future projects?
By creating an adequate time frame and limiting the number of participants as described in the theory section, the idea assessment and evaluation phase improves in terms of quality and resource use. In addition, observations show that biased and manipulated idea evaluation in design can be avoided by creating and preparing relevant evaluation criteria ahead of evaluation, in order to reveal the difference in advantages of alternatives. Interviewees point out that the effect of *winning teams* should at a given point in the project be measured as a guide of expected success by completion with regard to collaboration. They request a measurement practice limited to the most interesting parametres for success in a multidisciplinary engineering team.

SUMMING UP AND FURTHER RESEARCH

A proposed description of identified collaborative creative practices in production of innovative solutions in a multidisciplinary engineering project are presented in figure 2, based on key takeaways from findings and discussion. Identified practices align well with the proposed structure of Lombardo (2014), but are added adjustments regarding preparations and outcomes from each phase in order to assure continuous development of trust and increased use of creative resources throughout the process. Team Bispevika should pay attention to the importance of continuous process facilitation, as it is critical to the establishment of trust among internal and external stakeholders. As the facilitator focuses on creating awareness towards preparation and delivery of each session, the practice gains ownership and trust from participants. It should be noticed that the presented figure is a preliminary description on how creative collaborative practices are executed in the case study at a given point of the project, made by an external observer. In other words, the practices are not complete or finalized at this point. To summarize, the identified practices which will continue to be developed into the future, could create a form of standardization and process flow, leading to a new way of executing problem-solving processes in multi-disciplinary engineering projects. Despite a traditionally conservative view on the concept of creativity, these practices can - by focusing on collaboration in the creative process - contribute to the lean concept and improve the whole construction industry in a long-term perspective.

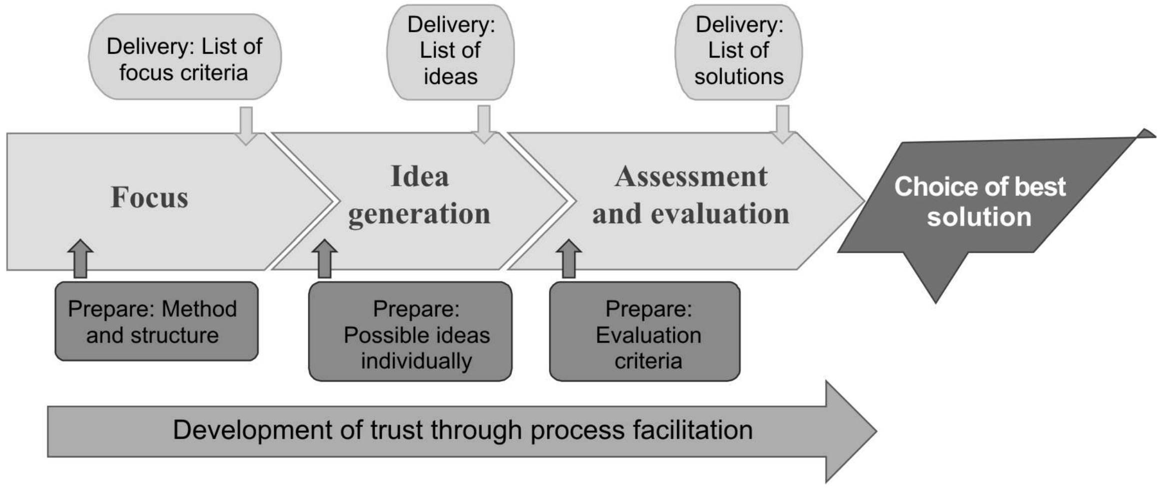

Figure 2: Identified creative collaborative practices in Team Bispevika, freely adapted from Lombardo (2014).

For future research, it would be interesting to take a closer look at how practices evolving creative processes are perceived by different sub-contractors and suppliers as well as the external design consultants to get a larger perspective. To expand the number of project activities from procurement and design to also concern property development, production and sales could result in a broader understanding of practices, as several project activities are intertwined in the daily work. To follow the project through several phases over time would also give more precise observations. Finally, it would be interesting to take a comparative look at existing desicion-making practices in the light of alean-influencedmethod like choosing by advantages(Arroyo et al, 2016).

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FRAMEWORK FOR PROGRESSIVE EVALUATION OF LEAN CONSTRUCTION MATURITY USING MULTI-DIMENSIONAL MATRIX

Yeshwant Sainath[1], Koshy Varghese[2], and Raghavan N[3]

ABSTRACT

Lean is a culture-based management system essentially aimed at waste elimination, thereby creating value for the customer. It is a transformation journey and to evaluate the progress on this journey at any time, the achieved state of maturity has to be assessed. We argue that Lean Construction management spans three stages or phases - P*hysical (Activity-based) Manifestation, Behavioral (Culture-based) Manifestation and Strategic (Long-term) Manifestation.* To evaluate the progress on this journey and assess the state of Lean maturity achieved across a project or the entire organization at any stage, a host of factors needs to be considered.

The distinctive factors relating to each of the above three stages are initially identified by literature survey and interviews. These factors are then assigned with different individual weights through findings from a detailed questionnaire survey. A weighted factor model is then developed to assess the overall maturity at project and organizational levels. The Lean scores for the various factors are shown on a Spider Radar and a bar chart and overall maturity level is plotted on a normative Lean maturity progression curve spanning across the three stages.

The model was developed based on data collected from 25 Lean practitioners across six organizations, which are implementing Lean construction in their sites. The model was then applied to projects of four different organizations and the Lean Construction Maturity Ratings were calculated. These scores were then discussed with experts to validate whether the scores appropriately reflected, in an overall qualitative sense, the Lean maturity of the projects surveyed. In view of the low level of spread of Lean practices across the Industry in this country, assessment of Lean maturity across an entire organization has not been taken up so far.

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KEYWORDS

Lean Culture, Lean Construction Maturity level, Normative Progression Curve, Questionnaire Survey, Lean practices.

INTRODUCTION

Over the last four decades, there has been a growing focus in both manufacturing and construction organizations on implementation and development of improvement techniques to increase benefits and reduce costs. The construction industry around the world faces a critical challenge to improve its innovation and productivity (Larsson et al., 2013) to be at par with the manufacturing industry as manufacturing sector has been more able to progress with innovation. Indian Construction is in its nascent stage of Lean adaptation and acceptance of Lean across various organizations can be best evaluated by determining the current state of maturity to determine the strengths and weaknesses in the Lean Construction implementation process (Bernardo M. B. S. Etges, 2013).

A framework is proposed in this paper covering various aspects of Lean in construction that will assist organizations to assess their current state and to know where they stand in the overall journey to Lean perfection.

LITERATURE REVIEW

In this section the information and data collected on a review of the various Lean maturity assessment models proposed by various earlier investigators are discussed.

Creating a Lean culture in the organization invariably requires behavioral changes in all organizational levels. On one hand, being Lean should be part of the core business strategy and should be considered in any important and strategic decision made by the company (Womack & Jones, 1996). On the other hand, equipping employees with appropriate tools and techniques and empowering them to use a suitable set of those techniques for managing construction can make a significant impact on an organization's performance (Shah & Ward, 2003). Accordingly the Lean usage will evolve from basic Operational or Physical levels through an evolution in Behavioral levels to a permeating Strategic level.

The concept of maturity models originated from quality management perspectives that describe quality improvement through a five-level maturity scale (Crosby 1979). Such a maturity model is generic and can be applied across any industry; but in order to operationalize it for a particular industry, two additional developments need to happen: Developing factors to define each maturity level; and developing a roadmap for strategy to enhance maturity.

A maturity model that defines the various applicable factors and improvement opportunities is very beneficial in bringing major transformation (Nesensohn, et al., 2014). Nesensohn et al. (2013a, 2014) and Nesensohn (2017) also show a detailed framework comprising various maturity levels, "ideal statements" and corresponding Factors, which enable the measure of current maturity of any construction project. The UK Highway Agency has developed an in-house Lean Maturity Assessment Toolkit

(HALMAT), based on the Lean Enterprise Self- Assessment Tool (LESAT) developed by the aerospace industry at the Massachusetts Institute of Technology (MIT).

Below are a few of the Lean Maturity Assessment Instruments culled out from available literature tabulated with their purpose and scope of assessment.

Table 1: Lean Maturity Assessment Instruments

Author Name	**Instrument name**	**Purpose**	**Scope of Assessment**
Nesensohn et al.,2014, 2015, 2017	Lean Construction Maturity Model (LCMM)	It provides organizations with factors, maturity levels and ideal statements which help in assessment of the current state in Lean Construction Journey	It comprises 11 key factors: 1. Lean leadership, 2. Customer focus, 3. Way of thinking, 4. Culture & behavior, 5. Competencies, 6. Improvement enablers, 7. Processes & tools, 8. Change, 9. Work environment, 10. Business results, 11. Learning and competency development.
Donovan, 2015	Lean Manu-facturing: Performance Evaluation Audit	This tool provides a checklist of various parameters for the assessment of an organization's current status in adopting Lean Manufacturing Criteria.	It includes a number of **yes/no** questions focused on various fields important in the Lean Management approach:: 1. Process planning and control, 2. Management and leadership, 3. Quality control and planning, 4. TPM, 5. Suppliers, 6. Selected Lean techniques, 7. Customer focus, and 8. Performance improvement
Department of Transport, UK	Highways Agency Lean Maturity Assessment Toolkit – HALMAT	The purpose of using the in-house developed assessment tool is to provide the organization with a structured means of assessing where it is in the journey of Lean.	Areas of coverage of the assessment toolkit: 1. Strategic use of Lean 2. Financial, information, and procurement systems 3. Lean leadership 4. People development 5. Lean structure and behavior 6. Collaborative working 7. Delivery of value 8. Standard work 9. Process flow 10. Process control and quality assurance

RESEARCH METHODOLOGY

Basic Premises

i) As Lean Maturity increases, the predominant outlook in projects shifts in 3 stages from Physical Practices through Behavioral Practices to Strategic Practices.While the lower practices are still essential, the emphasis shifts to the higher practices (Fig. 2). The interview respondents have also opined that with good adoption of Physical practices in Projects, a tendency to follow Behavioral Practices sets in, further maturing on to adopting Strategic outlook by and by. Though the journey is long, there is a continuous progression.

ii) Lean Maturity can be assessed on the basis of certain practices and concepts being implemented at the Project.

iii) The critical Lean Concepts and Practices can be prioritized for the three stages by observations in projects and taking inputs from expert Lean practitioners.

The following stepwise methodology approach is used in the process of developing the proposed framework based on the above premises:

- Step I - Exploratory study (Literature review & Lean academic expert opinions).This helped in identifying the various factors that can define the Lean maturity level based on which a preliminary framework was developed. T*he factors were divided into three stages (Physical, Behavioral & Strategic) which also corresponds to some degree with an organization's three tier management system (Lower, Middle & Top).*
- Step II - Industry Lean practitioner opinions/input: This helped in garnering hands-on experience from the industry experts who are practicing Lean tools & approaches, to identify the various factors in detail and *helped to develop a Lean Evaluation Checklist. (Ref. Figure2 for a typical Lean Evaluation Checklist.)*
- Step III - Questionnaire Survey: A five-point Likert Scale survey based on Strongly Disagree to Strongly Agree was conducted among Lean practitioners from various organizations to get their responses to identify the various Concepts and Practices which would define Lean maturity and a concept of Relative Importance Index (RII) was adopted to derive the weights for each factor.

Along with the survey responses, semi-structured interviews were conducted with various Lean practitioners across the spectrum of Clients, Consultants and Contractors to check whether the compliance to processes could be quantifiable on a binary scale, and whether the stage wiseapproach is valid. The overall response was quite positive. Again, it was important to know whether this model will help in improving the current state of maturity. Knowing the areas of weaknesses or lacunae, as seen from the Lean Evaluation Checklist, practitioners can identify the areas where they have to improve in future.

- Step IV - Development of Framework: A framework was developed linking the various Factors, Weights and Development Stages.

- Step V – Case Study for validation: Testing of the framework was done in a few organizations. Further testing is required to tone up and further improve the model.

PROPOSED FRAMEWORK

This research is aimed at capturing qualitative as well as quantitative data in the form of survey responses and semi-structured interviews to understand the various factors which define the degree of Lean Construction maturity and based on these data the framework is developed. Thereafter the concerned project sites were visited, relevant data collected by observations, followed by study of project documents and queries with the project personnel. Then this data was fed into this framework and the Lean Construction Maturity Rating (LCMR) determined. This index is also validated, though in a subjective manner, on the basis of overall observations of project sites and broad queries. Figure 1 illustrates the components of this model.

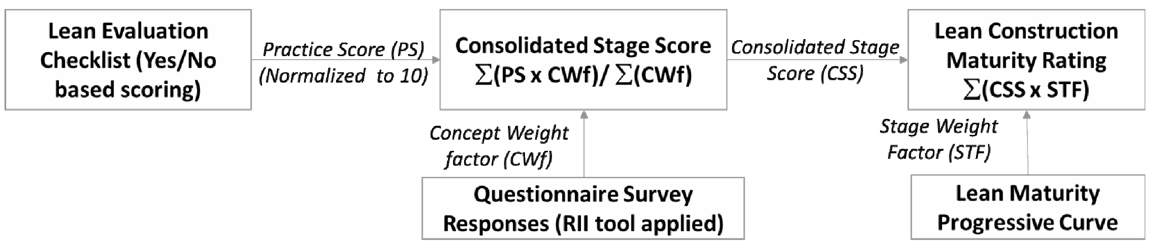

Figure 1: Framework for assessing LCMR

We argue that the journey of any organization towards perfection in Lean will cover different types of practices in three typical stages and every construction project would also have similar stages: Physical practices stage, Behavioral practices stage, Strategic practices stage. This was also got vetted through the interviews. In the first stage various Lean tools will be practiced with emphasis on Physical progress. In the second stage with the steady onset of a Lean Culture, Behavioral practices will start becoming dominant. In the third and final stage Lean culture would have permeated the whole set-up and Lean would be a Strategic concept covering all planning and implementation, with the highest Lean Maturity. Though the first stage is common in Projects and the next two stages in the overall organization, the progression towards higher stages is evident in projects with sustained practice of Lean.

Accordingly certain Lean Concepts are identified for each of the three Stages and for each Concept certain Practices are identified along with Attributes which define the Practice in some detail, to compile a Lean Evaluation Checklist (Figure 2). As the first step in the LCMR determination, evaluation of Project is assessed for perfection in each of the Practices, based on certain defined Attributes, on a Binary Mode, with “Yes” or “No” for whether each Practice is done or not done on the Project. The depth of practice and longevity of practice are also considered in an overall sense. Then the percentage of Yes’s obtained for the various Practices in each Concept is normalized over a base of 10 to obtain the Lean Practice Score (PS) for that Concept.

Concepts	Attributes	Processes	Y/N
Collaborative Working	Meeting & MOM	Are all the concerned stakeholders part of meeting & MOM been shared to all the concerned parties on regular basis ?	Y
	Partnering	Is Trust been generated for partnering with existing S/C & vendors instead of floating bid for new parties and wasting time & resources?	N
	Evaluation of S/C & Vendor	Is Past Performance Evaluation been done before getting Vendor & S/C on board and periodic evalution is recorded too ?	N
	Coordinated Drawing Sharing	Is coordinated drawing been shared with all the concerned parties - accepted & signed by them before commencement of activities ?	Y
	Change Notes Sharing	Are change notes been shared with all the concerned parties - accepted & signed by them before commencement of activities ?	Y
	Contractual Stipulation	Is contractual Clause w.r.t Lean construction methodology been added before getting on board all the Stakeholdes - Subcontractors & Vendors ?	Y

Figure 2: Lean Evaluation Checklist – Typical Concepts, Attributes and Processes

In parallel a five point Likert Scale survey has been carried out covering a large number of Lean practitioners from various Projects to identify Lean concepts and practices which are most critical to attain Lean Maturity and the Lean Practices for each Concept are accordingly ranked in terms of importance. Then using a Relative Importance Index (RII) statistical approach conducted over the questionnaire responses, RII scores are derived for each Concept and they are seen to vary from 0.75 to 0.95, with the higher scores indicating higher relevance. Hence to enable further processing, the RII scores are converted to Concept Weightsfactor (CWf) as per following Table 2:

Table 2: RII and Weights distribution

RII	**>0.90**	**0.85 – 0.90**	**0.80 – 0.85**	**0.75 – 0.80**
CWf	4	3	2	1

The RII scores and the weights for the various Concepts are shown in Table 3.

Table 3: Practices, their RII Scores and Concept Weights

Concepts	**RII**	**Concept Weights (CWf)**
Physical Manifestation		
1. Implementation of Lean Tools & Processes	0.87	3
2. Continuous Improvement	0.93	4
3. Focus on Value Creation	0.84	2
4.Work Standardization	0.77	1
Behavioral Manifestation		
5. Lean Culture & Behavior	0.89	3
6. Waste Identification& Productivity	0.81	2
7. People Development	0.90	4
Strategic Manifestation		
8. Collaborative Working	0.89	3
9. Strategic Use of Lean	0.88	3
10. Leadership to drive Lean	0.85	3
11. Customer Focus	0.91	4

In the second step a Consolidated Stage Score (CSS) is obtained for each Stage as follows:

CSS = $\sum(PSi \times CWfi)/ \sum(CWfi)$, where PSi is the Lean Practice Score for each Concept obtained from the Lean Evaluation Checklist and CWfi is the Concept Weight Factorfor that Concept, with "i" summed up over the number of Concepts for each of the three Stages. Thus three CSS numbers covering the three Concepts will be obtained for each of the three Stages.

In the third step the Maturity Level of each Stage is factored in by using a Stage Weight Factor (STF). Duly recognizing that the final LCMR is a summation of the individual scores covering all the Concepts of all the Stages and at the same time recognizing that the higher Stages should have higher scores for the Concepts relevant to the higher stages, the LCMR is derived as follows:

LCMR= $\sum (CSSj \times STFj)$, with "j" summed up for the Concepts of the three Stages. Depending on exactly in which Stage a particular Project figures, the STFs will vary for the three Stages, as follows (Figure 3 and Table 4).Hence determination of STFs is somewhat iterative. The curve shown in Figure 3 is depicted as a Learning Curve. Quantitatively, based on various interviews it has been postulated that at end of Stage I Maturity the Lean Construction Maturity Rating corresponds to 4, at end of Stage II it is 7 and at the end of stage III it is 10. Theoretically there is no upper limit to the maturity level, which keeps improving with "Continuous Improvement". The above is also validated to some extent in the limited number of detailed studies made at some sites.

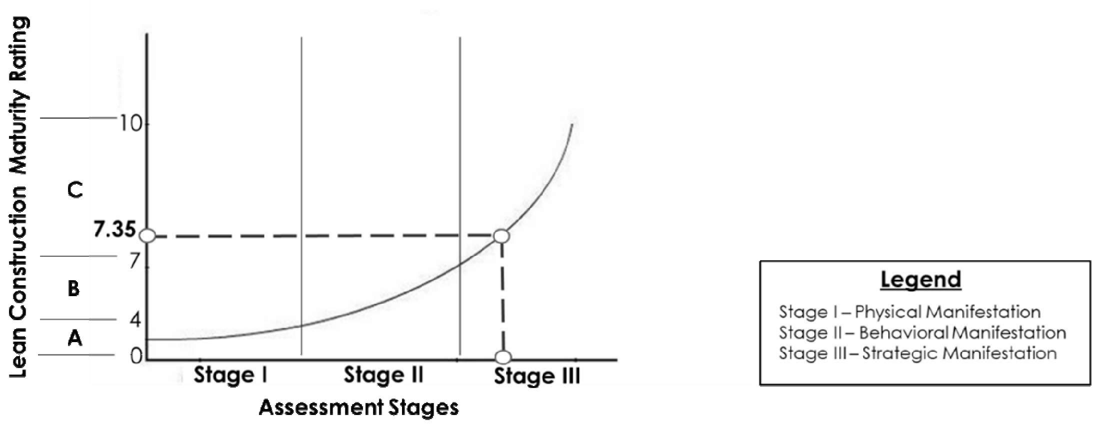

Figure 3: Lean Maturity Progression Curve

Table 4: STF percentages for the three Stages for various LCMR ranges

		STFj		
Zone	**LCMR**	**Stage I**	**Stage II**	**Stage III**
A	0-4	70%	20%	10%
B	4-7	55%	25%	20%
C	7-10	40%	30%	30%

LCMR is evaluated by trial and error. Initially it is assumed that the Project would be in Zone A and the STF percentages are applied accordingly. If the resulting LCMR is not compatible with Zone A , i.e. it is not within the range of 0 to 4 then Zone B percentages are tried out and then Zone C percentages, till convergence is reached for one of the three Stages. Thus the final LCMR is obtained.

Sample Data

The model starts with Lean Evaluation Checklist where all the Concepts, Practices and Attributes are defined.Figure2 above, shows a sample for Collaborative Working as a Concept, the Attributes which come under this Concept and the Processes which pertain to the Practices. These are scored as 1 or 0 depending on the observations. Table 5 shows all the 11 Concepts which further drop down to 63Practices under 3 stages making it 3 x 11 x 63 matrix for defining Lean Construction Maturity Rating.

In the above Figure2, we can see 4 'yes' out of 6 practices. When normalized to 10, it converts to 6.67 (which can be seen in table below). Table 5 shows the working for some sample data. The second column shows the Concept Weights CWfi and the last column shows the Scores Psi for the various Concepts as well as the CSSj for each of the three stages.

Table 5: Sample data and working of scoring system

Concepts	CWfi Weights	Psi Score
Physical Manifestation		**8.1 (CSSj)**
1. Implementation of Lean Tools & Processes	3 (Wfi)	7.33 (PSi)
2. Continuous Improvement	4	8
3. Focus on Value Creation	2	10
4.Work Standardization	1	6.67
Behavioral Manifestation		**7.5**
5. Lean Culture & Behavior	3	7.5
6. Waste Identification & Productivity	2	5
7. People Development	4	10
8. Collaborative Working	3	6.67
Strategic Manifestation		**6.3**
9. Strategic Use of Lean	3	7.5
10. Leadership to drive Lean	3	5
11. Customer Focus	4	6.67

As per default Zone A, the LCMR would be = (8.1 x 0.7) + (7.5 x 0.2) + (6.3 x 0.1) = 7.77

But as the LCMR lies in the range of 7 – 10, Zone A is not applicable and Zone C weightsare applied, i.e. LCMR = (8.1 x 0.4) + (7.5 x 0.3) + (6.3 x 0.3) = 7.35

To check, Zone B weightsare applied, i.e. LCMR=(8.1 x 0.55) + (6.6 x 0.25) + (6.3 x 0.2) = 7.56. Here as LCMR does not lie in the range of 4 – 7, Zone B classification isnot applicable.

From above, LCMR with Zone C weights converges within the range (7 – 10). Therefore the final LCMR = **7.35 (Ref Figure 3)**

The Project people can also get some idea of the areas in which they are strong in Lean practices and the areas which need to be developed further. The following Bar Graph (Figure 4) or the Spider Radar Diagram (Figure 5) give an idea for the same.

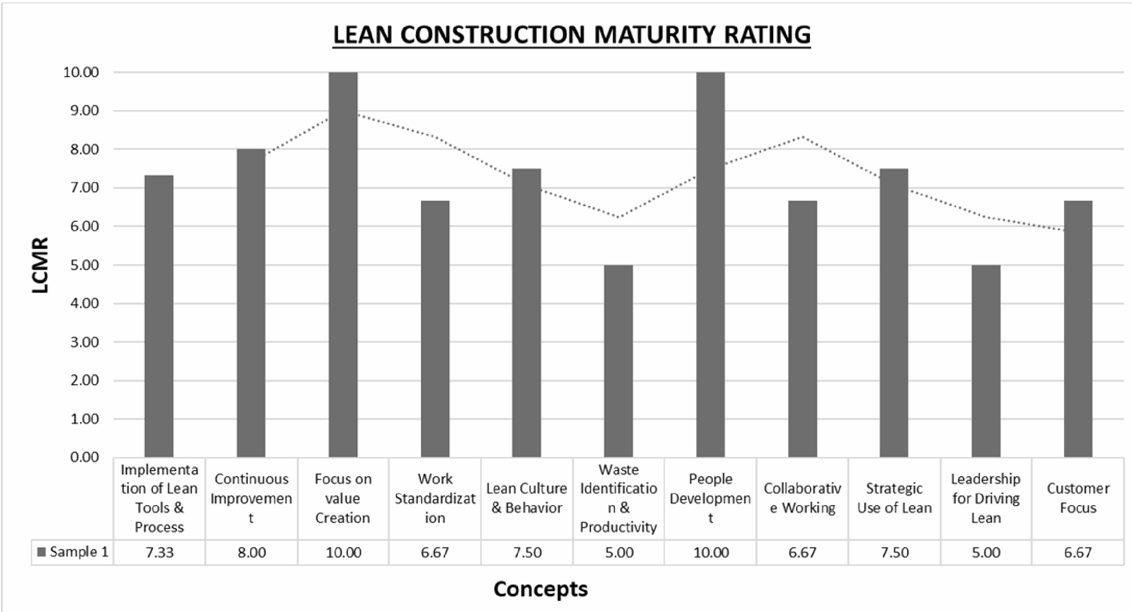

Figure 4: Lean Construction Maturity Rating - Bar Graph representation

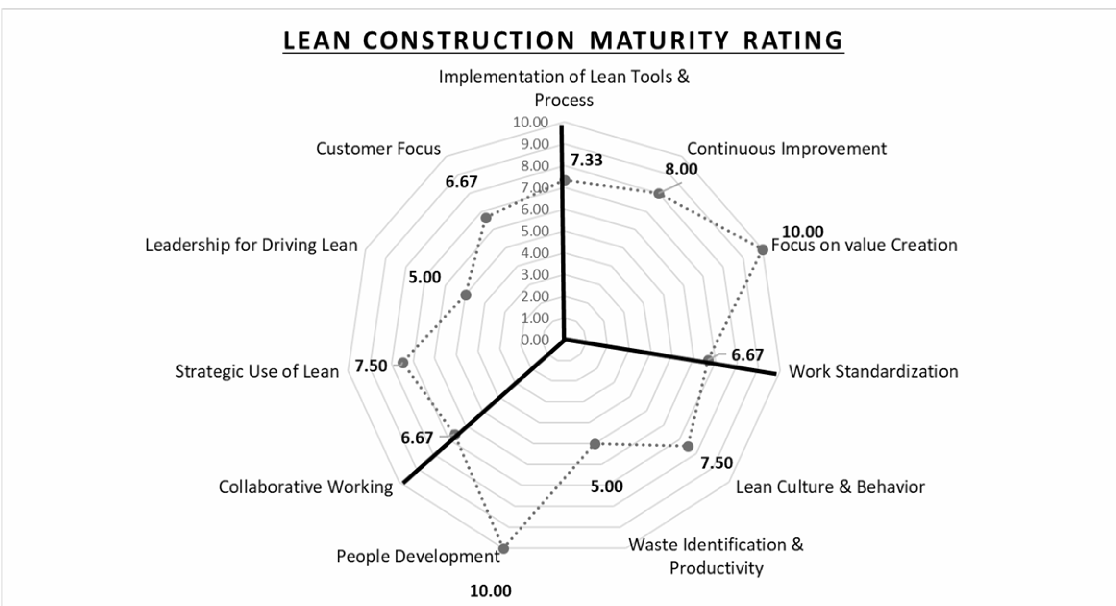

Figure 5: Lean Construction Maturity Rating- Spider-Radar Graph representation

LIMITATIONS

All the parameters of Lean might not be convertible to quantifiable scales and some of the Practices considered under each Concept might be project specific or need some more detailing to draw up the Attributes. Also, the fruitfulness of Lean Implementation can only be realized over longer periods of time at enterprise level, rather than at project levels and tangible benefits associated with Lean may not manifest in short term projects. More work is required to validate the model for assessing Lean Maturity at organizational levels, rather than at project levels.

For future works on this topic more thorough engagements with Lean practitioners to capture salient attributes which add to Lean Maturity as well as overall qualitative insights from seasoned Lean experts for a particular Project or organization to validate the quantitative derivations under this framework would be highly beneficial to further validate this model.

CONCLUSION

This framework provides a means to measure the current state of Lean maturity to determine the prevailing degree of Leanness and to understand the areas requiring improvement. It also helps to a degree in determining the organizational maturity in totality, in the form of physical, behavioral and strategic manifestations.

This model would also help an organization to focus on qualitative aspects such as people development, culture building and strategic leadership to drive Lean, apart from the usual implementation of Lean tools and processes as only tools or only culture cannot bring about the changes that construction industry requires so badly. Appropriately designed training programmes and workshops can be conducted to sensitize the industry and the construction personnel to realize the aspects which contribute to Lean Maturity and help them learn the processes to go further on the path of Lean Maturity.

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THE LAST PLANNER SYSTEM: COMPARING INDIAN AND NORWEGIAN APPROACHES

Ramakrishnan Ravi[1], Ola Lædre[2], Roar Fosse[3], Kalyan Vaidyanathan[4], Fredrik Svalestuen[5]

ABSTRACT

Construction projects around the world currently use the Last planner system (LPS) with different approaches. In this paper, we compare the Indian and Norwegian industry because of their contrasting cultural settings, in order to gather experiences and formulate possible improvements to their LPS approaches. A general literature study regarding LPS and its components was carried out. Data from two cases in India and six cases in Norway were collected with the help of three case specific and five general interviews.

The study revealed similarities in scheduling and planning, root cause and constraint analysis, PPC measurements (daily and weekly) during the meetings. The major difference was that the Indian companies use LPS as a problem solving technique in the middle of the project and the Norwegian companies use it proactively as a part of their system. A major conclusion drawn in the paper is that the participants felt more ownership to the schedule and the activities after the introduction of LPS. It became a promise of what they could do, rather than an order from the manager.

KEYWORDS

Last planner system, Hofstede Analysis, People, Culture and Change

INTRODUCTION

Poor project performance in construction is often related to factors like uncertainty or variability in workflow (Howell and Ballard, 1998; Ballard and Howell, 2003). The Last Planner System (LPS) was developed in order to reduce those uncertainties in the workflow (Ballard and Howell, 2003). According to Mossman (2014, pp.1-5), LPS intends

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to improve the reliability and predictability of the plans used for construction activities during the implementation stage through an integrated approach. It has proven benefit on project performance for more than 20 years in multiple countries, across building construction, heavy civil engineering construction, highway and infrastructure projects, including ship building and pit mining (Liu and Ballard, 2008; Ballard, 1993; Ballard and Howell 2003; Alarcón et al. 2008). Engebø et al. 2017found that, adjusted for the number of inhabitants, the interest for Lean Construction is much higher in Norway than in India. This correlates with previous experience of the first author from both the Indian and Norwegian construction industry and is a key motivation to compare the implementation of the last planner system between India and Norway, respectively.

In the following, the paper presents the main results from a literature review. Then a short explanation of the applied research methods is given. The findings and discussion part follows this, before the consequences of cultural differences between India and Norway are analysed. Finally, the paper presents conclusions on the three research questions.

LITERATURE REVIEW

The Last Planner System (LPS) focuses on planning and production control where the different components include master schedule, phase planning, look ahead (make-ready) planning, production planning, production management and learning (Ballard and Howell, 2003; Ballard, 2000; Mossman, 2014). Anextensive study from Daniel et al. (2015)shows the different components of LPS used in 57 case studies across 16 different nations(including seven from Norway and one from India). Figure 1 gives an overview of the components that are frequently used. This case study has been used to identify the LPS components that are used around the world and it would be a good base to compare these with the actual components that are used in the Indian and Norwegian projects.

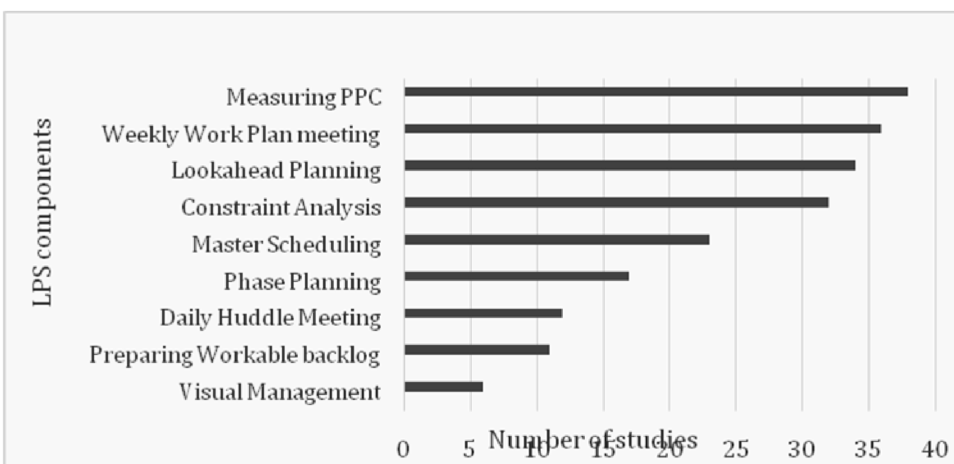

Figure 1: Some of the LPS components used in 57 cases (based on Daniel et al.2015)

A study from Johansen and Porter (2003) reveals that cultural barriers like attitude to work have a say when LPS is implemented. In an attempt to get a better insight in this statement, the authors have studied a cultural assessment field called Hofstede's cultural dimensions theory. Hofstede is perhaps more known in fields such as sociology and psychology than engineering, but the authors argue that with culture and people being such a strong proponent of Lean practices, such cultural analysis tools could provide valuable insights into factors of success or failure of certain practices in certain cultural conditions.To help understand the difference between the cultures of countries, such as Norway and India, Hofstede looks to score them within six so-called cultural dimensions. First, **Power Distance** is “the extent to which a society accepts the fact that distribution of power in institutions and organizations is unequal” (Hofstede, 1980b, p. 45).**Individualism** is “the degree to which people in a country prefer to act as individuals rather than being a member of a group” (Hofstede, 1994, p. 6).**Masculinity** is “the extent to which the dominant values in a society are related to their assertiveness, acquisition of money and things” (Hofstede, 1980b, p. 46). **Uncertainty avoidance** is “the extent to which a society tolerates ambiguous situations and tries to avoid these situations by establishing more formal rules and believing in absolute truths” (Hofstede, 1980b, p. 45).**Long-term orientation** is “the ability of a society to connect the past with the current and future challenges” (Hofstede, G., 2011).Finally, **Indulgence** is “the extent to which a society allows relatively free gratification of basic human desires related to enjoying life and having fun.” (Hofstede, G., 2011). Hofstede’s cultural index has some limitations. For example, it presumes the whole population is equal, but not all sub-cultures and individuals necessarily fit into it.Nevertheless, the data collected is important as long as the context and content of the questions is phrased in the right manner (Clearlycultural.com, 2018).Critics claim that this model does not capture the complete phenomenon, as culture has more than six dimensions (Chao & Moon, 2005).

RESEARCH METHODOLOGY

The research questions in this paper are:

- How is the Last Planner System implemented in India and Norway?
- What are experiences gained with implementation in both the countries?
- What are potential improvements that could be made to LPS considering the cultural aspects?

A literature search for LPS theories and its components was carried in research databases, both with keywords and by using backwards snowballing (Wee and Banister 2016). This study has helped in identifying LPS components that are in theory and whether the same set of components are being used in the case study projects.

Two case studies from India have been studied, namely one Marine jetty project and one residential project. Nadhi Information Technologies, a consultant company facilitating contractors in India to implement LPS in their projects and having a lot of experience in implementing LPS in India, provided both these cases. Six residential, commercial and office building projects from Norway were also studied. Since, contractors in Norway have a longer history of Lean practices and a project management system inbuilt with LPS, more number of projects could be studied from two of the major contractors in Norway. Three cases were from Skanska and three were from Veidekke Entreprenør AS. The projects range from residential, commercial and office building projects. The lead author conducted a document study of documents received from the respondents. The Indian documents were mainly project details(location, project cost, type of project etc.), changes caused in the project by implementing LPS, PPC measurements, productivity reports from site, cycle time charts etc. The Norwegian documents were mainly handbooks explaining their LPS implementation. The case studies were based on semi-structured open-ended interviews. The respondents were sorted in two categories, namely case specific respondents and generic respondents. In order to avoid bias, the respondents answered identical questions from an interview guide. By interviewing construction managers and LPS experts, different perspectives were accounted for. In total, four interviews were conducted in India and two in Norway.

With the help of the project data collected (changes in the LPS metrics) and the interviews with the lean experts (the extent to which different LPS components were implemented in the site), cross analysis was done. These findings were analysed with the help of Hofstede's six cultural dimensions to reveal the cultural enablers and roadblocks for implementation of LPS in both countries.

FINDINGS AND DISCUSSION

Since it was difficult for the authors to give a detailed explanation about each case and each interview, the information presented in the section below is an amalgamation of both the sources of data.

INDIA

The Institute for Lean Construction Excellence, India (ILCE – http://www.ilce.in) has been creating a basic awareness of lean amongst both mid managers and top executives over the past few years through seminars, workshops, education and running local chapters. There are high expectations on the results from lean and what it can achieve for projects (in terms or bringing delayed projects back on track and eliminating cost overruns). From the two case studies and the interviews general experience, a typical approach to implementing LPS in India is as follows: The need for LPS is felt a few months into project execution, when conventional approach has led to delays. There is pressure to bring the project(s) back on track. A third party lean consultant is hired to introduce the lean construction techniques (including LPS), does the site observations to understand the current condition of the project, report the "as-is" situation and a "to-be" intervention plan to the higher management. The Lean initiative is often kicked off at the site with awareness workshops and possibly simulation games (e.g. the parade of trade game) (Tommelein et al.1999).Then, the expectations from the site going forward is set by the third party consultant.

A phase schedule based on the contractual milestones is prepared, which is then broken down into a rolling 6-week look ahead schedule, weekly plans and daily plans as part of the weekly planning process. A weekly work planning meeting is held in order to plan the work that has to be executed in the upcoming week. The meeting is also used to discuss top delay reasons of the PPC and potential improvements. Daily Standup meetings of maximum 20 minutes are conducted to gather PPC and delay reasons, as well as discussing shared tools and equipment for the next day. There is a strong emphasis for crews not to focus just on completing their workload, but to generate adequate finished work for the trade behind them, to ensure adequate flow of work at a reliable pace. Since LPS is often implemented in the middle of Indian projects, there is often inadequate time and focus on training up-front to properly establish the necessary culture and mindset. This often leads to participants initially struggling with common LPS skills such as clearly expressing what they need from each other, formulating well-described tasks, properly matching workload with needed labor etc. However, with time an increased schedule reliability and overall efficiency of the execution team have been observed in the studied cases.

There are also organizational challenges; for instance, if the lean consultant is hired by the contractors, the client might not endorse lean and understand the need for efforts such as removing constraints as part of the look ahead (make ready) process. This is partially because owners want the freedom to make changes until the end and partly because they also lack awareness of the lean process. There are also socio-cultural challenges, such as entry-level field engineers finding it difficult to say “no” to what they perceive as unrealistic requests from their managers. Even worse, they might be forced to give commitments that satisfy the expectations of management irrespective of the actual situation. One reason behind this, we postulate, is the Indian education system where students from their childhood are taught to respect elders and teachers (hierarchy) without asking questions. Therefore, lean consultants have to “unlearn” this habit to create an environment of freedom to say no.

Despite the mentioned challenges, the interviews identified some clear pockets of success in implementing LPS. One of the projects experienced a reduction of cycle time by around 40% (Vaidyanathan 2015). In the second case study also, the contractor experienced a 45% reduction in completion of coping beams in civil works. PPC on daily basis increased from 40% to 91% and PPC on weekly basis increased from 36% to 82%.The increase in PPC was due to the increased awareness of non-completion by introducing a rigorous application of Value stream mapping of reasons for those non-completions. A more significant intangible benefit was the recognition from the Client who noted that the contractor’s ability to make and keep commitments had significantly improved in the six months after the adoption of LPS (Madhusudhanan 2017).

NORWAY

The Last Planner System seems to have entered the Norwegian industry around mid-2000s, with predominantly two large contractors incorporating it into their planning and control systems; Veidekke and Skanska (Kalsaas et al., 2009).Two major contractors in Norway - Veidekke Entreprenør and Skanska Norway – have LPS built into their project management systems.One reason of analyzing the LPS strategies of two different companies is to figure out the degree of similarity between them and the strategical differences in their system keeping the Norwegian culture in mind. These two contractors have a similar conceptualization and implementation of LPS, expect for the meeting structure. Employees get central training in LPS, as well as project-specific support during execution. Their planning hierarchies follow the theoretical prescriptions for LPS with master and phase scheduling, look ahead planning, making commitments, weekly and daily planning, tracking of progress and learning.

In terms of meeting structure, Veidekke has four weekly progress meeting. The first one focusses on workforce and subcontractors plan their weekly work plan. They have another meeting where the foremen and subcontractors make their 2-4 week look ahead plan. In the third meeting, the site manager meets the project manager to discuss the 5-9 week look ahead schedule. In the fourth meeting, all subcontractors meet the foremen to discuss the work done that week by measuring the PPC and prepare work for the next week. For making work ready, they have an MS Project schedule linking every activity to each of the seven pre-requisites and a YES/NO column, whereas only activities with YES on all seven are ready to be included on the weekly work plan. If there is a problem regarding any of the pre-requisites, someone is made responsible for removing the constraints by Friday of that week. Incomplete activities in the PPC review are moved to the next week as a part of workable backlog. Skanska usually have two progress meetings per week for production work. One meeting involving participants from all the trades and one is for the foremen to coordinate. In addition, they have a daily job briefing, where each crew goes over their upcoming daily tasks, coordinates against other trades, material deliveries etc. The progress of the design schedule is quite thoroughly reviewed as part of the weekly Last Planner process described in Fosse & Ballard (2016). If needed, Skanska teams add other progress meetings, and often also a PPD (production-procurement-design) coordination meeting for the in-house managers. Skanska's most of the projects plan their on-site activities location-based in their pull-planning sessions as a part of LPS in their system.

LPS is out of many project participants' (especially the sub contractors) comfort zones compared to traditional planning methodologies. Many are used to having schedules created just for their trade and working in silos, without the rigorous coordination between trades and phases as LPS often promotes. From the interviews with the Norwegian practitioners, it was identified that there lies a challenge in managing people on different hierarchical levels looking at different time frames. For example, a manager (the leader) who looks two to four weeks ahead can disrupt the planning ability of a foreman who is used to look at (and good at coordinating) one week ahead.

LPS IMPLEMENTATION MATURITY MATRIX

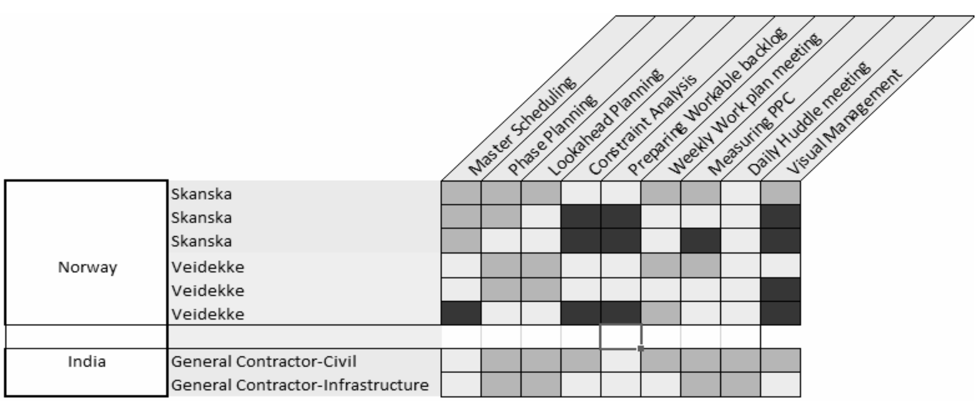

Figure 2: LPS Implementation Maturity Matrix

With the available case studies and interviews from the Indian and Norwegian side, an attempt has been made to summarize the implementation grade of the LPS components in the investigated cases from Norway and India. The colors presented in Figure 2 represent the degree of implementation and these scores were given by the authors based on findings from the interviews and the case studies and these scores are subjective in nature. Green denotes that the practical implementation is similar to LPS theory, yellow to some degree or acceptable substitute practices and red denotes not corresponding at all. An important learning from the matrix is that the Norwegian projects, although having LPS incorporated in their systems, only use selected components on many projects. The Indian projects on the other hand, use almost all LPS components as described in theory, irrespective of a positive or negative outcome. The lean experts of Veidekke and Skanska experienced project success despite poor LPS implementation, as well as project failure despite successful LPS implementation. Therefore, it is difficult to directly correlate LPS implementation with project success based on LPS metrics.

HOFSTEDE ANALYSIS RESULTS

The Hofstede values of Norway and India are given in Figure 3, and they will be used to analyze the cultural reasons behind the usage of LPS components. These scores have been obtained from the Hofstede's cultural dimension scores for different nations and the website link for checking the scores has been provided in the references.

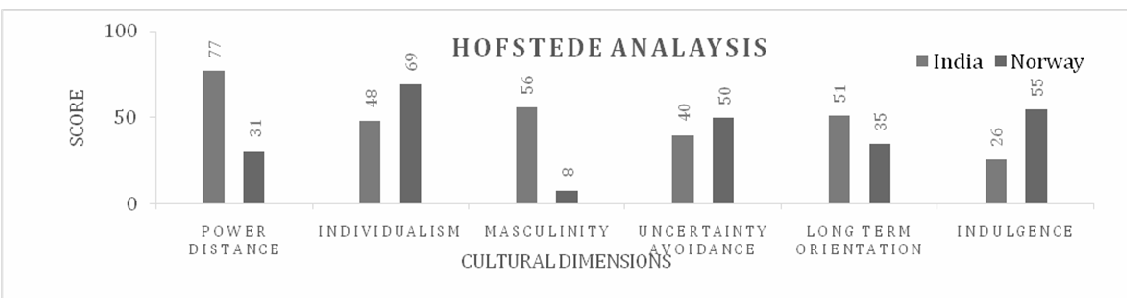

Figure 3: Hofstede Analysis results for India and Norway (Hofstede Insights, 2018)

Power Distance, India 77, Norway 31. An example would be socio-cultural challenges presented under the Indian side. This could indicate that Norwegians have a flat hierarchical structure, increasing their ability to say "no", which seems like a very important premise for reliable promises. This might explain why Norwegian contractors have LPS incorporated into their systems of standard planning practices.

Individualism, India 48, Norway 69. This factor relates to how the two countries see it natural to act as a single person or as a team. One way of interpreting this is that it should be more natural in India to appreciate LPS as a way of working as teams.An example would be the increase in the PPC shown in the Indian case studies, as it increased when people started to work more as a team, not just achieving individual goals.

Masculinity, India 56, Norway 8. This factor could be related to how decisions are made. Indians have assertive decision-making power within a few individuals of a group, while Norwegians might rather listen to all opinions before making collective decisions. This may cause that the pull-planning sessions in Norway are better to coordinate trades involved than those in India.

Uncertainty avoidance, India 40, Norway 50. This factor however could be related to how important it is for the teams to make work ready in a timely manner rather than accepting that not everything is in place before execution of work and making-do. Another example would be organizational challenges presented under the Indian side, where the owners hesitate to take responsibility on the work of Lean experts.

Long-term orientation, India 51, Norway 35. This indicates a better pre-condition for lookahead-planning in India than Norway. On the other hand, it might also indicate that India is more culturally prone to plan construction projects too much in detail too early, rather than following the LPS principle of planning to the right level of detail to the right time and accepting that things don't go as planned, but rather be able to change accordingly in an agile way.

Indulgence, India 26, Norway 55. This factor could be related to the social processes of LPS. Norwegians might be more comfortable with the informal tone and inter-personal communication often related to several components of LPS.

CONCLUSION AND RECOMMENDATION:

Looking at implementation experiences of the practitioners from the Indian and Norwegian industry, the need for cultural change to adjust to a new process such as LPS might take more time than anticipated by lean advocates. In terms of implementation, the findings from the interviews seem to correlate well with the Hofstede analysis of the two countries. Indian workers and entry-level engineers might struggle with saying "no" to their manager rather than giving a reliable promise because of the power distance. Norwegian contractors might have challenges coordinating people, as they can be individualistic in nature. Masculinity might lead to Indian project teams having a few strong individuals making decisions on behalf of the team, while a Norwegian team depends on group decisions. Furthermore, Hofstede's six cultural dimensions have been helpful in explaining the experiences related to different LPS components. For instance, look ahead planning should correlate with the ability to think long-term, constraint analysis should correlate with the ability to accept uncertainty. Based on differences between the Norwegian and Indian cultures, the potential improvements that could be made in order to improve the process that could involve change in their cultural ethos include:

- **Norway:** Use a Bottom up approach for LPS on the Norwegian side, where the subcontractors and foreman can be taught to plan for the next day in the beginning and a step by step increase to asking them to do the look ahead plan for 6-8 weeks. Indian counterparts could try LPS at two levels (learning from Norway): a short-term one that only involves coordination among contractors and a medium-term one that involves owners and contractors coordinating design and procurement.

- **Norway:** For the Norwegian counterparts to try other aspects of LPS and see if that leads to improved reliability and efficiency of project delivery. Particularly, the daily stand up meetings and value stream mapping is something they could try.
- **India:** The execution engineer, in India, or the person responsible for the activity should be given the freedom to say "No", so that he can make reliable commitments. Owners should not involve in disrupting the planning ability of the contractors in the Indian side; they should be less "masculine" about it in the interest of the project. Regarding the Norwegian side, the foreman who has to look ahead plan for 6-8 week ensure that their actions do not disrupt the 1-2 week plan of the sub-contractor.
- **India:** Clients and management (especially in cultures such as India) should try to be less "masculine" and empower entry-level field engineers to have opinions. Subcontractors and foremen can be gradually empowered to increase their planning capabilities and responsibilities. Especially if just asked to do short-term daily planning, one could increase responsibility to do look ahead planning and have more impact on identifying and handling constraints.

All in all, both sides have something to learn from each other's successes (or lack thereof). And both sides have some room to improve their cultural baggage to improve the adoption of the principles of LPS and achieve better success in project delivery through the use of LPS. In general, the Lean Construction community should have even more discussions about the cultural pre-conditions of the countries, companies and project organizations where Lean Construction practices are implemented. There is a need for improved insight of what factors that enable successful adoption.

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ENABLING LEAN AMONG SMALL AND MEDIUM ENTERPRISE (SME) CONTRACTORS IN SRI LANKA

Ranadewa, K.A.T.O.[1], Sandanayake, Y.G.[2], and Mohan Siriwardena[3]

ABSTRACT

Lack of sufficient attention to the possible benefits of adopting lean concept has hindered the performance of small and medium enterprise (SME) contractors in Sri Lanka. Insufficient knowledge on minimising non-value adding activities (NVAA) is considered as the major barrier to implementing lean. Moreover, there is a lack of empirical research identifying NVAA, in order to trigger lean adoption in Sri Lankan SME contractors. Hence, the paper investigates NVAA, their significance and the causes, which hinder lean implementation in Sri Lankan SME contractors. A literature review, followed by five case studies were carried out, and the data were analysed using 5-why analysis. According to findings, lean construction is still a relatively unfamiliar approach among SME contractors in Sri Lanka. Some organisations follow lean techniques in an ad-hoc manner without an adequate understanding of the concept. The studyfurther identified defects, inventory and waiting as major NVAA categories relevant to SME contractors. Lack of finance, insufficient training, cultural inertia, lack of individual capacities, lack of networking and collaboration, and lack of action learning were identified as the root causes for NVAA of SME contractors. Although respondents expressed their willingness to implement lean to enhance value, they identified lack of capacities as a major constraint against enabling lean adoption among SME contractors in Sri Lanka.

KEYWORDS

SME Contractors, Lean Construction, Case Studies, Sri Lanka.

INTRODUCTION

SMEs form a significant pillar of the construction industry in many economies. Although the challenges of lean implementation in construction and solutions to overcome them have been previously explored (Shang & Pheng, 2014; Jadhav, Mantha & Rane, 2014; Aziz, & Hafez, 2013; Bertelsen & Koskela, 2004; Ogunbiyi, Oladapo & Goulding, 2013)

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in construction industry, there is a dearth of research on lean implementation in construction SMEs in Sri Lanka. In order to successfully implement lean in construction SMEs, it is essential to identify NVAA, which is the first principle of lean construction (Koskela, 1992). Hence, this paper focuses on identification of NVAA and their causes, which hinder lean implementation in Sri Lankan SME contractors.

This paper commences by introducing construction SMEs in Sri Lankan context and importance of lean construction to overcome their challenges. Thereafter, it discusses the NVAA in typical construction projects. Next section presents analysis of empirical data used to identify the wastes and there causes for SME contractors in Sri Lanka. The paper contributes to the body of lean construction knowledge, in particular identification of priority areas for improving lean adoption in Sri Lankan SME contractors.

LITERATURE REVIEW

SMALL AND MEDIUM ENTERPRISES IN CONSTRUCTION INDUSTRY

SMEs act as the main pillar of a booming economy of a country, an engage the prevalent portion of the workforce (Woschke, Haase & Lautenschläger, 2016), particularly the construction SMEs. Construction SMEs consist of more than 70% of the workforce in a country (Harvie, 2004; Saleem, 2010; Emine, 2012). Similarly, Sri Lankan construction SMEs play a significant role in the economy providing job opportunities similar to large construction companies (Ranadewa, Sandanayake & Siriwardena, 2015). Balachandra (2014) specified that the majority of registered contractors fall into the category of SME in the Sri Lankan construction industry. Yet, there is no published definition for construction SMEs in Sri Lanka. However, the category of SMEs in Sri Lankan service sector includes firms with less than 300 employees and less than SLRs 750 (approximately US$ 5) Million annual turnover (Ministry of Industry and Commerce, 2014). Althoughthe contribution of Sri Lankan construction SMEs is vital, there is a lack of published evidence on the number of employees to define SMEs in the construction industry. Hence, a definition was developed based on the service sector annual turnover and the Construction Industry Development Authority (CIDA) Sri Lanka registration for construction contractors in Sri Lanka. Accordingly, medium-sized contractors were categorised under whose annual turnover is in between SLRs 250 - 750 (approximately US$ 2 - 5) Million (Grade C3-C2) and small-sized contractors having an annual turnover between SLRs 16 - 250 (approximately US$ 0.1 - 2) Million (Grade C6-C4).

CHALLENGES FACE BY CONSTRUCTION SMES AND WAY FORWARD

Ofori and Toor (2012) identified the risks faced by construction SMEs in developing countries as lack of job continuity, the deficiencies in construction industry, difficulties in operating environment of the industries, access to finance, competition from SMEs. Moreover, researchers (Rymaszewska, 2014 and Chiarini, 2012) added lack of technology, uncooperative government laws, absence of skilled workers and expertise as constant issues faced by them. Hence, there is a need for construction SMEs to adapt to changing environments (Ofori & Toor, 2012), be able to improve their creativity, develop their networks and aim to develop and implement new construction processes yielding higher value at lower costs (Bertelsen & Koskela, 2004).

The conventional systems used in the industry pursue the task of project completion, however, neglected minimisation of NVAA to maximise value (Koskela et al., 2014). Therefore, construction SMEs need to hunt for techniques, concepts and strategies, while increasing the value addition. Correspondingly, organisations are pursuing to maximise value addition through embedding lean (Nesensohn, et al., 2014). Further, lean noted as one of the best approaches for improving value (Aziz & Hafez, 2013). However, Howell & Ballard (1998) specified that moving towards lean needed a twist in the rationale to do construction as well as the management of construction. SMEs can also be benefited by converting to lean organisations, by adjusting their processes (Rymaszewska, 2014). Although, a number ofresearchand successful application of lean can be found in the global construction context, research on lean application in Sri Lankan construction industry is limited to a few initiatives in the past (Senaratne and Wijesiri (2008); Senaratne, Ekanayake & Siriwardena (2010); Thilakarathna & Senaratne (2012). Although Researchers highlighted the importance of implementing lean,it is still in its infancy in construction SMEs. Therefore, there is a need to investigate the nature of lean implementation in SME contractors in Sri Lanka. Investigation of the extent to which NVAA are identified by SMEs in Sri Lankan construction is a starting point in this regard.

NON-VALUE-ADDING ACTIVITIES (NVAA)

Waste is known as NVAA in the lean construction lexicon (Emuze & Saurin, 2016). NVAA are activities that add no value as per the requirements of customers to a product or a service (Alves, Carvalho, and Sousa, 2012). Womack and Jones (2003) defined it as any activity thatuses resources without value creation. Construction Industry Institute noted that 57% NVAA and 10% value addition in the construction industry, whereas manufacturing industry has 62% Value addition and 26% NVAA (Mossman, 2009). Hence, the construction industry needs to maximise the value while removing the NVAA.

Removal of NVAA is a fundamental concept of lean construction and one of the most efficient ways of enhancing capacities and improving the profitability of an organisation (Koskela, 1992; Ranadewa, Sandanayake & Siriwardena, 2017). They were categorised into seven areas namely overproduction, overstocking, unnecessary movements, waiting, transportation, over processing and defects (Ohno, 1988; Ogunbiyi, et al., 2013). Nevertheless, Alves et al. (2012) referred to non-utilization of human potential as the eighth waste by considering Green’s (1999) critique ofthe negligence of human stress as a waste. Hence, identification of these eight types of wastes and addressing them accordingly will help enable lean. Antosz and Stadnicka (2017) noted that49% of the responded organisations agreed that waiting for material as the major waste. They also reported that 41% of organisationswanted to remove unnecessary movements and 39% wanted to remove machine failures by implementing lean. Moreover, Alarcon et al. (2001) highlighted the importance of exploring the root causes of waste. This fact has been further proven by a study carried out by Sri Lankan researchers (Kulatunga,et al., 2006),which identified root causes of waste in design decisions, methods of construction or even with attitudes of people. According to Alwi, Hampson and Mohamed (2002), waiting time, especially for instructions, lack of design and documentation contribute to NVAA during the construction process, representing a lack of human resources skills.

Gavilan and Bernold (1994) added that issues in design, material management, procurement, and processes, as the causes of NVAA. As suggested by Howell & Ballard (1998), waste is a cost that could have been avoided within the activities, such as rework, or cost due to extended activity duration along the critical path. Hence, this will affect both costas well as the time duration. This highlights the importance of identifying and reducing the NVAA in the construction projects. However, the underlying nature of waste in the construction industry is not clearly visible compared to manufacturing and production. Similarly, neither NVAA nor VAA to enable lean in organizations have been explored in detail with reference to construction SMEs in Sri Lanka. Therefore, there is a need to explore the root causes of NVAAs in the construction SMEs in Sri Lanka.

RESEARCH METHODOLOGY

This research aimed to investigate NVAA, their significance and the causes, which hinder lean implementation in Sri Lankan SME contractors. Hence, a literature review was carried out to explore the theoretical identification of NVAA in the construction industry and in particular within SME contractors. Multiple case studies were conducted to explore the NVAA in Sri Lankan construction SMEs. The profile of the case study SME contractors are summarised in following Table 1.

Table 1 Profile of the case study organisations used for the research

	Case A	**Case B**	**Case C**	**Case D**	**Case E**
Grade	C2	C2	C4	C4	C6
Size	Medium	Medium	Small	Small	Small
Nr of Employees	50	60	45	20	20
Nr of Projects	11	05	04	03	03
Years of exp.	34	15	22	10	06
Field of activity	Building	Building	Building	Building	Building
Respondents	▪ Chairman ▪ Project Manager ▪ Site Engineer	▪ Managing Director ▪ Project Manager ▪ Site Engineer	▪ Managing Director ▪ Technical Officer ▪ Technical Officer	▪ Chairman ▪ Project manager ▪ Technical Officer	▪ Managing Director ▪ Technical Officer ▪ Technical Officer

The empirical data collection methods adopted within the case studies were, semi-structured interviews with project participants, non-participant observations of progress meetings and study of substantial of the project (tender documents, meeting minutes).Employing semi-structured interview method is preferred in qualitative approach (Edwards & Holland, 2013) since the respondents have a structured flow to ask questions from interviewees. Three respondents from each case were interviewed.

All five SME contractors represented different approaches and strategies to identify NVAA in their projects. Hence, the data from case studies were collected and analysed using 5-whys analysis to identify commonalities from their diverse experiences. Ohno (1988) specified that the 5-Whys technique was developed and fine-tuned within the Toyota Motor Corporation as a critical component of its problem-solving training to determine the root cause of a defect or problem by repeating the question 'Why?'. Correspondingly, Ohno (1988) specified that often root causes are hidden under more obvious symptoms, and only by unpeeling the layers of the problem can the root be found. Similarly, Tommelein (2015) highlighted the importance of going to the *gemba* and repeatedly asking Why to explore the root cause to improve the system. Murugaiah et al. (2010) specified that the application of the 5-whys analysis provides a fact-based and structured approach to problem identification and correction focuses on both reducing & eliminating NVAA. Hence, 5-whys analysis was used to identify the root causes.

RESEARCH FINDINGS

NVAA identified in the construction projects were categorised into eight types. The root causes of them were identified using 5-whys analysis and the findings are presented in Figure 1. Each factor is presented with (X/Y) values. X represents the number of causes (incoming arrows) each factor is responsible for and Y represents the number of effects (outgoing arrows) created by each factor, in order to identify the significance.

WHY 1

Findings of the case studies identified 29activitiesthat can be attributed to the eight types of NVAA in construction projects done by SMEs. As per the findings, inventory, waiting, defects and skills misuse are the most significant types of NVAA in construction SMEs, as they have 5, 4 and 7 outgoing arrows respectively. Waste due to defects was considered as significant by both top management and middle management as it directly affects both cost and time of the project. Getting the employees to reach their full potential at work under stressful conditions is a tough challenge (Dobre, 2013). Similarly, the respondents emphasized that people are working 1-2 levels below their true capability and this caused the waste of skill utilisation. Though top management has thoroughly emphasized that learning from one site being used well on another, site engineers disagree. In their opinion, they are losing learning opportunities due to high workload.

According to responded project managers, neither overproduction nor over processing has been a major issue for construction SMEs. However, the analysis of project documents revealed evidence of some level of overproduction and over processing in almost all the projects. Yet, the project managers have not been clearly identified them as waste. The research identified case A as the company with the highest lean maturity which has less NVAA. Case D was identified as the company with lowest lean maturity where the employees themselves unaware of the steps involvedin the processes. However, the presented data is not sufficient to provide justification for the lean maturity as it involves further studies. Consequently, most significant effects were the factors which cause more NVAA in the project (a large number of outgoing arrows as per the Figure 1). Correspondingly, the research identified delay in delivering material (9), cost of moving to and from storage (9), unnecessary movement of people and equipment (13), walking between different workplaces (12), taking unnecessary steps (11), work done to fill the gaps (9), not meeting specifications first time (8), time overrun and missed deadlines (12) and losing time and skills improvements (12) as the major effects.

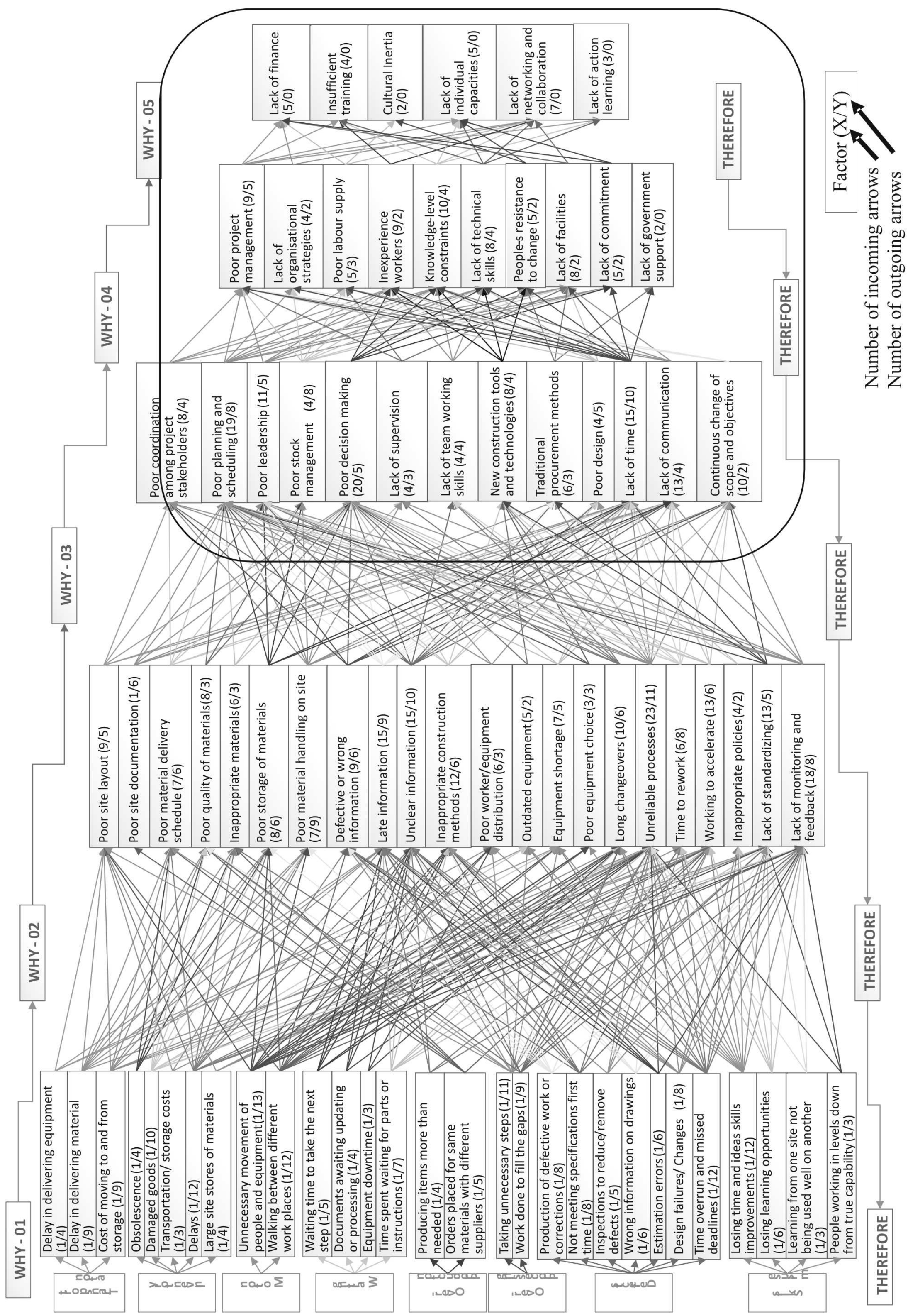

Figure 1: 5-whys analysis for NVAA in construction projects of SMEs

As the next step, (*WHY 2*) the reasons for the identified causes were explored.

WHY 2

The discussed 29 causes of NVAA can be attributed to individually or in a combination of 22 factors as shown in Figure 1.Out of them, 10 factors; poor site layout(9), defective or wrong information(9),late information(15), unclear information(15), inappropriate construction methods(12), long changeovers(10), unreliable processes(23), working to accelerate(13), lack of standardizing(13) and lack of monitoring and feedback(18) considered as the most significant causes for '*WHY 2*'. As construction SMEs are limited to small projects or subcontracting projects of large organisations, they have to wait for information, resulting in significant waste. Correspondingly, the pressure caused by large organisations compel SMEs to accelerate their work, which leads to generate more waste. The respondents emphasized that long changeovers (which received 10 arrows in Figure 1)is another reason for them to accelerate their work. Lack of standardising, lack of monitoring and feedback within SME organisations have worsened the situation. Use of inappropriate construction methods was identified as another significant cause as part of '*WHY 2*'. Hence, the processes turn out to be unreliable. Out of the 22 causing factors, most significant effects were poor material handing on site(9), late information(9), unclear information(10), unreliable processes(11), and lack of monitoring and feedback(8).Causes of these factors were examined during the next stage (*WHY 3*) of the overall analysis.

WHY 3

Most of the factors to answer '*WHY 3*' were caused by poor planning and scheduling(19), poor decision making(20), poor leadership(11), lack of time(15), lack of communication(13) and continuous change of scope and objectives(10). Further, the respondents have added poor coordination among project stakeholders, poor stock management, too late supervision, lack of team working skills, new construction tools and technologies, traditional procurement methods and poor design to this list of causes. Yet the most significant effects are the lack of time (10) and poor planning and scheduling (8) out of the 13 factors identified during the empirical study. Therefore, the study further questioned 'why' during the next phase to identify the root causes.

WHY 4

The respondents, in particular, the middle managementemphasized that lack of effective project management skills and methodology (9) and lack of organisational strategies (4) as the main causes. However, top management contended that lack of workers (5), inexperienced workers (9), knowledge-level constraints (10), lack of technical skills(8), lack of commitment (5) and people's resistance to change (5) as the significant causes to answer 'WHY 4' in Figure 1.The respondents further specified that the lack of facilities (8) as a major cause and bureaucracy (2) as an uncontrollable cause for theabove-listed waste. However, knowledge-level constraints (4), lack of technical skills workers (4) and lack of effective project management methodology (5) were the most significant effects, which required more attention from construction SMEs.

WHY 5

According to research findings, lack of finance (5), insufficient training (4), cultural inertia (2), lack of individual capacities (5), lack of networking and collaboration (7) and lack of action learning (3) were identified as the root causes at the end of 5-why analysis. Networking and collaboration will offer construction SMEs the opportunity to learn new trends and technologies in the construction market and get expert opinions to overcome NVAA in their construction organisations. However, unlike large construction organisations, construction SMEs lack capacities in networking and collaboration, which caused the most significant root cause for the majority of wastes. Serpell et al (1995) specified that the waste occurs due to controllable and uncontrollable root causes. Correspondingly some of the listed root causes are controllable, whereas some are uncontrollable. Most of the SME contractors take no notice of NVAA arising due to preventable internal causes; hence miss the opportunity to reduce the cost of the project. The main uncontrollable cause is the cultural inertia when comparing to other lean implemented countries. People resist changing their attitudes towards construction due to cultural inertia. However, appropriate change management strategies have the potential to address the above-mentioned cultural inertia. All other listed root causes are controllable.

The causes identified under 'WHY 3', 'WHY 4' and 'WHY 5'collectively can be considered the major causes and should inform the development of capacities necessary for an organisation to implement lean (refer the causes within the red outlined area in Figure 1). Hence, construction SMEs in Sri Lanka require identifying the gaps in their organisations' capacities to reduce NVAA. Therefore, efforts towards capacity building for construction SMEs is an important step to overcome the NVAA.

CONCLUSION & RECOMMENDATIONS

This paper investigated the significance of NVAA and their causes of SME contractors in Sri Lanka. A literature review followed by five case studies were carried out to collect data. NVAA identified in the construction projects were categorisedinto 8 types and identified the root causes of them using 5-whys analysis.

The findings highlightthat lack of finance, insufficient training, cultural inertia, lack of individual capacities, lack of networking and collaboration and lack of action learning as the root causes for the generation of NVAA in Sri Lankan construction SMEs. However, Sri Lankan construction SMEs have not adequately identified the majority of their NVAA and their causes. Hence, the research findings will guide construction SMEs to understand the importance of identification of NVAA in construction projects. It will further pave the way towards the identification of root causes to their wastes and address them accordingly. This study further proves that a detailed understanding of the processes and extensive explorations of all possible causes using the 5-whys analysis will reduce NVAA. In addition, it was also evident that inexpensive or zero cost solutions could be implemented to reduce NVAA. Hence, construction SMEs in Sri Lanka needs to find a way to overcome the controllable root causes using '02 Hows' as per the lean lexicon. This will pave the way for further research of this study. Some respondents already expressed their willingness to implement lean to overcome NVAA of their organisations. Yet, the research findings evidenced lack of capacities as a major constraint against enabling lean adoption among SME contractors in Sri Lanka. Hence, the research findings will pave the path to identify the capacities necessary to reduce NVAA among SME contractors, which will be the focus of the next phase of this research.

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INDICATORS FOR OBSERVING ELEMENTS OF LINGUISTIC ACTION PERSPECTIVE IN LAST PLANNER® SYSTEM

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ABSTRACT

The implementation of the Last Planner® System increases the reliability of planning and performance levels through the management of commitments. So far, the conversations during which commitments are set at planning meetings have not been analyzed in sufficient depth. However, this analysis is essential to generate reliable commitments that reduce the uncertainty and variability of projects. The research reported in this paper moves toward this analysis by developing indicators of commitments based on the Linguistic Action Perspective, developed by Fernando Flores. Indicators of commitments (i.e. definition of roles and responsibilities, declaration of the relevance of each commitment); requests and promises (i.e. making the deadline explicit); and foundations of trust (i.e. reliability), were developed and tested based on the methodology "Design Science Research". To verify the feasibility of measuring these indicators, a pilot test was conducted, which consisted of a Villego® Simulation applied to a group of students. Given the nature of this simulation, only part of the indicators could be verified, while the remainder is currently being verified through observation on site. The indicators that were validated are a useful tool to measure, control and improve the management of commitments in planning meetings, as they provide fast and specific feedback on these aspects, which undoubtedly enriches implementation of the Last Planner® System.

KEYWORDS

Linguistic Action Perspective, Last Planner® System, Commitments Management, Villego® Simulation, Planning meetings.

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INTRODUCTION

The main problem of the construction industry is that the productivity factor has not increased as in other industries over the last fifty years (Eastman et al. 2011). To improve productivity, efficiency must be increased through better planning and control of projects, standardization and strengthening of the technical and operational capacities of workforce(McKinsey & Company 2009).

Therefore, it is necessary to generate changes in behavior and training in the use of Lean tools and concepts in the construction industry(Salem et al. 2006), mainly because it differs from manufacturing due to its structure, which presents greater complexity and uncertainty(Ballard and Tommelein 2016). Last Planner® System developed by Glenn Ballard and Greg Howell in the 90's(Ballard and Tommelein 2016), is one of the methodologies that has led the introduction of concepts and principles of Lean Production in construction (Daniel et al. 2015).

LAST PLANNER® SYSTEM AND PERSPECTIVE LINGUISTIC ACTION PERSPECTIVE

LAST PLANNER® SYSTEM

Last Planner® System (LPS) is a methodology of planning and control of commitments, based on the principles of Lean production philosophy and oriented to increase reliability of planning and levels of performance(Ballard and Tommelein 2016), which in turn reduces uncertainty and variability of projects. Reliability of production is affected by the effectiveness of the control of dependencies and fluctuations between activities (Goldratt and Cox 2013). An example of reliability measure is variability (O'Brien et al. 2008), understood as the potential changes in execution time or duration of a process (Alves and Tommelein 2003). Uncertainty is due to the existence of non considered variables, such as: availability of suppliers, unclear or incorrect designs, availability of labor, and administrative problems, among others (Rodríguez et al. 2011).

COMMITMENT MANAGEMENT IN LAST PLANNER® SYSTEM (LPS)

Due to the importance of achieving an adequate management of commitments, to reduce the uncertainty and variability of construction projects, it is necessary to strengthen the commitment management system in weekly planning meetings, because a coordinated action is achieved through a complex network of requests and promises that may well be the only viable method of coordination under dynamic conditions(Ballard and Tommelein 2016). In this sense, Howell et al (2004) propose the Linguistic Action Perspective (LAP) developed by F. Flores as a referential framework or paradigm suitable to understand the functioning and effectiveness of LPS.

LINGUISTIC ACTION PERSPECTIVE (LAP)

Linguistic Action Perspective was developed by F. Flores (2015)and it is basically an application of Speech Act Theory (e.g. Austin, 1971;Searle, 1969) to organizational management. F. Flores (2015)argues that conversations do not simply precede action, but rather constitute actions themselves through the commitments that emerge. This way, language is the primary means for creating a common future, for the coordination of human action, or in other words, for cooperation (2015). This idea refers to the founding work of Austin (1971)and the notion of illocutionary acts, or the actions we carry out when we say certain words. For example, by saying "I promise" I change the world, both the actions I take and those taken by others expecting me to do what I promise. This idea was later developed by Searle (1969), who proposed a taxonomy of speech acts.

Understanding "conversations for action" as those conversations whose purpose is the coordination of actions, Flores proposes a basic and universal structure, based on the performance of certain speech acts (2015). Thus, every conversation for action includes four basic speech acts: 1) request or offer, 2) promise or acceptance, 3) declaration of compliance and 4) declaration of satisfaction. These speech acts, in Searle's taxonomy, correspond respectively to directives (request), commissives (offer, promise and acceptance) and declaratives (statement of compliance and declaration of satisfaction), which are precisely those that modify the possibilities of action in the future, or in other words, those that modify the state of affairs through words (Searle 1975). Flores also uses these acts to define four stages of a conversation for action, in which a network or chain of commitments is established: 1) preparation of a request; 2) negotiation and agreements; 3) execution and declaration of compliance; and 4) acceptance and declaration of satisfaction. It should be noted that variations in basic movements may occur, such as declining a request, revoking a previous commitment or making a counteroffer: this, according to Flores, does not decrease the reliability but increases it (2015).For more details see Figure 1.

Figure 1: Network or Chain of Commitments Source: Own elaboration, based on (F. Flores, 2015)

PRACTICAL PROBLEM THAT IS BEING ADDRESSED

Although, as previously suggested, LAP has been proposed as a suitable framework for understanding the effectiveness of LPS (e.g. Howell et al., 2004; Macomber & Howell, 2003), until now there are no quantitative instruments to measure specific elements of LAP. A first effort to provide empirical evidence on the usefulness of LAP to understand LPS are works of Viana, Formoso, & Isatto (2011, 2016). The first of these works (Viana et al. 2011) proposes, based on a case study, a descriptive model of the networks of commitments in LPS, as well as a detailed analysis of planning meetings. The second study (Viana et al. 2016) is built on the previous one and specifically contributes to identify interruptions (breaks and failures) that occur in the stages of a conversation for action (Flores 2015), as well as quantify how participative the environments are, measuring the times dedicated to the different activities during the planning meetings.

However, the analysis offered by the aforementioned works does not explain the relation between the way in which the commitments are established and the compliance of those commitments, measured by percent plan complete, and therefore the effectiveness of the LPS. In this sense, our proposal for measurement and control of commitment management seeks to reduce the uncertainty and variability of the projects.

RESEARCH METHODOLOGY

PROCESS OF DESIGN AND CONSTRUCTION OF THE INDICATORS

To fulfill the objective, the research methodology was based on Hevner's "*A Three Cycle View of Design Science Research*" (2007). The following steps were carried out:

1. To study the Linguistic Action Perspective, to generate a *Knowledge Base*, based mainly on F. Flores (2015).
2. To identify the elements of this perspective that were potentially quantifiable, creating a list of concepts and data to be measured.
3. To develop indicators that could measure and control the previously identified elements, to generate the *Design Science Research*.
4. To discuss with a panel of international experts the feasibility of measuring and controlling these indicators, which allows improving the initial design.
5. To validate proposed indicators, verifying the feasibility of observing these indicators by means of a Villego® simulation applied to a group of students as a pilot test, to validate them through the *Environment* in a controlled situation.

INDICATORS: PROPOSAL AND VERIFICATION

INDICATORS

The authors propose a series of *Key Performance Indicators* (KPIs) according to Linguistic Action Perspective to measure and control fundamental aspects of the commitments, requests, promises and foundations of trust.

Within the KPIs that measure and control the commitments, the relevant data to be evaluated are: the network or chain of commitments, roles and responsibilities of the performers, declaration of the importance of the commitment and the availability of the performers (The worker's agenda). On the other hand, to measure and control requests and promises, among the data to be evaluated are: specify the deadline, unnecessary requests, and incomplete promises. Finally, to measure and control the foundations of trust, the main data to be evaluated are: competence of the performer, reliability and engaged participants.

It is worth mentioning that these indicators are designed to analyze the management of commitments in weekly planning meetings, so the frequency of measurement is every 7 days. However, a measurement from at least 2 weekly meetings is required in order to complete the network or chain of commitments, since in the first meeting the request is usually prepared, negotiated and the agreement is reached, while in the second meeting the execution and declaration of compliance is verified, together with the acceptance and declaration of satisfaction. (The list of proposed indicators can be observed in Table 1.)

TABLE 1. KPI Linguistic Action Perspective in Last Planner® System

Objective	Measure Name	Description	Formula	Means of Verification
Measurement and Control of Commitments	% compliance network or chain of commitments	KPI measures the percentage of compliance with the chain of commitments; that is to say, that the 4 movements for the coordination are fulfilled	(Number of commitments in which the 4 movements for coordination are fulfilled) / (Total number of commitments) x 100	That the 4 movements for coordination are fulfilled
	% definition of roles and responsibilities of the performers	KPI measures the percentage of commitments that define roles and responsibilities of performers	(Number of commitments with defined roles and responsibilities) / (Total number of commitments) x 100	Roles (Who): Client and Performer Responsibilities (What): Definition of the promise of which the performer takes charge
	% fulfillment of roles and responsibilities of performers	KPI measures the percentage of commitments in which the roles and responsibilities of previously defined performers are met	(Number of commitments that fulfilled previously defined roles and responsibilities) / (Total number of commitments) x 100	That the performer (not another) fulfill the promise and declare compliance to the client
	% declaration of the importance of commitment	KPI measures the percentage of commitments that declare the importance (priority) of this, explicitly	(Number of commitments declaring importance) / (Total number of commitments) x 100	Declare the importance (priority) of commitment in the first 2 movements
	% compliance with priority commitments	KPI measures the percentage of commitments that were declared important (priority) and that are effectively met	(Number of priority commitments fulfilled) / (Total number of priority commitments) x 100	Review of priority commitment review agreed previously
	% verification of availability of performers in agreements	KPI measures the percentage of commitments that verify the availability of performers in the negotiation stage and agreements	(Number of commitments that verify availability of performers in agreements) / (Total number of commitments) x 100	Verification of the availability of performers in the negotiation stage and agreements. The executor (workers) agenda can be requested from the foreman
	% verification of availability of performers in execution	KPI measures the percentage of commitments that verify the availability of performers in the execution stage	(Number of commitments that verify availability of performers in execution) / (Total number of commitments) x 100	Compliance with the verification of the availability of performers in the execution stage
Measurement and Control of Petitions and Promises	% specify the deadline	KPI measures the percentage of commitments that specify the deadline	(Number of commitments that specify the deadline) / (Total number of commitments) x 100	Specific deadline: date and time (AM, PM)
	% of unnecessary requests	KPI measures the percentage of commitments that make unnecessary requests	(Number of commitments that make unnecessary requests) / (Total number of commitments) x 100	When the client declares that the deadline specified in the request does not correspond to the last responsible moment and / or requested something that was not necessary (does not add value)
	% of incomplete requests and promises	KPI measures the percentage of requests and promises that do not comply with explicit conditions of satisfaction, background of obviousness and / or specific term	(Number of commitments that make requests and incomplete promises) / (Total number of commitments) x 100	Explicit conditions of satisfaction, background of obviousness and specific deadline
Measurement and Control of Fundamentals of Trust	% compliance of the performer's competence	KPI measures the percentage of commitments where the performer is able to perform in the required domain	(Number of commitments where performer is competent) / (Total number of commitments) x 100	Performer is able to perform in the required domain (recurring performance according to accepted standards)
	% reliability compliance (* complementary to PPC)	KPI measures the percentage of commitments where the performer is able to perform reliably and timely in the required domain	(Number of commitments fulfilled + number of commitments revoked + number of counteroffers) / (Total number of commitments) x 100	Performer keeps his promises on time (PPC), counteroffer or revokes
	% Engaged participants	KPI measures the percentage of meeting participants who are engaged to it	(Number of participants engaged to the meeting) / (Total number of attendees) x 100	Participant attends the meeting, arrives at the time and remains in an attitude that suggests concentration (does not interact with the cell phone, looks at the speaker, takes notes, etc). (Failing to comply with any previous aspect, justify it before or during)

Source: Own elaboration, based on (F. Flores, 2015)

VILLEGO® SIMULATION

To analyze and validate each of the proposed indicators, it was decided to verify the feasibility of observing and measuring these indicators by means of the Villego® simulation. For this purpose, 11 volunteer students of the sixth semester of Civil Engineering, at the Pontificia Universidad Católica de Chile, were asked to perform the simulation. The authors video-recorded the two rounds of the simulation (simulation of the traditional process of planning and simulation with LPS) to be able to analyze each one of the proposed indicators.

First Round Villego® Simulation

After giving the general instructions of the simulation, students were asked to define the roles and responsibilities that each member would assume in this round, defining the following roles: administrator, quality, technical inspection, security, warehouse, and several subcontractors identified with different colors; gray, blue, white, yellow, green and red.

Second Round Villego® Simulation

After giving the new general instructions of the simulation, the students were asked to redefine the roles and responsibilities of each member, according to the lessons learned from the initial round.

RESULTS VILLEGO® SIMULATION AND COMPARISON WITH ACTUAL EXPERIENCE

To determine the feasibility of observing the list of proposed indicators, the videos of both rounds were analyzed once the simulation was completed. The differences between the results obtained in the Villego® simulation and the expected results (according to preliminary field studies) in a real planning meeting are described below.

1. **Compliance network or chain of commitments**
   - Simulation: the two initial movements for coordination always occurred, but Administrator most of the time "imposes" the conditions and deadlines, without much space for negotiation. Then, the declaration of compliance was taken for granted, simply with the phrase "ready". Acceptance and declaration of satisfaction in general was not made explicit.
   - Real: it will depend on the degree of maturity in the implementation of the LPS and the management of commitments that the team has.
2. **Definition of roles and responsibilities**
   - Simulation: roles and responsibilities are defined at the beginning of the simulation. This is intrinsic to the Villego® simulation.
   - Real: in general, the role of participant in the meeting should be previously defined (each stakeholder in a construction site has a clear role to perform).

3. Fulfillment of the roles and responsibilities of the performers

- Simulation: all the commitments fulfilled the previously defined roles and responsibilities, since the same foremen perform the work.
- Real: difficult to comply, because generally the last planner is the foreman.

4. Declaration of the importance of the commitment

- Simulation: the importance of commitment was never stated, because it is a simulation, where time is very limited and all tasks are critical.
- Real: it is desirable that there is a declaration of importance, in key commitments of the project, currently this does not happen.

5. Compliance with priority commitments

- Simulation: the importance of the commitment was never declared.Therefore, no further verification was necessary.
- Real: should be fulfilled with the declaration of the importance made, to generate confidence in the team, currently this does not happen.

6. Verification of availability of performers in agreements

- Simulation: it is redundant because roles and responsibilities are defined at the beginning of the simulation.
- Real: it is difficult to comply, because generally the last planner is the foreman, and the one who performs the action (performer) is a worker dependent on him.

7. Verification of the availability of performers in execution

- Simulation: it is redundant because roles and responsibilities are defined at the beginning of the simulation.
- Real: it should be fulfilled, since once assumed the commitment by the foreman, it should generate an agreement with the worker (performer) in order to verify the commitment previously assumed.

8. Specify the deadline

- Simulation: yes, weekly planning is carried out according to simulation restrictions.
- Real: it indicates the date of fulfillment of the commitment, but not the approximate time, since usually is not even indicated whether the term will expire in the morning or in the afternoon.

9. Unnecessary requests

- Simulation: no unnecessary requests were observed.
- Real: sometimes unnecessary requests are made when a correct weekly planning and an adequate analysis of the executable work inventory are not carried out. The above is due to problems in the implementation of the LPS.

10. Requests and incomplete promises

- Simulation: due to the nature of the simulation, space is not given for this type of considerations.
- Real: a high percentage of requests and promises are incomplete, since the conditions of satisfaction are not always explicit. This can lead to misunderstandings that lead to non-compliance of commitments.

11. Compliance of the performer's competence

- Simulation: a change of roles and responsibilities was performed, according to the competencies that the team could detect from round 1.
- Real: the competence of the performer should be verified through their technical experience (Curriculum Vitae) and their social skills (how they work with their co-workers).

12. Reliability compliance

- Simulation: no counteroffers or revocations were observed, probably due to the conditions of the simulation (shortage of time).
- Real: currently it is difficult to measure because it occurs outside the meeting, it is expected that there will be counteroffers and revocations by the foremen (last planners) and workers (performers). It´sconsidered essential to measure this indicator, since currently the PPC only measures if the commitment was fully complied with and this is associated with the degree of reliability of the commitment.

13. Engaged participants

- Simulation: due to the conditions of the simulation, it was evident that they attended the meeting and arrived at the time (they were there). But, regarding the attitude of concentration, it was verified that not all the assistants fulfilled the required attention: they looked at the cell phone and spoke among themselves (on topics unrelated to the meeting). Also, nobody took notes.
- Real: currently the participants do not arrive at the time nor do they attend the meeting in an attitude that suggests concentracion.

CONCLUSIONS

Because the construction industry has not yet reached the productivity levels of other industries, project planning and control must be improved to generate a change in the industry. Last Planner® System (LPS) is a methodology for planning and control of commitments, which seeks to reduce the uncertainty and variability of construction projects by increasing the reliability of planning. In this sense, Linguistic Action Perspective (LAP) developed by Fernando Flores, proposes a basic and universal structure of the conversations by means of which said commitments are established, based on the performance of certain speech acts.

Due to the fact that at the date of the present investigation, there were no quantitative instruments available to measure specific elements of LAP, apart from the work done by Viana et al., (2011, 2016), the authors created and validated a set of *Key Performance Indicators* as a proposal for measurement and control of fundamental aspects of the commitments, requests, promises and foundations of trust.

The methodology used by the team to carry out the indicators was *Design Science Research.*

Given the nature of this simulation, only able to verify the indicators of commitment; compliance network or chain of commitments; definition of roles and responsibilities of the performers; fulfillment of the roles and responsibilities of the performers; specify the deadline; compliance of the performer's competence; and engaged participants. On the other hand, indicators of: declaration of the importance of the commitment; compliance with priority commitments; verification of availability of performers in agreements; verification of availability of performers in execution; unnecessary requests; incomplete promises and promises; and reliability compliance, are currently under verification process in construction projects in Chile.

In addition, the authors propose as future lines of research: apply case studies in weekly planning meetings in construction projects and other industries, worldwide and determine the recommended values to improve communication and achieve a proper implementation of LAP in LPS.

Finally, the authors consider that this first generation of validated Key Performance Indicators are a useful tool to measure, control and improve the management of commitments in planning meetings, as they provide a fast and specific feedback on these aspects, which without doubt undoubtedly enriches Last Planner® System.

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APPLICATION OF SOCIAL NETWORK ANALYSIS IN LEAN AND INFRASTRUCTURE PROJECTS

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ABSTRACT

The communication structures between project participants have a great influence on the success of a project. Some can be described explicitly but most are informal and tacit. Social Network Analysis (SNA) is a tool to identify and model actual social structures with a set of metrics. This paper examines the application of SNA in German, Swiss and Chilean construction projects in order to identify the suitability of SNA in the Architecture, Engineering and Construction (AEC) industry. The scope of the present work focuses on differences when applying SNA to projects and organizations, influence of project complexity, cultural aspects and the use of SNA-metrics for a project benchmarking.

KEYWORDS

Social network analysis (SNA), information flow, collaborative work, organizational design

INTRODUCTION

During the last years, Lean construction principles and practices have proven to be a good alternative to decrease the variability and uncertainty in project planning and execution. Although the introduction of Lean construction has positively impacted project management, there remains further scope for improvement. "Lean thinking" aims to

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introduce improvements mainly at process-level, creating solid structures and smart systems to increase productivity. Such improvements work well in the manufacturing industry, where processes run within a stable framework, producing defined and repetitive products. By contrast, the framework of processes in the construction industry is unstable; it deals with the fabrication of unique products at different places, relying much more on dynamic communication and social interaction. Thus, focusing only on process optimization may not have the desired impacts.

Lately, the study of human relations and the resultant information flows within a project or organization have demonstrated to have a great relevance on project performance. Hence, the application of Social Network Analysis (SNA) within the ambit of Architecture, Engineering and Construction (AEC) offers great potential, since it can be used a) to discover the importance of informal social structures that coexists with formal ones, b) to move towards a more flexible organizational team model which is work-oriented and more dependent on knowledge assets (information flow), and c) to quickly develop close cooperation relationships(Cross et al. 2002).

The application of SNA in the AEC industries is still a novel approach under development. Several attempts have been carried out during recent years to give interpretations to its results and to find correlations between Key Performance Indicators (KPIs) and different SNA-metrics. Nevertheless, most of these studies had to be done almost from scratch. This implies that none of these were undertaken based upon the already assimilated knowledge and/or through analysis of various Lean approaches utilized by projects executed in different countries.

The aim of this work is a comprehensive investigation about how SNA can be applied in the setup of Lean construction projects in the German and Swiss construction market. Furthermore, a comparison with a Chilean infrastructure project is undertaken in order to assess the influence of cultural aspects.

BACKGROUND

COMMUNICATION-STRUCTURESAND LOWPRODUCTIVITY IN CONSTRUCTION

Over the past two decades global productivity in construction remained meager, in comparison with other industries. Many root-causes of this problem are related to communication issues: a) informality and corruption distort the market, b) construction is opaque and highly fragmented, c) design processes and investment are inadequate, and d) poor project management and inefficient on-site execution (Barbosa et al. 2017).

Management practices and human related issues are determining internal factors which influence project performance(Chan et al. 2004). Also, the relationships between the collaborators of an organization have been linked directly with their ability to fulfil objectives (Anklam 2003).In Germany, these type of factors have also been identified as the main causes of deficiencies in construction (Jungwirth 1991).

When it comes to infrastructure projects, in addition to the factors mentioned above, other factors related with communication play a greater role: a) communication with communities neighboring the project: lack of confidence, misinformation and confusion about roles, rumors, community conflicts, expectation management (Mazzei and Scuppa

2006), b) engagement with stakeholders: specially involving the private sector in "reality checking" the results of planning, in particular relating to the financing of projects (Glaister et al. 2010), and c) poor execution: incomplete design, lack of clear scope, ill-advised shortcuts, etc. These projects are so complex that even routine issues can become a major problem (Garemo et al. 2015).

It seems that the analysis of human relations and their consequent information flows within projects or organizations can make a significant contribution towards more productive project execution. Thus SNA is attracting increasing attention in order to enhance trust and collaboration (Chinowsky et al. 2008).

LITERATURE REVIEW: SNA IN THE INTERNATIONAL AEC INDUSTRY

Over the last 5 years, several studies have been carried out on SNA in Chile. Flores et al. (2014) proposed the analysis of 9 networks: interaction, frequent interaction, relevant information, problem solving, successful planning, innovative ideas, leadership, trust and professional feedback. Data was collected through web-based surveys and the analyzed metrics were network density, network diameter, average path length and average degree (Alarcón et al. 2013; Segarra et al. 2017), as well as the difference in network shape. Recent studies have found interesting relationships between project's Last Planner System® (LPS) KPIs and SNA-metrics(Castillo et al. 2015, 2016, 2018).

In the work made by Schröpfer et al. (2017) SNA is applied in three case studies in Germany and in two cases in UK. The research focuses on the analysis of knowledge transfer among project members, relating it to trust networks within the organizations. The findings of the study showed that "large amounts of tacit knowledge were transferred through strong ties in sparse networks […] strong ties do not necessarily equate to a dense network, but can exist in a very sparse network as well." (Schröpfer et al. 2017)

In the USA, SNA has also been implemented, analyzing the importance of early communication in construction projects (Malisiovas and Song 2014). Instead of using a questionnaire survey, they used indirect sources of information: meetings, conversations, e-mails, phone calls, videoconferences, etc. They found that "higher density reveals a higher level of communication, large modularity may imply the creation of isolated groups, as the network becomes more complex its length gradually increases, increasing of the average shortest path reveals a possible threat of future isolated populations to appear, thus leading to poor utilization of individual knowledge and experience."

SNA has also been used to detect unethical behavior in the construction industry and the relationship between corruption and Integrated Project Delivery (IPD). Project participants having high number of connections and centrality have more to lose from unethical conduct than those who are isolated in the network; as they are under an increased surveillance due to their multiple connections, which determine the extent to which news of unethical behavior are disseminated to other project participants. In the study, three communicational structures were identified: a) structural hole, b) mixed and c) simmelian triad. From the analysis of the different structures, the authors concluded that "implementation of Lean IPD in construction may be an effective grass roots weapon for combating corruption" (Thameem et al. 2017).In another study related, Hickethier et al. (2013)have applied SNA to investigate the impact of IPD practices in projects. The researchers concluded that SNA can be used to support the implementation of this collaborative approach. IPD promotes the participation of a greater number of people in the project design, thus increasing the need for coordination. Thereby, SNA can assist the coordination of this larger design team. In Israel, SNA has been implemented in a LPS-Project to explore three aspects: communication, reliability, trust (Priven and Sacks 2013). In China, Li et al. (2011) used SNA with an indirect method of data collection at the 2010 Shangai EXPO, analyzing the relationships of 49 organizational units, 5 major projects and 8 government departments. They considered consortium relations, strategy alliance relations, team relations, contractor and subcontractor relations, working staff relations and other informal relations as connections between them. They concluded that SNA provides a new research perspective, e.g. of construction organizations.

METHODOLOGY

In light of this background, the research aims to answer the following questions:

- How important are cultural aspects when implementing SNA?
- Is SNA equitably suitable for the analysis of projects and organizations?
- How does project complexity influence the applicability of SNA?
- Is it possible to use SNA-metrics for statistical benchmarking of projects?

In order to answer these questions, proven concepts of past SNA implementations were taken to build a first conceptual framework of a SNA-Instrument. Then, the instrument was tested and refined in iterative loops each time in a more complex project scenario: firstly, in a simple organization (consulting office), secondly in two construction projects, thirdly in a complex organization (6 subsidiary consulting offices) and c) in an infrastructure project. The iterations were done in Germany, Switzerland and Chile. The resulting structure of the SNA instrument is illustrated in the Figure.

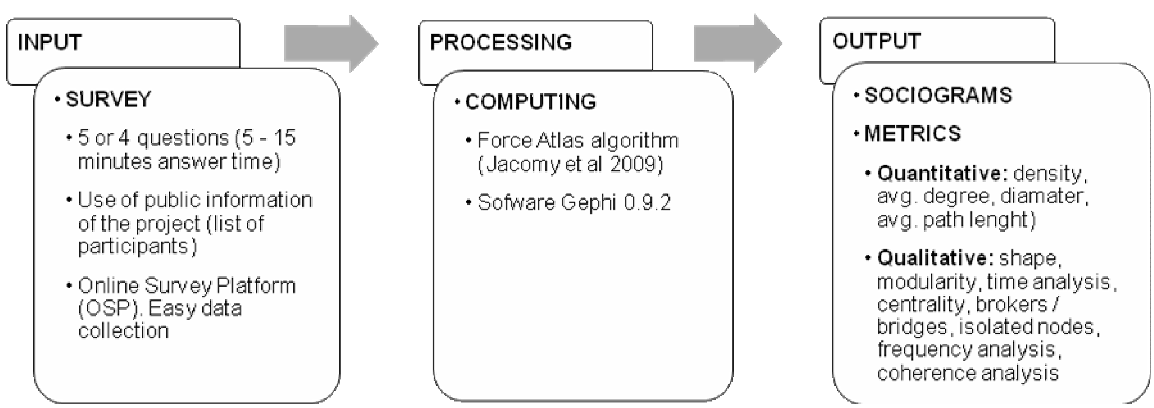


Figure 1: SNA Instrument Structure

The five survey questions concern five different social networks. Table 1contains a brief description of the networks, questions and motivation.

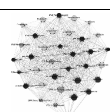
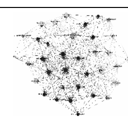
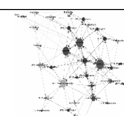
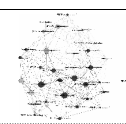
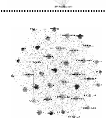
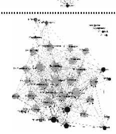
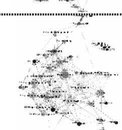
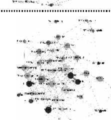
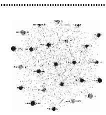
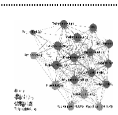
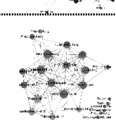
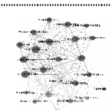
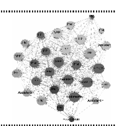
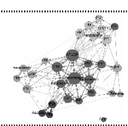
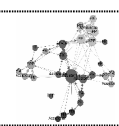
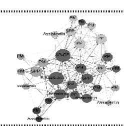
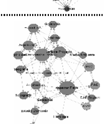
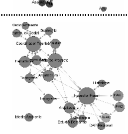
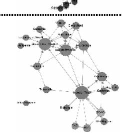
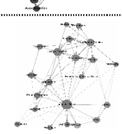
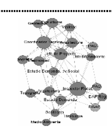
Table 1: Networks analyzed in the SNA Instrument

No	Social Networks	Exploratory question regarding the network	Motivation
1	(RIN) Role identification network	Do you know the role of this person in the project/organization?	Avoid delays finding information, solve problems
2	(WIN) Work Interaction network	Have you interacted with this person in the project/organization during the last 3 months?	Basic network to analyze. Collaborative work
3	(PPRN) Planning & problem resolution network	Select the people with whom you plan and solve problems effectively with. Consider only the past 3 months	Inclusion of stakeholders
4	(KN) Knowledge network	Select all those involved in the project from which you have learned something new that means a contribution in the project you are working on. Consider only the past 3 months	Improve knowledge transfer
5	(TN) Trust network	Select all those involved in the project/organization that you trust in the quality of their work. Consider only the past 3 months	Measure trust in work relationships, in terms of quality and time requirements

RESULTS AND DISCUSSION

Table 2 summarizes the different scenarios used for the iterative design of the SNA-Instrument. Furthermore, it depicts the identified socio grams, in which it can be seen how the different groups (marked with colors) are distributed and with what degree of density they are clustered.

Table 2: List of measured contexts

Project / Organization	RIN	WIN	PPRN	KN	TN
Organization 1 Consulting Office **Germany**					
Project Office Building Construction **Switzerland**					
Project Research center Construction **Switzerland**					
Organization 6 Consulting Offices **Germany**					
Project Airport Expansion Design **Chile**					

The social networks of the observed organizations and lean projects in Germany and Switzerland in general obtained better metrics values than the infrastructure project in Chile. This was demonstrated by higher densities; lower network diameters and average path lengths, more central participants; and better distribution of nodes and network shape. Thus, resulting in better communication and knowledge transfer. The low communication level of the infrastructure project is attributed to the more diverse work teams that constituted the project which were situated in different geographical locations and did not devote 100% of their time to the project, but also to other activities (e.g.: government entities).

The question regarding the Trust Network (TN) was considered too compromising and personal in Germany and Switzerland and could not be applied in these countries. In Chile, the question was allowed.

CULTURAL ASPECTS

In countries such as Germany or Switzerland, where data protection is an important issue, people are more reluctant to respond to surveys without knowing exactly why and howthis information will be used. Obtaining information can be hindered in these countries because implementing SNA involves obtaining data directly from people. Attempts were made to obtain data about the social structure indirectly, through observations, nevertheless these alternatives were rejected because they did not provide high quality data to ensure correct visualization of the networks.

In these contexts, an in-depth explanation of SNA to the respondents, a careful preparation of the questions and a correct survey privacy statement are essential to achieve full survey participation.

PROJECTS AND ORGANIZATIONS

After the application of the SNA-Instrument in different contexts, it was found to be effective for both project and organizational analysis.

Furthermore, the SNA-Instrument can be used more than one time, to compare and register the evolution of the social network along the time. In organizations it can be applied regularly at pre-set time intervals. In projects, multiple SNA implementations might be difficult to carry out, so it is recommended to apply SNA at least at the beginning and at the end of the project. At the beginning it can be used as a good starting point to assess the quality of the communication in project. For example, if the density of the network is high, it may be known in advance that the introduction of new ideas will be more challenging, because in network which are closely connected, when the new information, and, or even, especially new innovation comes in, they might be reluctant to any change (Gasevic 2014). A SNA measurement at the end of the project, will help to demonstrate the effectiveness of the actions taken to improve communication.

PROJECT COMPLEXITY

The full potential of the instrument in identifying conflicting communicational configurations was witnessed in the most complex scenario (infrastructure project).

The SNA-metricsin this project point at weaker communication networks than in normal projects, due to fragmented contracts. Such a fragmented project structure with work assigned to several different bodies, hamper the coordination and collaboration of stakeholders. The communicative structure is quite hierarchical, and therefore riskier, as it generates brokers (bottlenecks) that dangerously gain a lot of influence and power in the management of information within the project. The most significant flow of information goes through these hubs-members, which can filter the information according to their own criteria. Many decisions are made only by these members, so the risk of a bad – or even unethical(Thameem et al. 2017) – decision is concentrated in a few people. Furthermore, if these hubs-members resign or are absent from the project, it would immediately generate delays.

BENCHMARKING

The interpretation of the SNA-Instrument outputs was composed for two points of view: a quantitative analysis and a qualitative analysis (see Table 3).“The human eye is trained in pattern recognition” (Nooy et al. 2005), because of that it is important to make an analysis of the geometric shape of the networks, which will also provide important information. Metrics such as Diameter, Density, (In-Out-Average) Degree, Modularity and Centrality are calculated by algorithms. All of them are represented by numbers which can be categorized to identify the optimal intervals of these values.

Table 3: Type of Analysis for the SNA Instrument Outputs

Analysis	Based on	Instrument
Qualitative	Geometrical characteristic of the network	Sociogram
Quantitative	Numerical values of the network’s metrics	Sociometry

A good example of this categorization is the work done by Segarra et al. (2017) in the search for a trend of the density value according to the number of nodes in the network. The researchers measured the social structure of 8 organizations (architectural firms) for a period of six months in Chile, finding a clear trend for density.

“Density is inversely related to network size: the larger the social network, the lower the density, because the number of possible connections increases rapidly with the number of vertices”(Nooy et al. 2005). This can be easily verified by plotting the function of density. Since density $d(e,n)$ is a function of two variables:

$$d(e,n) = \frac{e}{n \cdot (n-1)}$$

Where:
d is the density of the network;
e is the number of actual edges in the network; and
n the number of nodes in the network

It can be plotted as a 3D surface depending on the number of nodes n and edges e, as Figure 1 shows. The greater the number of nodes, the number of edges that are required to obtain a high density becomes exponentially larger. This mathematical tendency was empirically proven by Segarra: "we observed that the density decreased as the number of nodes increased" (Segarra et al. 2017).

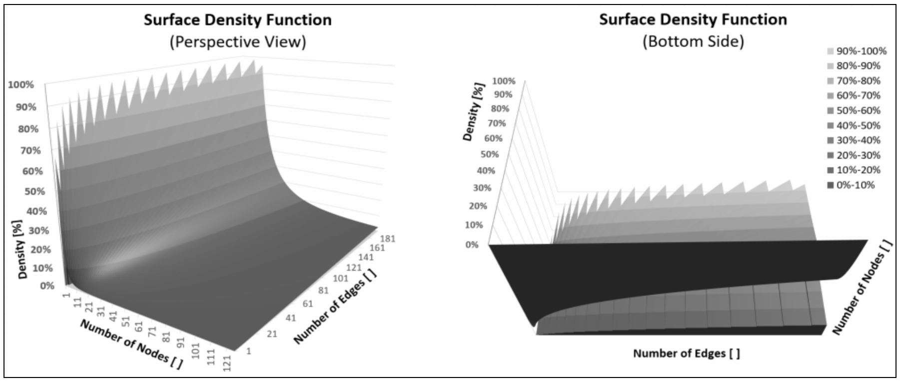


Figure 1: Surface of the Density Function (Perspective and Bottom Views)

What Segarra et al. (2017)found was an 8-points contour line of the shown surface.This density-tendency was found considering a period of six months; in this study the densities were obtained considering a period of three months. When all these values are plotted in the same graph, it seems that European projects and organizations register higher densities. It also seems that the Chilean infrastructure project is located near the points obtained in Chilean organizations, as it is shown in Figure 2.

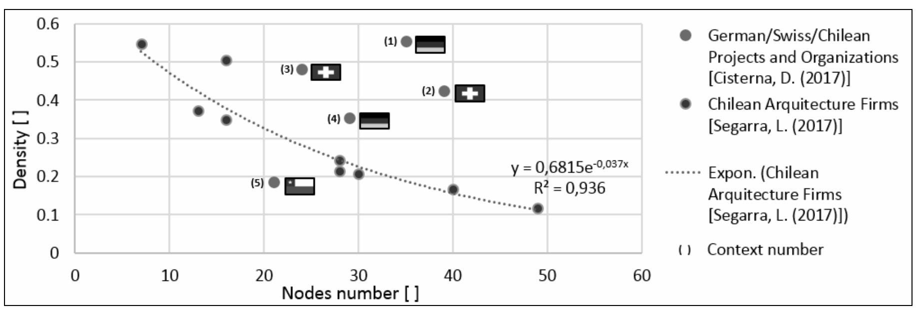


Figure 2: Density vs Number of Nodes. Comparison between Density Values

If the SNA-Instrument comes into use in a regular basis, it will be possible to add new trend lines to Figure 2. These trend lines can be classified by: type of organization (architecture, engineering, construction, consulting, etc.); type of project (industrial, housing, infrastructure, etc.); and, by geographical location. This can be done not only with the density of the networks, but also with all other metrics calculated through algorithms. Each implementation of the SNA-Instrument would feed a database, which will deliver increasingly accurate statistical trends. This database could be used for two purposes: **a) statistical benchmark**, which would make it possible to compare the SNA-metrics, obtained with historical average values, and **b) best practice comparison of SNA-metrics**, which would make it possible to compare the SNA-metrics of a certain project with the SNA-metrics of best practice projects. Considering that the density is directly proportional to the level of communication of the projects, the results of these benchmarks will answer questions such as: a) do projects and organizations in Europe generally have a higher level of communication than in South America? b) Do infrastructure projects generally have a lower level of communication than normal ones?

CONCLUSIONS

The results of the present research work confirm that the application of SNA in construction projects promotes an improvement of information flows, cooperation and mutual trust, because it provides a diagnosis of the social and communicational structure of the project, allowing them to be improved. The SNA-metrics can be used to identify formal and underrated or informal links between project participants, tacit knowledge networks or even network-structures prone to unethical behavior. Significant and meaningful results can be generated for both organizations and projects, especially if the analysis is performed recurrently over time. Even complex project environments, such as big infrastructure projects, can be described well. Such projects in particular usually have great potential for improvement, which can be identified with SNA-metrics. In addition, the metrics allow a cross-project comparison and benchmarking in order to identify best practice applications on the basis of described patterns, e.g. communication and information transfer patterns. The results of the SNA analyses are directly dependent on the openness and participation of the respondents, which is why cultural aspects (company or country) play an important role. Therefore, great importance should be attached to the conviction and involvement of the project participants.

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INNOVATION IN THE NEW ZEALAND CONSTRUCTION INDUSTRY – DIFFUSION OF THE LAST PLANNER SYSTEM

Richard J. Hunt[1] and Vicente A. Gonzalez[2]

ABSTRACT

Globally, the development, diffusion, and adoption of innovation within the construction industry has been shown to occur at significantly slower rates than other industries. This is due to a number of complexities which define the construction industry itself. One particular innovation which appears to be gaining momentum globally as a new standard in construction management is Lean Construction, and in particular, the Last Planner System of production control. The purpose of, and aims of this paper is to determine whether the views of New Zealand construction industry stakeholders regarding innovation align with the literature; to gauge to which degree The Last Planner System has been diffused within the New Zealand industry, and to gain an insight into stakeholder perspectives of The Last Planner System as an innovation. The study covered a range of industry stakeholders consisting of consultants, contractors, and project owners. The results of these interviews suggest that the challenges of construction innovation within New Zealand are consistent with the global outlook; diffusion of The Last Planner System is in its early stages and there is much scepticism within the industry as to the likelihood of its widespread adoption.

KEYWORDS

Innovation, Last Planner System, New Zealand, Lean Construction, Perspective

INTRODUCTION

A strong and well performing construction industry is vital to the economy of every country, contributing between 6-10% of GDP for most OECD countries (Eriksson, 2013). Until recently the New Zealand (NZ) construction industry has been a poor performer in this measure when compared internationally, in 2010 the industry contributed just 4% to national GDP(DBH, 2012).

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Low productivity within the sector was identified as a major contributor to the industry's poor overall contribution to the national economy (DBH, 2012). So in 2011 the NZ government established "The Building and Construction Productivity Partnership" (Ministry of Business Innovation and Employment [MBIE], 2016) which had a clear goal of a 20% productivity increase within the industry by 2020. At the time it was estimated that such an increase could add an additional $3 billion to the economy per year (DBH, 2012).

Since 2010 the NZ construction industry has seen unprecedented growth, this has seen GDP contribution double from 4% to 8% between 2010 to 2015 (DBH, 2012 & PWC, 2016). The key drivers of growth have been the Christchurch rebuild and increasing population demand in Auckland leading to massive investment in public infrastructure, commercial and residential construction. In 2014 the Productivity Partnership was disbanded (MBIE, 2016), with no evidence to suggest the industry was on target to achieve the 20% increase in productivity. The issue of productivity was sidelined whilst the industry rides an unprecedented wave of economic growth driven by macroeconomic effects.

In its inaugural report, the Productivity Partnership identified the key driver to increase construction productivity to be the adoption of new innovation across the industry (DBH, 2012). A qualitative study into onsite construction productivity in NZ by Durdyev & Mbachu (2011) found that the main contributor to poor productivity was ineffective project management. The Last Planner System (LPS) is an innovation in construction project management created under the principles of Lean Construction. LPS is a production planning and control system used to reduce workflow variability and increase planning reliability (Ballard, 2000). LPS has been shown successful in lifting project success and boosting construction productivity.

This research has three aims; Firstly, to highlight the complexities of construction innovation and contextualise it within the NZ setting; secondly, to prove the assumption that knowledge levels of both Lean Construction and LPS in NZ are low; and thirdly to explore whether LPS, as an innovation, could be widely adopted within the NZ industry. There have been numerous articles published relating to the implementation of LPS, mainly undertaken to quantify the benefits of LPS or to resolve the difficulties associated with implementation. Little research has explored how LPS as an innovation has diffused and been adopted throughout an industry, in exploring this the project attempts to address a gap in the literature by relating the adoption of LPS to the body of research on construction innovation.

RESEARCH METHOD & LIMITATIONS

The research was separated into two phases, phase one being a literature review exploring innovation in the construction industry. Phase two employedthe qualitative research methods of a questionnaire and semi-structured interview to assess the research objectives. It was anticipated that there would be a general lack of knowledge relating to Lean Construction and LPS.As such, two sets of interview questions were prepared, one each for those familiar and unfamiliar with Lean Construction and LPS. In order to obtain relevant insight from those unfamiliar with Lean Construction and LPS a 20 minute presentation was prepared on the topic.

Three interviews were undertaken with contractors, three with consultants, and three with construction/land development investment groups. Interviewees were all directors or high level managers within their receptive organisations. The contractor and consultants interviewees came from businesses that would be categorised as tier 2 within the NZ market, having between 100 and 400 staff. This group was chosen as anecdotal evidence suggested that tier 1 contractors in NZ had started adopting Lean Construction, while its diffusion to the wider industry was largely unknown. The investment groups were chosen on the premise that they were large enough to have an influence as to the adoption of innovation within the projects they funded.

Limitations of the research included the use of a presentation to deliver information about Lean Construction and LPS to the participants, every participant stated the explanation was clear. However, the presentations contents,variance in delivery and participant understanding present limitations on views developed towards Lean Construction and LPS. A further limitation is the small sample size of the study and the wide range of industry stakeholders interviewed, however the qualitative research method employed meant that sample size was not as relevant as in quantitative research, where large and representative samples are used to generalise results (Palacios, Gonzalez& Alarcón2013).These qualitative methods were chosen as the research is also exploratory in nature, seeking to gain insight into a concept which has been given little academic attention within the NZ environment.

INNOVATION IN THE CONSTRUCTION INDUSTRY

A COMPLEX AND TRADITIONAL INDUSTRY

The construction industry is vastly more complex than most (Aouad et al., 2010). At the institutional level the industry is fragmented, made up of many diverse professions, trades and organisations. Whilst at the operational level firms are almost exclusively project based, undertaking complex tasks (Bresnen, Goussevskaia & Swan 2005). The success of a project is dependent on the competencies of the collective group forming a "temporary multi organisation" (Davidson, 2013). These complexities inhibit the spread of innovative practises both within and between firms, impacting an organisation's ability to learn from experience and develop innovation from within (Gann 2001).

The introduction of innovation within a project adds a significant degree of risk to the implementing organisation. The unknown element of new knowledge within the project environment can have a ripple effect of secondary and tertiary impacts which are difficult to predict (Slaughter 2000). Generally the implementation of a new innovation within a project requires the cooperation and buy-in of all members of the "temporary multi organisation" to be successful (Blayse & Manley, 2004).

The nature of the product being built and the expectation of quality and durability does not always provide incubation for innovation(Pries & Janszen, 1995). Traditional forms of construction contracts and procurement are also inhibitors of innovation (Eriksson, 2013). Design-bid-build contracts do not encourage innovation due to a separation between design and construction, promoting minimal collaboration and adversarial relationships (Kumaraswamy & Dulaimi, 2001). Design-build contracts improve design outcomes and reduce conflict, however as they are still procured based on the lowest price method there is little incentive for the contractor to outlay additional expense on innovative design (Eriksson, 2013).

DIFFICULTIES IN DEVELOPMENT

Construction firms (especially contractors) are constantly innovating at the local level, developing ingenious solutions to the variety of site specific problems encountered when delivering bespoke designs (Aouad et al., 2010). These local innovations may save time or money within a specific project, however firm development of these innovations into marketable product is rare. Innovation remains hidden due to lack of formal R&D within all but the largest firms (Aouad et al., 2010). The majority of NZ construction firms are incapable of direct investment into R&D expenditure due to their size, with over 95% of construction firms employing less than 19 people (MBIE, 2016. Small Business). This combined with minimal investment or incentive to innovate within government policy (Gann 2001) creates a void in the industry where formal R&D is left almost exclusively to large organisations and the manufacturers of construction products.

Universities, as knowledge creators play a major role in the development of innovation in the construction industry through basic and applied research (Aouad et al., 2010). In spite of this, the industry views universities as one of the least important sources of information ([DTI] 2006). In the UK there is seen to be many "systematic and cultural" differences between universities and the industry, limiting successful collaboration and development of construction innovation (Treasury, H. M. S. 2003). It is believed that improved platforms of engagement between the two sectors would improve the innovation landscape of the industry (Gann 2001).

DRIVERS OF INNOVATION

Clients are seen as being vital participants in driving innovation. They are able to exert pressure on stakeholders to improve project performance and demand higher standards. This acts as a catalyst for consultants and contractors to seek new strategies (Gann & Salter 2000). The more experienced and technically competent the client, the greater influence they can have over the innovation agenda of a project (Nam & Tatum, 1997).

Traditionally, manufacturers and suppliers of construction products have been viewed as the primary source of construction innovation (Pries & Janszen 1995). These firms operate in more stable and standardised environments than project based firms. The end result is sustained investment in internal R&D (Gann, 2001) which stimulates the innovation process (Anderson & Manseau 1999).

Industry relationships are significant to construction innovation as they are one of the key communication channels through which new knowledge is diffused throughout the industry (Dubois & Gadde, 2002). The wider and more diverse an individual's professional network, the greater exposure they have to new ideas. Increased attendance of diverse and high quality networking events linking academia and multiple sectors of the industry is seen to greatly enhance innovation diffusion (Abbott, Jeong & Allen 2006). At the project level, strong relationships between contractors and consultants can see innovation flourish. If firms and individuals are able to engage from project to project, the higher the chance of inter-project and organisational learning (Dubois & Gadde 2002).

RESULTS AND DISCUSSION

DIFFUSION OF INNOVATION

The most important communication channel for the discovery of new innovation was stated by all nine participants as industry relationships, strongly agreeing with the literature. Examples stated by participants included undertaking projects with a variety of contractors and consultants, discussion with manufacturers, looking at competitors, and maintaining a wide professional network of associates. Only one interviewee noted that they looked to their staff as a source of innovation, highlighting the complexities of intra-organisational knowledge sharing within project-based organisations.

Four participants had employees sporadically working on in-house innovation, while none had a dedicated R&D team. With one participant stating "The big organisations have a budget for innovation rather than just an interest." These two points support the view of Gann (2001) that construction firms mainly adopt innovation once it has been first been trailed and exploited within another industry or by industry market leaders.

All participants attended industry seminars and conferences however these were largely confined to their specific areas of expertise, an example of the fragmented and complex nature of the industry. It would appear that diverse industry networking events, linking multiple disciplines and academia as highlighted by Abbott et al (2006) are either not a frequent occurrence within NZ or are not seen to add value by NZ construction firms.

None of the participants read academic publications. Suggesting that the NZ industry places a low level of significance on information produced within academic institutions, as shown to be true in the UK and Europe. The idea that academics have the capability to achieve change through academic research within such a practical industry with heavily ingrained methodologies is questioned by Gann (2001). This idea was also expressed by participants, who believed that in an industry dominated by *"alpha males,"* as one participant put it, the change process, especially by an outsider, is a challenging prospect.

There was an interesting split between the consultant and contractor participants as to the importance of the client as an innovation-driver. Consultants saw the client as vitally important in facilitating new innovation, with most reiterating that the experience and technical knowledge of the client was influential on design outcomes and the incorporation of new innovation. Contractors largely did not see the client as exerting influence over their innovation agenda. The adoption of innovation by contractors was due to site-specific issues, with one contractor stating "*We look for innovation when we are forced to"* and to improve internal efficiencies. Tighter bonds of trust are held between consultants and clients, whilst the contractors are largely left on the outside. The contractor participants confirmed this, stating a hierarchal relationship wherein contractors are thought of as *"low level tradespeople"* by the professional practises. This is an unfortunate cultural aspect that predominates within the industry, creating a further innovation void.

The construction industry is known to be especially susceptible to macroeconomic effects which bring about the “Boom-Bust” cycles which so heavily affect the industry. These pronounced cycles also appear to be a driver of low investment in innovation in NZ. Four participants stated that implementing new innovation in the midst of the current boom was difficult. One participant stated *“Companies don't have the financial flexibility to take a long term view, they are just peddling to keep up in a boom and peddling to hold on on the way down”* .

DIFFUSION OF LPS

It is believed that Lean Construction and LPS is currently confined to a small number of the larger commercial and civil contractors and has not yet widely diffused throughout the NZ construction industry. All of the consultant and owner participants were *not at all familiar* with the terms. With one contractor being *not at all familiar* with both terms, one being *slightly familiar* with both terms, while the third contractor was *moderately familiar* with both, having had limited practical experience using the system on one project. The wider social systems in which organisations operate have not yet embraced the Lean Construction philosophy. Meaning that through the communication channels open to them, the innovation has not been spread. This deduction is made on the finding that each participant, as a director or high level manager, maintains wide-reaching professional networks, all read industry related publications and attend numerous industry related seminars or conferences per year. A distinct lack of knowledge and understanding about Lean Construction across the wider industry is therefore inferred.

The contractor who did have practical experience in using LPS was engaged as a subcontractor operating alongside one of the largest construction firms in NZ, on a major infrastructure project. This participant also worked for the largest company interviewed. It would seem that the diffusion of LPS throughout the industry is confined to organisations who’s social systems overlap the larger companies currently implementing LPS. The participant was full of praise for the system, especially the improved communication channels. The participant made the comment *“We liked it because it gave us some certainty,”* although the firm had not yet been persuaded by the experience to adopt LPS internally.

Based on the researcher’s explanation of LPS, all participants stated they believed that LPS could provide improvements on projects currently in progress and to their organisation as a whole. Many believed LPS could provide numerous benefits to current industry standards of operation. Seven participants stated that they would undertake further research on LPS, seeing great value in the adoption of elements of LPS across their organisations, with participants stating:

“I think we could embrace this as an innovation”

“I’ll be honest and say that I hadn't considered this concept before but as you have explained it, it makes total sense”

“I think the system would give the investor a more positive influence over the project team, which I think is good for the health of a project”

IMPLEMENTATION OF LPS

THE MASTER PLAN

All participants were skeptical about the practical implementation of certain elements of the system. Implementing the *Master Plan* was thought to present the most challenges. This is based on an ingrained culture of mistrust and scepticism which exists between consultants and contractors across the industry. Participants stated that the traditional methods of procurement inhibit the early contractor involvement required within the Master Plan stage of the system, with two consultants stating;

> "*Contractors thrive on the confusion of a large land development project and are reliant on variations to make money, if they saw there was a way for projects to run more smoothly they may get scared about that*"
> "*The big and experienced contractors are very careful of being open, lest they disclose where they may be able to achieve variations*"

One contractor stated that early involvement form his side was fraught from the outset as engineers and architects believe themselves to be superior to contractors. Being treated on a similar level and having his company's concepts and ideas taken seriously wasn't something he was accustomed to. The views presented above by the consultantswere also inferred by the contractors, with one stating;

> "*A lot of contractors would say, I don't want to pass over my intellectual property to a designer*"

If the implementation of LPS is to be achieved in NZ from project initiation, stakeholders should keep an open mind, especially around the use of advanced forms of contract which encourage cooperation between the project team. Alliance contracting has been shown to be effective within NZ when undertaking public infrastructure projects (Skellern 2016). There appears to be no reason as to why the wider NZ construction industry could not acknowledge the benefit of such forms of progressive contracting. There is a perception that alliancing is reserved solely for large scale infrastructure projects, however its potential positive influence extends across the industry. Mathews & Howell (2005) suggest a relational contracting approach designed specifically around the collaborative principles of Lean Construction called Integrated Project Delivery (IPD). Under IPD the project owner, architect, engineers, main contractor and key subcontractors are united together under a single relational contract called an Integrated Agreement. Profit and risk is shared between the integrated team based on pre-determined agreements and formulas. Projects utilising IPD have been shown to produce amazing results when implemented successfully (Lichtig 2006).

REMAINING ELEMENTS

The participants perceived that reverse phase scheduling would be the most straightforward tool to implement. They believed that the project team could be brought together in the post-tender stage of a traditional contract to create the most relevant and workable project program. Implementation of the in-construction elements of LPS, the look ahead plan and the weekly work plan were viewed by participants with scepticism. There was a disconnect between consultants and contractors as to whose responsibility it would be to implement and manage the day-to-day running of LPS on site. Both parties were wary of the buy-in required from all stake holders and saw this as a limiting factor to successful implementation. Two interviewees stated implementation should be client-driven, as they are the ultimate benefactor of reduced project cost and running times. However, making clients aware of the system is seen as a huge challenge, especially as Lean Construction and LPS is yet to widely diffuse throughout the industry. One participant suggested a solution of introducing professional consultants to the project to teach and co-ordinate the system, noted in the literature as vitally important to successful implementation.

All participants bar one thought that the widespread adoption and implementation of LPS as a fully integrated system within the NZ construction industry was a difficult proposition. In summary, the research participants shared key sentiments regarding the implementation of LPS in NZ; the system is a fundamental change in thinking to nearly all aspects of the project lifecycle, requiring buy-in from all stakeholders; the NZ construction industry is resistant to change, with ingrained cultures of operation making the adoption of innovation slow. The factors stated by participants relate directly to a vital explanation in the literature of the industry’s low level of innovation adoption - that the construction industry is vastly more complex than most.

CONCLUSION

The research found that the adoption of innovation within the NZ construction industry is fraught with the same complexities which see slow rates of innovation the world over. These complexities see the status quo maintained and only gradual advancements achieved over time. The study suggests that knowledge levels of Lean construction and LPS are low across the wider industry, and there was a great deal of apprehension shown by participants about the chances of its widespread adoption throughout the industry.

If the NZ construction industry is to see improvements in construction productivity, deemed vital by The Productivity Partnership in 2011, it is proposed that increased adoption of Lean Construction principles and LPS across the industry is required. The paper presents a number of ways which could advance the diffusion and adoption of Lean Construction & LPS throughout industry:

1. Improved platforms of engagement between academia and industry. This would enhance networking as a means to incubate research collaboration on Lean Construction, also boosting levels of wider innovation within the industry.
2. A greater role played by Universities in facilitating adoption, largely through the undertaking of empirical research on the implementation of the LPS, to demonstrate that benefits are not confined to overseas organisations.
3. The Government as a driver of Lean Construction, through promoting awareness throughout the industry, as a sponsor of academic research and through incentivising its use within the industry. Ultimately change should be industry driven, however, due to the economic benefit proposed by increased construction productivity, a proactive approach should be taken by central government.

4. Little research has been undertaken into the marketing and advertising of Lean Construction and LPS as means of improving its diffusion throughout an industry. Much could be done to increase the flow of Lean Construction knowledge throughout NZ.

The incorporation of Lean Construction principles and LPS as standard practise within the industry could see a hugely positive transformation of the NZ construction industry. As well as boosting productivity it would serve as a driver of industry wide innovation growth.

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EXPLAINING THE BENEFITS OF TEAM-GOALS TO SUPPORT COLLABORATION

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ABSTRACT

The importance of a collaborative environment to achieve success in projects has been widely discussed in the literature and different mechanisms have been developed and introduced to support a collaborative approach to construction projects, i.e. new forms of agreement, new office arrangements, financial incentives, a shared risk and reward approach, the development of shared goals, etc. However, the literature related to these mechanisms is predominantly prescriptive, with little evidence and justification on why some of these mechanisms might be important to support collaboration. In this paper, we focus on discussing the development of shared goals as a means to support collaboration. We collected findings from two case studies in which an explicit process for goal setting and tracking was used to emphasize a collaborative environment. The technique used in these projects are not new and have been documented elsewhere. However, the benefits of these kind of techniques to support collaboration have not been fully explored in the lean construction community. Thus, the intent of this paper is to report some of the benefits that a goal setting exercise brought to two construction projects while having a theoretical discussion to explain why such process can be beneficial and should also be considered - along with other mechanisms - as an important element to support collaboration.

KEYWORDS

Collaboration, commitment, goals-setting, process, vision

INTRODUCTION

Collaboration can be understood as an "interorganizational relationship with a common vision to create a common project organization with a commonly defined structure and a new and jointly developed project culture, based on trust and transparency; with the goal to jointly maximize the value for the customer by solving problems mutually through

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interactive processes, which are planned together, and by sharing responsibilities, risk, and rewards among the key participants" (Schöttle et al 2014).

Past research advocates that to support collaboration, teams should share a common vision and define shared goals (Appley and Winder 1977, Mattessich and Monsey 1992, Schrage 1995). Past studies within the IGLC community have demonstrated that continuous improvement efforts that include an explicit goal-setting and progress tracking process can support the establishment of team priorities, enable candid conversations and collective problem solving, as well as improve interpersonal relationships (see Tillmann 2014a, 2014b). However, those studies do not explicitly highlight the contributions of a goal setting and tracking process for collaboration from a theoretical standpoint.

Thus, the aim of this research was to understand the theoretical contributions of an explicit process for goal setting and progress tracking to support collaboration. To answer this question, a literature review was carried out to explain the theory of collaboration. Then a framework with the key characteristics of collaboration was developed to support the analysis of empirical data. Two case studies that used a similar process described in Tillmann 2014a and 2014b were analyzed. Findings are presented in this paper with the accompanying theoretical discussion.

LITERATURE REVIEW

COLLABORATION AND GOALS

Schöttle et al. (2014) analyzed the literature between 1977 to 2014 to understand the difference between cooperation and collaboration and concluded that cooperation and collaboration can be described as a continuum where cooperation is on end and real collaboration on the other end. Between both ends different concepts exists, which weren't further detailed. Their conclusion relies on the Wood and Gray (1991) definition that collaboration requires "shared rules, norms, and structures, to act or decide on issues" and on the approach of Denise (1999), Sioutis and Tweedale (2006), Camarinha-Matos et al. (2009), and Podean et al. (2011) that collaboration is a "shared creation." Besides, collaborations are temporary (e. g. Schrage 1995, Kumar and van Dissel 1996, Denise 1999, Sioutis and Tweedale 2006, Garmann Johnsen and Ennals 2012), because if the purpose is fulfilled the collaboration ends (Schöttle et al 2014), and fragile, because of the development process which usually contain complex dependencies (Wood and Gray 1991, Kumar and van Dissel 1996, Thomson and Perry 2006, and Huxham 2006). Thus, collaboration "emerges over time, while actors interact formally and informally with each other to create new rules and structures" (Schöttle et al. 2014 based on Thomson and Perry 2006, and Thomson et al. 2009). Therefore, to develop collaboration many authors argue that common goals are required (Appley and Winder 1977, Mattessich and Monsey 1992, Schrage 1995, Kahn 1996, Huxham and Vange 2000, Huxham 2006, Camarinha-Matos and Abreu 2007, Camarinha-Matos et al. 2009, and Garmann Johnsen and Ennals 2012). For example, Mattessich and Monsey (1992) state that beside others "concrete attainable goals and objectives" as well as a "shared vision" are success factors of collaboration. Also, Schrage (1995) names a shared understood goal as a success factor for collaboration.

Nevertheless, because Schöttle et al. (2014) point out that the terms cooperation and collaboration are used interchangeable, the purpose of this paper is not to make a distinction between these two terms nor will this paper define the degree of cooperation or collaboration the teams of the two cases achieved. In accordance to Schöttle et al. (2014), we argue that full collaboration is the perfection of working together; a target which teams strive to achieve, but never totally achieve. Therefore, the object of this paper is to justify the use of tools which help to develop collaboration

GOALS, GOAL-SETTING, AND GOAL COMMITMENT

Widmeyer and Ducharme (1997) define goals as "guides for action." Johnson and Johnson (2009) agree with Widmeyer and Ducharme (1997) and explain that beside that, goals are important, because they motivate behavior, provide the basis for conflict resolution, and prerequisite for assessment and evaluation. Latham and Locke (2006) define goals as "a level of performance proficiency that we wish to attain, usually within a specific time period." Furthermore, they state that goals regulate behaviors, increase efforts, encourage the search for strategies, and give a meaning to a task as well as accomplishment and therefore goal-setting gives direction and affect action (Latham and Locke 2006) and specify goal-setting as a "discrepancy-creating process, in that the goal creates constructive discontent with our present performance" (Latham and Locke 2006). Latham and Yukl (1975) define goal-setting as a mean to improve performance. Then again, setting goals is based on importance and self-efficacy (Locke and Latham 2002, Latham and Locke 2006) and affected by leadership (Locke and Latham 2006).

By reviewing the literature of goal-setting theory Locke (1996) argue that the more difficult and specific goals are the more critical is the commitment for achieving the goal, but the higher is the performance if the commitment is there. The commitment in turn depends on the importance and the attainability of the goal for the individual commitment giver as well as the self-efficacy to accept feedback that helps to set and perform goals (Locke 1996). Therefore, Locke (1996) defines goal commitment as "the degree to which the person is genuinely attached to and determined to reach the goals." This in turn depends on whether or not goals are assigned or self-set. Hinsz (1995) summarize that goal commitment is assured if individuals feel somehow involved in the selection of assigned goals or if it is ensured that self-set goals are specific and challenging and e. g. Locke (1996) and Locke and Latham (2006) explain that assigning goals without explanation result in less commitment. Thus, goal commitment is important link goal and behavior (Klein et al. 2001). Besides, when implementing a goal setting and tracking exercise it needs to be considered that the process is influenced by past experience and affected by direction, persistence, effort, and training to not fall back to old habits (Locke 1996).

GROUP-GOAL-SETTING AND EVALUATION

Johnson and Johnson (1987) define a group goal as "a future state of affairs desired by enough members of a group to motivate the group to work towards its achievement."

Zander (1971) explains that although an agreement among the group exists, team goals consist of four types of goals (1) group goals, (2) group goals for members, (3) members goals for self, and (4) members goals for group, and that those individual and group goals are in a circular relation to each other. Team goals help the group to stay focused (Johnson and Johnson 1987), can increase team cohesion (Johnson and Johnson 1987, Widmeyer and Ducharme 1997) and team effectiveness (Widmeyer and Ducharme 1997). To achieve commitment regarding group goals Johnson and Johnson (2009) identified two ways: (1) goals have to be specific, trackable and measurable, achievable and challenging, relevant to the members, and transferable to other situations, or (2) goals need to be formed together by the group. Besides, the desirability of a goal and the relation of the team impact the commitment (Johnson and Johnson 2009). Pritchard et al. (1988) argue that systems which are developed by their users are much more effective as systems which were imposed top-down, because involved participants are much more aware about their issues and needs to design a functional process. Durham et al. (1997) suggest that "teams engaged in new, complex tasks should be allowed to set team goals, even if formal goals are assigned. Team-set goals are more likely to lead to effective performance, because they take into account what teams believe they can achieve." Furthermore, Seijts and Latham (2000) found that the larger the group the more important it is (1) to align individual and group goals, (2) fostering the collective beliefs of efficacy, (3) to increase the belief that collaboration results in positive outcomes, and (4) to develop commitment to group goals to avoid the occurrence of social dilemma.

RESEARCH METHOD

A case study approach was chosen for this research as it allows for a deep understanding of the subject (Yin, 2014). The aim of the case studies was to collect empirical data that could support the evaluation of a goal-setting mechanism and its contribution to the different elements that constitute a collaborative environment. Two case studies were carried out. Both cases had limited ability to introduce other mechanisms to support collaboration (i.e. multi-party agreements, shared financial structure). However, in both cases, a goal setting and tracking exercise was utilized.

In order to support data collection and analysis, an analytical framework was developed based on the reviewed literature (Table 1). Data was mainly collected through interviews. The interviews were carried out in November 2014[3]. Participants of the interviews were the owner, general contractor, and the architect in case 1 and project manager and general contractor in case 2. Open-ended questions were asked regarding the project delivery system, implemented methods and tools as well as about the working environment. Afterwards the interviews were transcript and based on Mayring (2010) and Kuckartz (2014) qualitative content analysis used to analyze the interviews.

[3] The interviews were collected, transcript, codified, and analyzed by the first author as part of her PhD thesis.

Table 1: Observed collaboration characteristics

Observed characteristics	Case 1	Case 2
Inter-organizational relationship	x	x
Common vision	x	x
Common project organization	x	x
Commonly defined structure	x	x
Jointly developed project culture	x	x
Trust	x	x
Transparency	x	x
Jointly maximize customer value	x	x
Interactive processes, which are planned together	x	x
Sharing responsibilities	x	x
Sharing risk and rewards	x	x

CASE STUDIES DESCRIPTION AND FINDINGS

The two case studies in which a goal-setting and tracking exercise was carried out were both Laboratory renovations. The first project was the renovation of an anatomy teaching lab on the 13th floor of an occupied building (US$ 7.4M, substantial completion in August 2012). The second case was a project to remediate the existing plumbing and electrical system underneath the first floor (US$ 21.4M, substantial completion June 2014). In both cases, a traditional construction management at risk contract was used, with no arrangements to share risks and rewards, no multi-party agreement and no co-location.

On both public projects, different tools and techniques were implemented by the general contractor (which was the same in both projects). Those include: Last Planner System, Building Information Modelling and a shared goal-setting and tracking exercise to support collaboration. The participants of the self-setting goal and evaluation process are summarized in Table 2.

Table 2: Participants of the goal-setting and tracking process

Participants	Case 1	Case 2
General contractor	x	x
Owner and facilities maintenance	x	x
Project manager (external consultant owner)	x	x
Architect	x	-
Design team	x	x
Main subcontractors	-	x
User representative	x	-

The process included a series of workshops to develop an agreed upon vision and a periodic review of progress towards the goals, in which project participants would discuss current status and opportunities. Figure 1 shows the PDCA-cycle of the implemented process. Further explanation can be found in Tillmann (2014a, 2014b).

The vision established by the team reflected specific goals that needed to be achieved. These included project goals such as to be on time and on schedule and to incorporate built in quality. Besides the typical project goals, the team set specific goals to support the working environment. For example, one goal was "having fun".

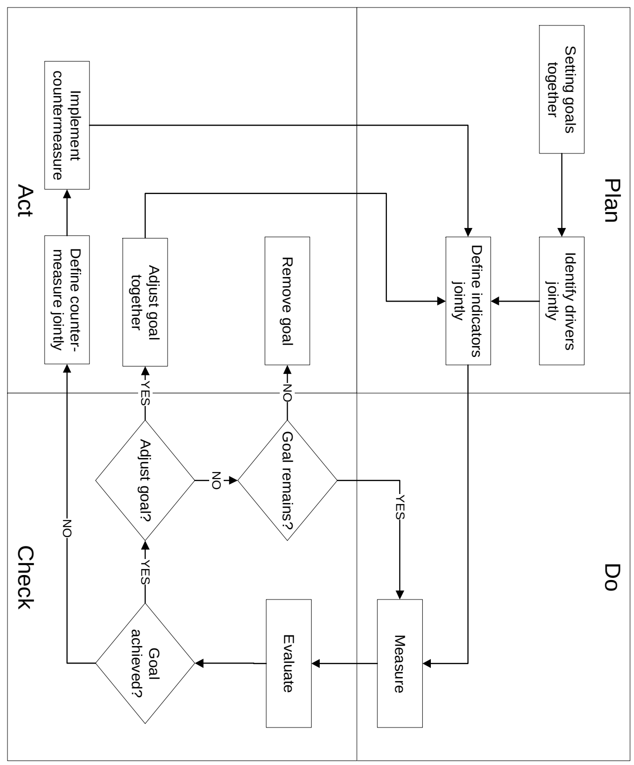

Figure 1: PDCA-cycle of goal-setting and tracking process

To track progress, team used both quantitative (i.e. expected vs. actual costs, expected vs. actual schedule performance) and qualitative data. Qualitative data was gathered through surveys and focused on the opinion of team members, especially regarding soft aspects of project management (i.e. teamwork, fun, building relationships, etc.). In case that there was a discrepancy between goal and progress, countermeasures were defined and implemented. If the team evaluated that "having fun" was not achieved one countermeasure would be to have lunch together and establish a rule to not talk about work during lunch time, for instance. Instead, people would talk about their private life, which contributed for increased empathy and stronger relationships.

Interviewees mentioned that some progress measurements should have been defined more clearly, and that goals such as building new relationships needed to be adjusted, because they change over time. Figure 1 shows how goal adjustment should be included as part of the process. Furthermore, it was stated that the individual evaluation of goals which were not self-set were difficult. This aligns with the statement of Locke and Latham (2002) and Latham and Locke (2006), who argue that goals need to be relevant for the individual. Thus, if a lack of identification occurs, the measurement needs to be clearly defined and might be adjusted in terms of group evaluation than by every individual. Despite these opportunities for improvement, project team members highlighted major benefits of this process for enhancing collaboration. These included:

- Open and increased communication among team members;
- Aligned expectations and improved team focus;
- Possibility to communicate dissatisfaction, talk about frustration and address issues;
- Smoother workflow;
- Development of an understanding of different personalities, while building relationships;
- Developing collaboration and building Strengthened trust; and
- Influenced the working environment and improved satisfaction.

DISCUSSION

Even though the characteristics of these case studies differed from the projects analyzed by Tillmann (2014a, 2014b), i.e. no integrated agreement, no arrangement to share risks and rewards, positive results were found. Teams observed improved relationships, greater empathy, an enhanced ability to candidly talk about problems and engage in problem-solving to support continuous improvement. This study provides further evidence that support the findings of other authors. As different studies point out, a goal-setting and tracking exercise which is carried out by project teams themselves increased communication and coordination (Johnson and Johnson 2009) and served as a “guide for action” (Widmeyer and Ducharme 1997). Furthermore, setting goals motivated the team (Widmeyer and Ducharme 1997, Locke and Latham 2006) and provided the basis for conflict resolution (Widmeyer and Ducharme 1997).

Table 3 gives an overview of collaboration characteristics based on the definition of Schöttle et al. (2014).The authors evaluate the table, based on their observation and on the interviews. It can be seen that the goal-setting and tracking process impacted collaboration, despite the fact that not all supporting mechanisms were in place, i.e. multi-party agreements or shared risks and rewards. Therefore, the goal-setting and tracking exercises were critically important for helping to align the different parties with respect to 7 out of 11 mechanisms that are considered desirable for supporting collaboration.

In the process of agreeing on goals, expectations were clarified, and the team got a better understanding of each other’s perspective. Moreover, targets were defined bottom-up, so that the different team members identified themselves within the goals (as previously observed by Locke (1996). Setting and tracking also social goals helped the team members to pay more attention to issues regarding the working environment and define countermeasure for team building on time. Overall, the goal measurement helped to see if things were going in the right direction or if the team needed to change something to be on track. Thus, in accordance to the literature review, the collaboration among the team members developed over time (Schöttle et al. 2014, Thomson and Perry 2006, Thomson et al. 2009), because they shared goals, informally interact with each other, opened up the discussion about what was important for their performance and based on that discussion, developed rules and norms to proceed in the right path.

Table 3: Affected collaboration characteristics

Affected characteristics	**Case 1**	**Case 2**
Inter organizational relationship	Yes	Yes
Common vision	Yes	Yes
Common project organization	No	No
Commonly defined structure	No	No
Jointly developed project culture	Yes	Yes
Trust	Yes	Yes
Transparency	Yes	Yes
Jointly maximize customer value	Yes	Yes
Interactive processes, which are planned together	Yes	Yes
Sharing responsibilities	No	No
Sharing risk and rewards	No	No

CONCLUSION

This paper provides greater insight into what collaboration means from a theoretical standpoint and greater support on understanding why goal setting exercises are important. Furthermore, it provides evidence that support past studies and reinforces the understanding of the contribution of establishing common goals in construction projects, even when companies are not aligned commercially. A goal-setting and tracking processes makes explicit important issues which are usually not verbalized by project teams. By clarifying goals and defining actions jointly, individuals focus on problem solving and achieve a greater alignment among themselves. Thus, the effect of the goal-setting and tracking process described here with respect to collaboration is high, even in traditional project arrangements. Some limitations include: the research did not consider the role of leadership during the team goal-setting and tracking exercises, and it did not differentiate between assigned, participative, and self-set goals. Therefore, additional research about goal-setting and tracking to understand and improve the process and to enhance collaboration is necessary.

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IMPACT OF GENDER BIAS ON CAREER DEVELOPMENT &WORK ENGAGEMENT IN THE OAEC INDUSTRY & LEAN PRACTICE

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ABSTRACT

This paper examines findings from a gender bias study in the Owner, Architecture, Engineering, and Construction (OAEC) industry. By definition, a bias is a deviation from what is normal, which is defined by social norms. If different attitudes towards male vs. female co-workers exist, then one group may gain subtle yet impactful advantages in career development and work engagement. To what extent does this happen within the OAEC industry, including lean construction practice? While several industries studied the negative impact of gender bias on women in the workplace, this has not been studied in the lean construction community. Thus, this study fills the gap. Lean is based on respect for people and continuous improvement. Do these principles translate into more equitable experiences in promoting ideas, and in career development and work engagement for men and women in the OAEC industry? Regardless, if gender biases are acknowledged, then what programs exist or might exist to provide support to the disadvantaged group and level the playing field? The authors addressed these questions by administering a survey over social networks. This paper highlights initial results to raise awareness of the existence and impact of gender bias and begin exploring methods to overcome it.

KEYWORDS

Gender Bias, Career Development, Work Engagement, Lean, Respect, Change Management

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INTRODUCTION

A bias by definition is a deviation from what is normal, where "normal" is defined according to social norms. Bias can be conscious or unconscious, and it may manifest in subtle or obvious ways (d'Orgeville et al. 2014). The term "gender bias" is a preference toward or prejudice against one gender over the other. McLoughlin (2005) identifies three types of biases towards women: Type I is singling out with the intention to harm (overt sexism); Type II is doing so with neutral intentions (tacit sexism); and Type III, a new type of gender bias, is singling out women with the intention to help them. According to d'Orgeville et al. (2014), "the vast majority of gender-related issues in [Science, Technology, Engineering, and Mathmatics]STEM fields arise from the fact that many men and women were raised, educated and became STEM professionals in traditionally male-dominated societies." They explain that a male-dominated culture is evident throughout society, and it is often cited as why females are rarely represented at the level they should be based on their numbers alone.

Multiple studies document gender bias in STEM education (e.g., PCAST 2012; Menches and Abraham 2007; del Puerto et al. 2011) and workplaces (e.g., Slaughter 2012; Sandberg 2013). This paper focuses on the Owner, Architecture, Engineering and Construction (OAEC) industry, where relatively less work has been done. The OAEC industry is male-dominated; men occupy most of the top positions in OAEC organizations. According to Chun et al. (2009), women are reluctant to join the OAEC workforce as they experience discrimination when they apply for a job or when they join the workforce. Chun et al (2009) conducted a survey to evaluate perceptions of women in construction management (CM) positions and found that, "Female construction managers (CMs) perceive bias against them in the form of scepticism and indifference as a response to their gender." They also explain that most respondents believe female CMs are as effective as male CMs and the authors hypothesized that negative perceptions relative to women would dissipate as more women filled the CM workforce.

Gender bias seems contradictory to lean, which is based on the principles of respect for people and continuous improvement. As a result, this paper explores the extent of gender bias within the OAEC industry and specifically, within lean construction practice. The removal of gender bias barriers will, ultimately, result in organizations gaining a competitive advantage in today's global markets (Maskell-Pretz et al. 1997). Thus, in addition to exploring the extent in which gender bias impacts career development and work engagement, the authors also explore how OAEC organizations are working to combat gender bias. The balance of this paper presents survey methods and results and closes with conclusions that serve as a foundation for future research and discussion.

RESEARCH QUESTIONS AND METHOD

This paper seeks to address the following questions: Does gender bias exist in the OAEC industry? How does gender bias impact recruitment and promotion? How does gender bias impact work engagement? and Do lean principles translate into more equitable experiences in career development and work engagement via lean construction practice?

The authors used a survey as the research method to answer these questions, distributed the survey over professional networks (e.g., LinkedIn, Facebook, Xing, and e-mail), and received answers from both men and women working in the OAEC industry.

The survey consisted of 19 questions grouped into five sections: (1) general information of the respondent and overall perspective on gender bias; (2) recruitment process; (3) promotion process; (4) work engagement via the reception to new ideas; and (5) programs in organizations to overcome gender bias. The authors analysed survey results in two ways – multiple-choice questions with yes/no answers and likert scale responses summarized using frequencies. Then, we summarized and generalized open questions, which is a method frequently used in Social Science (e.g., Mayring 2014).

RESULTS

Of the 153 survey responses, the authors removed one respondent who was not a part of the OAEC industry. Of the remaining 152 valid responses, 53% were women and 47% were men. 65% of the men and 44% of women reported being a parent.

In terms of OAEC industry experience, 8 respondents had less than 2 years, 26 had 2 to less than 5 years, 30 had5 to less than 10 years, 47 had 10 to less than 20 years, and 41 had more than 20 years. Survey respondents represented several countries: 46 from US; 29 from UK; 17 from Spain; 16 from Denmark; 11 from Germany; 4 each from Canada, Chile, and Brazil; 3 each from Finland and Ireland; 2 each from Australia, Mexico, and Norway; and 1 each from Argentina, Austria, Cameroon, Ecuador, Estonia, Greece, Hong Kong, Iran, and Israel.

The authors recognize that this is not a statistically representative sample of the OAEC industry. However, the participation of respondents from different levels of experience and geographical areas represent a diverse pool of professionals that provide some important conclusions and discussions about the questions being asked.

GENERAL PERCEPTION ON GENDER BIAS

The results show that 75% of women vs. 62% of men feel positively affected by their gender, but only 13% of women vs. 27% of men frequently or very frequently feel positively affected by their gender(Figures1 and 2).

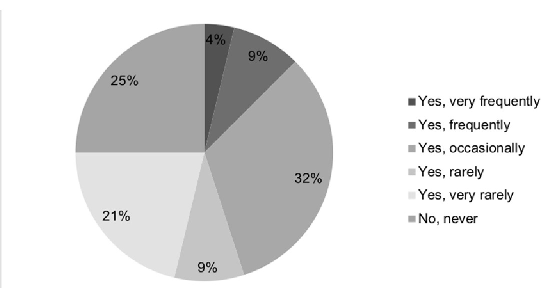

Figure 1: % of women who feel positively affected by their gender

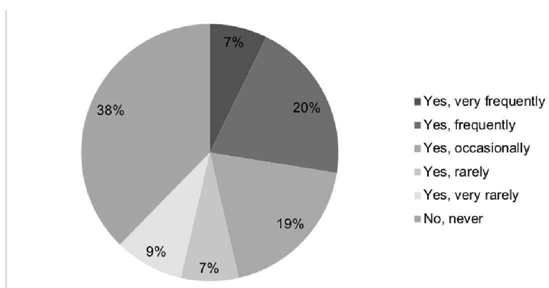

Figure 2: % of men who feel positively affected by their gender

In contrast, 89% of women vs. 21% of men feel negatively affected by their gender, and 32% of women vs. 0%of men frequently or very frequently feel negatively affected by their gender (Figures 3 and 4). These results demonstrate that women feel the negative and positive effects of their gender more often than their male colleagues.

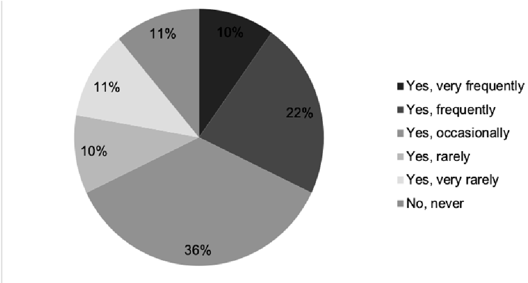

Figure 3: % of women who feel negatively affected by their gender

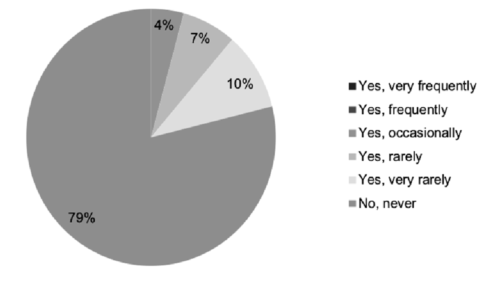

Figure 4: % of men who feel negatively affected by their gender

LEAN EXPERIENCE OF SURVEY RESPONDENTS

Since the authors specialize in lean research and practice, and we reached out to our professional networks to recruit survey respondents, half of all survey respondents have significant lean experience in their jobs (28% report implementing lean tools and methods very frequently and 22% report implementing them frequently). There is no significant difference between genders in terms of lean experience: 47% of women vs.52% of men reported working in a lean environment.

IMPACT OF GENDER BIAS ON CAREER DEVELOPMENT

Recruitment Process

About 16% of all survey respondents reported experiencing rejection in a recruitment process because of gender bias. When broken down by gender, 26% of women vs. 4% of men reported experiencing rejection in a recruitment process because of gender bias. This indicates that women are 6 times more likely to be rejected during recruitment because of their gender compared to men.

When asked for specific examples that illustrate rejection during recruitment, respondents provided more insights about this issue. The only male recruitment rejection example emerged when one male respondent noted that women are preferred for office roles, so he experienced problems when he applied to one of those positions. In contrast, female recruitment rejection examples ranged from directly receiving inappropriate comments such as “This is not a job for women,” to more subtle questions (or micro-aggressions) about plans to have children. Other female respondents reported being unsure about whether they were not selected due to being a woman. Quotes that highlight these perspectives include:

- *“In 1975 I was told being a female was a disadvantage and again in 1982 but not since then”*
- *“Passed over frequently for less qualified males, penalized for things beyond my control or that were the fault of a male”*
- *“When much younger, I had direct questions from an interviewer about why a woman would want to be an engineer - and was then hired for the job. At another*

firm, the principal never sent me [to a] *construction site job because he didn't think the foremen would treat me with respect / implement my recommendations"*

- *"I'm not sure if it happens to me but I believe in the recruitment process, the possibility of being* [a] *mother* [doesn't] *help us to 'open doors' to a new opportunity of a job"*
- *"I've been asked always about maternity, if I was thinking about having children, I was warned about the maternity leave of the company. When I said I wanted to be on site, I was told this was so hard for a woman"*
- *"I was qualified for the position I was applying, however, a male potential worker was employed"*

Promotion Process

17% of all survey respondents reported being delayed in a promotion due to gender bias. When broken down by gender, 32% of women vs. 0% of men reported being delayed in a promotion due to gender bias. In other words, one-third of female respondents experienced promotion delays due to gender bias, and only women experienced being delayed in a promotion due to gender bias.

Specific promotion delay examples include: seeing less qualified male colleagues get promotions before them, differences in salary found by chance, reluctance to give titles/positions of power to women doing the same job as men, and some women who are not sure they have experienced promotion delays due to a hidden evaluation process. Quotes that highlight these cases and reinforce the existence of gender bias include:

- *"I had more experience than an older male colleague but due to his age and sex was told that I couldn't go higher than him. My female line manager told me this."*
- *"I was one of two graduates from* [the same university] *hired for the same role, with the same experience. The male candidate was offered $5000 more than me annually."*
- *"Possibly. It's hard to know for sure what the reasons are when you don't get a promotion as quickly as expected"*
- *"Non-licensed individuals were promoted before me, a licensed individual"*
- *"They do not tell it straight, but all the guys played golf or football with the bosses, became friends and got the promotion thanks to becoming sport mates, they increased their profile and possibilities."*
- *"In the 1990s, I was leading a team of estimators, but was never given the title Chief Estimator. As soon as I left the company, the man I had trained was named Chief Estimator.*
- *"I strongly believe that my male co-workers were promoted before me and make more money than me."*
- *"As a female, I am super conscientious and will work the hours needed to complete the work, and not complain about the pay. Management takes advantage of this, as I have seen less hard-working men promoted and given."*
- *"There is a guy in my company who is 10 years younger, has really much less knowledge and no special expertise, but has the same position as I do."*

IMPACT OF GENDER BIAS ON WORK ENGAGEMENT

According to Schaufeli et al. (2002), "a positive, fulfilling, work-related state of mind that is characterized by vigor, dedication, and absorption". As a result, to begin investigating the impact of gender bias on work engagement, the survey asked respondents if they had ever experienced the sensation that their ideas were not taken that seriously because of their gender.

36% of all survey respondents reported experiencing the sensation that their ideas were not taken that seriously because of their gender (Table 1). When broken down by gender, 62% of women vs. 4% of men reported experiencing the sensation that their ideas were not taken that seriously because of their gender.

Dueto this stark contrast, we then evaluated the results according to the intensity in which the respondents were involved in lean practice. Earlier, we noted that 28% of respondents reported implementing lean tools and methods very frequently and 22% reported implementing them frequently. We characterize these respondents as "Intense Lean" practitioners vs. those that are not (including respondents that reported implementing lean tools and methods occasionally, rarely, very rarely, and never).

Might these intense lean respondents encounter less rejection of their ideas because they were working within a lean environment that would prioritize respect for people and continuous improvement? Or would these intense lean respondents instead encounter more rejection of their ideas since respondents that implement lean very frequently and frequently tend to be involved in the role of a change agent, so there is a higher likelihood that their ideas involve asking their co-workers to try a different approach or method for completing a specific work task but their co-workers remain resistant to change?Yet another facet to consider – are intense lean respondents more observant of their co-workers actions, comments, and moods during meetings or work sessions (Flores 2016) and thus be more attuned to the subtle sensation that their ideas were not taken that seriously because of their gender?

The results revealed 39% of intense lean respondents vs. 32% of non-intense lean respondents reported experiencing the sensation that their ideas were not taken that seriously because of their gender (Table 1).

Table 1: Respondents that experienced the sensation that their ideas were not taken that seriously because of their gender (according to gender or intensity in lean practice)

Ideas not taken seriously	All	Women	Men	Intense Lean	Non-Intense Lean
Yes	54	51	3	29	25
No	98	30	68	46	52
Yes [%]	36%	62%	4%	39%	32%

Thus, while the gender of respondents had a major correlation to the likelihood they would report experiencing the sensation that their ideas were not taken that seriously because of their gender (62% of women vs. 4% of men), the intensity in which the respondents were involved in lean practice only had a minor correlation (39% of intense lean respondents vs. 32% of non-intense lean respondents). Table 2 breaks down the analysis further to help reveal additional insights.

Table 2: Respondents that experienced the sensation that their ideas were not taken that seriously because of their gender (according to gender + intensity in lean practice)

Ideas not taken seriously	All	Women + Intense Lean	Women + Non-Intense	Men + Intense Lean	Men + Non-Intense Lean
Yes	54	27	24	2	1
No	98	11	19	35	33
Yes [%]	36%	71%	56%	5%	3%

Table 1 and 2 reveals: (1) Compared to their male colleagues, women are 17 times more likely to experience that their ideas are not taken that seriously,(2) Compared to their intense lean male colleagues, intense lean women are 13.5 times more likely to experience that their ideas are not taken that seriously,(3) Compared to their non-intense lean male colleagues, non-intense lean women are 24 times more likely to experience that their ideas are not taken that seriously.

Even though this survey is addressing the respondents' perceptions, and there is no plausible way to verify every claim made, it is alarming that 62% of women feel that their contributions are not taken seriously and this value increases to 71% for women involved in intense lean practice. This finding might be related to a recent study indicating that in departmental talks with roughly the same amount of men and women attending, men ask 2.5 times more questions when compared to the women attending these events, and they also usually ask the first question. The difference in the number of questions asked by people from both genders disappears when a woman asks the first question and other women follow suit (The Economist 2017).

In total, 42 women (52%) provided examples of occasions when their ideas were not taken that seriously because of gender. Most respondents claimed that their male colleagues are not listening to /are ignoring them, they are not taken seriously / are discounted, interrupted /spoken over, their male colleagues are repeating their ideas and being supported, and got the recognition for the idea.

PROGRAMS TO COMBAT GENDER BIAS

About a third of respondents stated that their organizations have a program to address gender bias, whereas two-thirds do not have such a program. The majority of programs reported were sessions for raising awareness about gender bias (34), mentoring (22), supporting colleagues (22), and coaching (10).

Women reported that programs that have worked for them in the past consisted of sessions raising gender bias awareness for men (12) and mentoring by males or females (10). Another large portion of respondents decided to address the problem of gender bias by working harder than men (5).

In terms of programs that respondents wished their organization implemented, both women and men proposed having sessions or conversations more frequently to raise awareness and establishing a more transparent and fair processes for hiring and promoting individuals. In addition, it was interesting to note that10 men and three women stated that these types of programs were not needed, and several men answered, “Do not know.” Some insights on gender bias programs from women include:

- *“I don't want programs, I just want it to be naturally ingrained in the daily work life. If something happens to me personally, I make sure to point it out to the offender(s)”*
- *“Talking openly about it (diversity) and ensuring there is an understanding from seniors that we are all equal”*
- *“More awareness for male colleagues. If the men we work with aren't aware of the issue, it's challenging for them to make corrections”*
- *“To oblige organizations to hire the same quantity and in the same conditions both men and women (gender equality)”*
- *“Human Resource selection process without names, photos, age…”*
- *“Programmes are not necessarily the answer, it's about changing behaviours”*

Examples of programs that men wish to have to deal with gender bias:

- *“Actions to overcome gender bias should start with the organisation identifying the extent to which employees feel affected by it, including details of why they feel that way, under what circumstances and how often. Running awareness sessions without first identifying these details could limit the intended positive impact.”*
- *“Raising awareness, education and discussion, should be more prominent in our organisation. This includes understanding a woman's perspective on the OAEC. IE what are the real issues that still need to be addressed and the perceptions that also stop women pursuing a career in OAEC. In our organisation, there is far too much of a bias in management towards men, to change this bias does require some positive action and a strategy agreed to achieve positive action.”*
- *“Equal salaries for equal jobs.”*
- *“This is very much a male dominated sector with an embedded culture. It will take time for females to be accepted into traditional male roles especially on site teams.”*

DISCUSSION

The survey respondents comprised of women (53%) and men (47%) representing 22 countries, and about half of the respondents implement lean in some form with varying degrees of intensity. By any measure, women perceive that their gender affects them negatively more often than their male colleagues and that is substantiated by other findings of this study. Female respondents in this population were six times more likely than male respondents to experience rejection in recruitment, and a third of them indicated that they experienced delays in the promotion processes due to their gender. Moreover, when it comes to sharing ideas, two-thirds of female respondents indicated that their ideas are not taken seriously, and in some cases, they report that these ideas are not taken seriously until a male co-worker proposes the same ideas or explainsit. Most female respondents report that they feel their ideas are ignored within the OAEC community, and this represents an important and urgent area for improvement. This discussion becomes even more timely and relevant within the Lean community when we consider that lean promotes respect for people and shared values and goals to promote continuous improvement. In a Lean environment, all should be respected for their ideas and contributions and feel safe and encouraged to share their thoughts.

Several people were aware of gender bias as an issue, however there is no consensus about how to fix the problem. Perhaps lean principles and tools can help with providing more transparency in the hiring and promotion processes. Future research is needed to understand how, for example, a more transparent and fair decision-making process such Choosing By Advantages could help beyond its current applications (Arroyo et al., 2016). In terms of promoting women's ideas, it is important to acknowledge that most of the examples given are perceptions, which may or may not be grounded in reality; these do not necessarily represent facts (Flores 2016). However, these perceptions of women's capabilities may be understood by men and women as facts, and may, in turn, be limiting career advancement opportunities for women. In addition, many men and women present a mood of resignation about the state of gender in the OAEC Industry, which inhibits a learning predisposition that is required to affect change (Flores 2016). Finally, categorically dismissing the ideas of any portion of the workforce, in this case, women, seems a poor strategy for continuous improvement; indeed, such behaviour limits the possibility of implementing lean principles.

CONCLUSION

The results of this study show women and men perceive gender bias in the OAEC industry. Often, this bias seems to negatively impact the working lives of women. Women perceive their gender as a reason to not be recruited or be delayed in promotion; women report (with alarming frequency) experiencing gender bias when sharing ideas.

Women that reported having implemented lean with higher frequency actually reported a higher percentage of their ideas not being taken seriously due to gender bias, this was counterintuitive to the researchers. Respondents might be in an environment that seems welcoming to new ideas; however, this study illustrates that regardless of lean implementation, women feel their ideas are not heard. This suggests that despite a "lean" culture promoted in some OAEC organizations, women do not feel heard.

Female respondents present more negative perceptions about gender bias and how this affects their work lives. Whether these perceptions are supported with evidence or not, which was not part of the scope of this research, these negative perceptions influence what women in the OAEC Industry think is possible or not in terms of career advancement and the pursuit of their ideas. Most male respondents recognize or observe gender bias in the OAEC Industry. Paradoxically, a larger portion of men compared to women think that gender bias is not an issue, and no programs or strategies are necessary for correction. However, the majority of men and women explicitly wish to have better programs or deliberate actions to overcome gender bias in the OAEC Industry. The most often suggested intervention is to raise awareness, and have more open conversations to share perceptions of gender bias.

More research is needed to understand how to implement interventions and programs to overcome gender bias. Further, the authors plan to conduct statistical analysis of the survey data to determine if any of the trends reported herein show statistical significance.

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INTEGRATED PROJECT DELIVERY FOR INFRASTRUCTURE PROJECTS IN PERU

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ABSTRACT

Integrated Project Delivery (IPD) implies a transformational change of the behavior and project's means and methods used by project participants. The aim is to break down the traditional silos of construction and to improve collaboration, communication, and alignment between different stakeholders of a project. As infrastructure projects are often more complex, integration is more necessary in these projects. In this paper, the authors explore introduction of the IPD concept and its strategies into infrastructure projects in Peru, and explore the contextual nuances of the adaptation of the concept and associated challenges. While some Lean construction concepts have been increasingly adopted in Peru with support of Peru's Lean Construction Institute, there is still a lack of knowledge in the market about IPD, its principles, and tools to facilitate implementation. The authors studied a company that recently aimed to change current practices through fostering co-location of stakeholders in early stages and involvement of key partners in early stages of decision-making. Evidence shows some challenges to overcome to effectively work collaboratively in a common space. This paper explores the maturity of the industry in Peru, identifies potential challenges for implementing IPD, and proposes steps to foster integration. Proposed steps include developing a sense of community and training participants in IPD related concepts, basic principles, means, and tools as well as incentivizing participants.

KEYWORDS

Integrated Project Delivery (IPD), Peru, infrastructure projects, integration, collaboration, early involvement, co-location, new market, developing countries.

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INTRODUCTION

During the 80's and 90's Peru suffered an economic crisis that limited investment in infrastructure projects (World Bank 2017). Consequently, the public construction sector slowed down and traditional delivery methods such as Design Bid Build (DBB) and Design Build (DB) dominated the market (Medina 2014). Today, the Peruvian economy is growing. The construction sector grew an average annual rate of9.7% in the last decade (INEI 2016). But the construction industry has been slow to respond to changes and continued with traditional processes. This is despite the fact that the need for investing in infrastructure projects is very high, and there is a need for change of practices to respond to this need.For example, more than 25% of the Peruvian population do not have access to drinkable water. Furthermore, as shown in Figure 1, there is a need for further investment for building projects in transportation, healthcare, energy, telecommunications, and education, with up to $1.6 billion (USD)estimated cost of meeting those needs (Bonifaz et al. 2015). As a result, the efficiency of the construction sector as the provider of infrastructure development is critical during this transition.

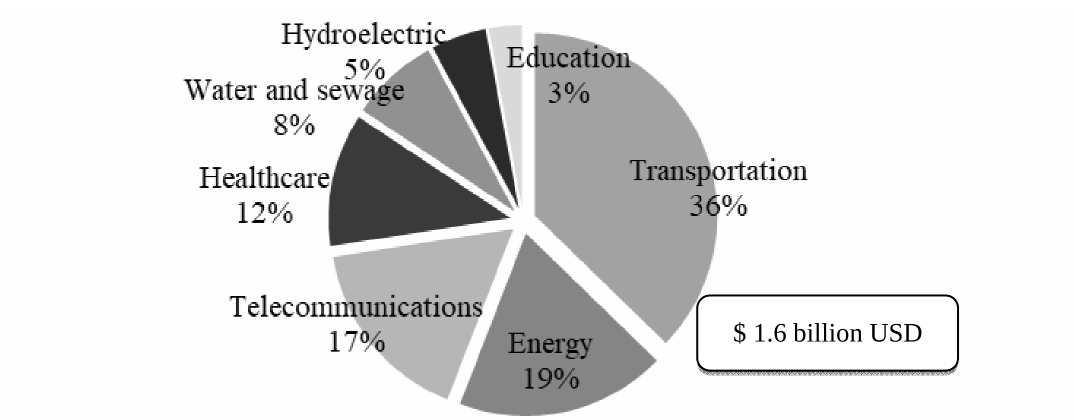

Figure 1: Infrastructure Gap in Peru (Bonifaz et al.2015, "A plan to get out of poverty: National Infrastructure Plan 2016-2025", AFIN)

Poor project performance and client dissatisfaction have been attributed to different causes such as fragmentation or "the silo effect" that obstructs coordination and integration (Walker et al. 2016; Xue et al. 2005), and lack of leaders who understand and commit to new systems (Fernandez-Solis et al. 2013). Similar issues have been reported in the Peruvian construction market; issues linked to the lack of integration and misalignment of goals between stakeholders (Canales 2014).

Integrated Project Delivery (IPD) has emerged as an alternative approach for delivering value to clients and improving overall project performance by aligning stakeholders interest and objectives (Mesa et al. 2016; Kim et al. 2016). Instances of IPD projects transitioning from an individual mindset to a collaborative approach have been documented by practitioners and academic researchers (Walker et al. 2016; Cohen 2010; Forero et al. 2015). Although IPD has primarily been applied to the design and construction phase of projects, an integrated project is shaped and delivered with an eye to the entire lifecycle of the constructed asset (Cohen 2010). Consequently, IPD is a good fit for infrastructure projects delivered in the form of private-public partnership (PPP) due their high complexity. One of the first practices that the company under study is fostering to make projects more integrated is co-locating major partners early in the project to work together. Early contractor involvement has been a feature of more advanced practice for some time, but adding co-location is intended to increase the benefits of that involvement, however, some challenges are observed in the process. The authors summarized a list of principles and tools (Fig. 2) that facilitate IPD implementation and present a detailed analysis of those which are being used in the Peruvian construction industry.

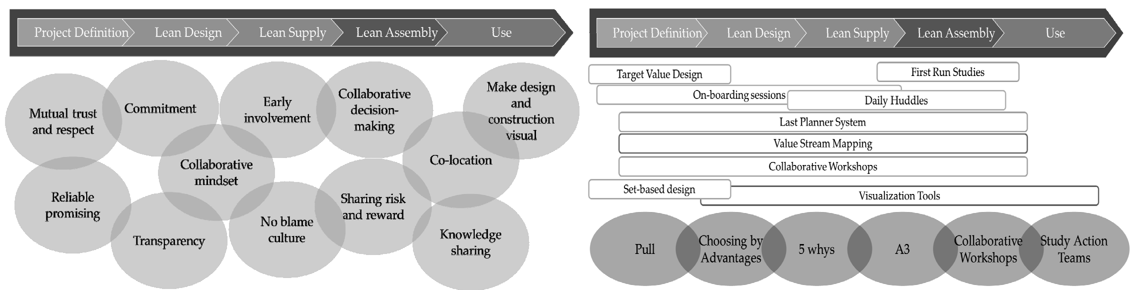

Figure 2: Principles in an IPD project and tools that facilitate IPD implementation

RESEARCH DESIGN

A case study is conducted to explore the why's and how's of the contemporary phenomenon of integration in a new market in its real-world context (Rowley 2002; Yin 2009). As IPD is relatively new in Latin America's construction industry, the case study method allows us to analyze and better understand its applicability in the Peruvian culture. The case is focused on a Peruvian holding company composed of firms with development, engineering, construction, and operations/maintenance missions and competencies. While the company delivers the PPP project largely by itself, the challenge is to coordinate and integrate the involved firms to act for the good of the whole, and not try to suboptimize each of their parts. Main obstacles to integration include:(1) incompatibility of the current management system for integration, (2) lack of procedures that instigate integration, and (3) need for alignment mechanisms (KPMG 2013). Consequently, integration need to be fostered through the structure of the organization to improve project performance and quality of work environment.

As part of the case study, the authors conducted an extensive survey of Peruvian professionals involved in the delivery of the studied infrastructure division. The goal was to gauge the stakeholders' perception and expectations for being involved in a collaborative delivery model and currently applied practices. Through the survey outcomes and field observation, the cultural context and current practices were investigated and further steps for improvement were developed. These further steps are presented in the conclusions section of this paper. Thirty people (30) from the case study were invited to participate in the survey; 26 of them responded. The number of respondents by position were: project managers (16), designers (2), construction managers (2), field engineers (3) and technical office engineers (3). Examples of infrastructure projects in Peru that the participants have been involved in include: Linea 1 metro of Lima (PPP), Linea 1 expansion project (PPP), Linea 1 operations concession (PPP), Linea 1 second expansion (PPP), Cayetano Heredia hospital (PPP), Quellaveco mining project, and Cerro del Aguila hydroelectric project.

RESEARCH FINDINGS

LEVEL OF COMPLEXITY

Integration between parties is shaped differently as project's complexity and uncertainty increases (Mitropoulos and Tatum 2000).The survey included a question with the Likert scale rating between 1 to 5measure the respondents' perception of project complexity. This question was included to confirm the assumption that infrastructure projects are highly complex. It seems likely that high complexity can either motivate and encourage people to perform better or demotivate them should they think that the tasks are far from their capabilities. Furthermore, the perception of the level of complexity might trigger the change in behaviors labeled as "This is how I've always done it" (Fernandez-Solis et al. 2013).As shown in Figure 3, the participants reported that the projects (all in the infrastructure division) have a medium to high complexity. It has been argued that increased complexity of projects requires collaborative and creative behaviors in order to be successful (Ballard et al. 2011). Further, the IPD delivery system has demonstrated its capabilities in dealing with complex projects (Cohen 2010; Mesa et al. 2016; and Ballard et al. 2011). However, there are questions how to promote the desired behaviors.

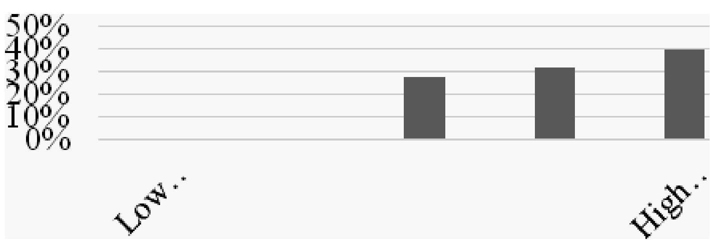

Figure 3: Level of complexity

LEAN, BIM, AND IPD LEVEL OF KNOWLEDGE

The study also analyzed the level of familiarity of the participants with Lean, BIM, and IPD. The results for each category is shown in Table 1. As the studied company has been implementing Lean Construction for some years, most of the participants (93%) were familiar with Lean and used it to some extent. On the other hand, around two thirds of the participants were familiar with the concept of IPD or have only heard about it. Therefore, to encourage successful take up of the concept in the new market, training would play a crucial role.

Table 1: Knowledge of Lean, BIM and IPD within the participants

Answer	LEAN	BIM	IPD
Yes	93.3 %	73.3 %	40.0 %
A little bit	6.7 %	20.0 %	26.7 %
No	0.0 %	6.7 %	33.3 %

TOOLS FOR FACILITATING IPD IMPLEMENTATION

Projects using IPD employ multiple tools (Fig. 2)to facilitate implementation of IPD even when the level of awareness about these tools as part of IPD is very low. The results shown in Figure 4 support what the researchers have observed during site visits in the company. Generally, there is a lack of knowledge in different projects about tools available for use in the projects. Even though most of the participants (89%) are aware of the Last Planner System, there seems to be considerable opportunity to start using the big room effectively, while there is also a need to establish an on-boarding process for the whole team. Studies suggests also that tool such as co-location, on-boarding, A3, and CBA can potentially impact a successful implementation of IPD in projects (Cheng 2016). Therefore, the efforts of the company in fostering co-location might need an adjustment to make it more effective.

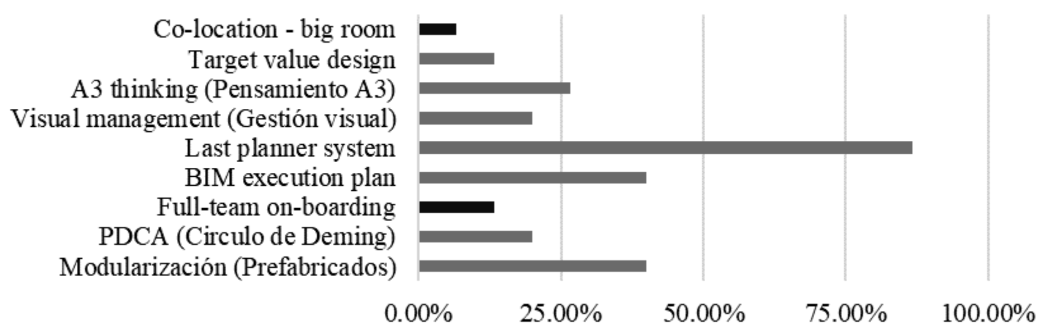

Figure 4: Tools being used by survey respondents

CASE STUDY: CO-LOCATING AND COLLABORATIVE DECISION-MAKING

Fully "93.3%" of survey respondents considered the early involvement of project stakeholders very useful. As part of the case study in the company, the researchers focused on "Project A", the first attempt to apply IPD in the organization. Project A involved major stakeholders early in the project as shown in Fig. 5. Specifically, the engineering and construction companies engaged the operations and maintenance company to work with them early on.

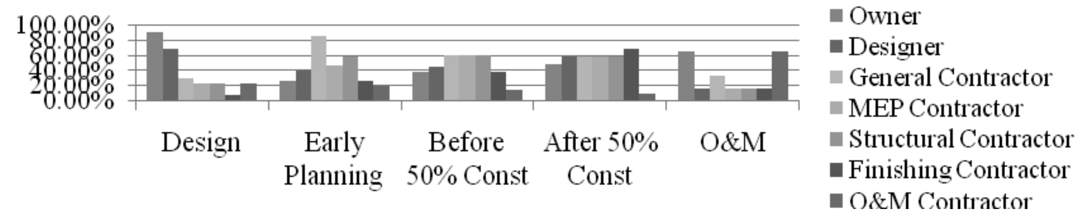

Figure 5: Co-location of participants for project A

As developing highly effective meetings is fundamental when co-locating the project teams, the researchers asked the participants how they would improve the team meetings. The responses varied from "attending meetings with a mindset of looking for solutions instead of imposing ideas on others", "attending on time and having all the decision-makers coming to the meeting", "involving people actively and keeping a weekly routine", "having short meetings previous to the general one and making sure commitments are completed in advanced", "establishing commitments with the project team", "improving accomplishment of activities committed in the previous week and removal of constraints". The common theme among the observed concerns of the participants was about bringing people together and keeping track of their task compliance. IPD works when individuals are in the social exchange framework to make and keep commitments (Mossman et al. 2011).The process of improving how meetings are held may also help to transform the culture to one of increased trust, collaboration, and shared learning.

Co-locating parties impact positively the decision-making process. Involvement of different parties in making decisions was also explored in the study (Fig.6).Results show that there was more involvement in making decisions in early phases than later. Team members' level of involvement varied in decisions concerning project scope, cost, schedule, change orders and interferences. Therefore, when compared to traditional approaches, there seems to be an improved in bringing stakeholders earlier to improve project delivery.

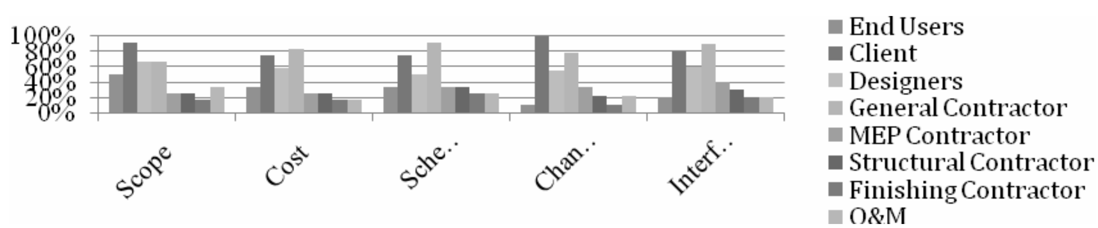

Figure 6: Parties involvement in decision-making process

In Figure 7, the main drivers that the participants consider when selecting key partners for their project were explored. As compared to traditional mindset in construction where the main driver tends to be only cost, the new approach is pushing companies to consider factors such as technical proposal, expertise, and design. When dealing with complex projects such as *Project A,* a diverse set of people need to be involved in the team that can potentially create a more creative solution to deal with the high level of project complexity. In *Project A*, the team had $9 million at risk, therefore converting risks into opportunities was considered necessary for all parties.

For a more accurate and precise selection of key partners, tools shown in Figure 4such as CBA and A3can be applied that will help the team to take more informed decisions based on the advantages to the project. Moreover, on-boarding processes are needed when bringing people to get involved in early stages of the project (Seed 2015), which allows participants to comprehend the process and its effectiveness while getting used to new tools.

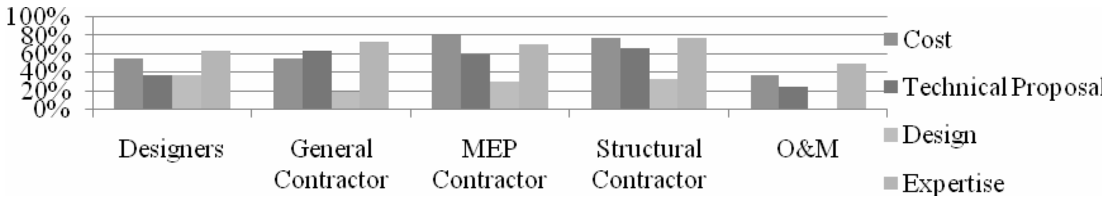

Figure 7: Factor considered for choosing partners

ESSENTIAL FACTORS FOR IMPLEMENTING IPD

The author aimed to understand the participants' perception about key principles or factors to achieve an integrated project and delivering a successful project. They were given a multiple-choice question, with the option to include additional choices. A summary of the responses is presented in Fig.8.Surprisingly, "respect" was the lowest factor rated by participants which suggested the need to change the current mindset regarding core values. However, this answer could have also be received due to a misunderstanding by the respondents since one of them later stated that respect was already implicit in the way they behave and it was not seen as a separate principle. IPD necessitates cultural change through

a more collaborative mindset as it requires new ways of behaving and thinking (Ballard 2008; Pishdad-Bozogi 2016). In a scenario where survival is more important than working conditions, there is a need to go back to basics and keep in mind that Lean requires respect.

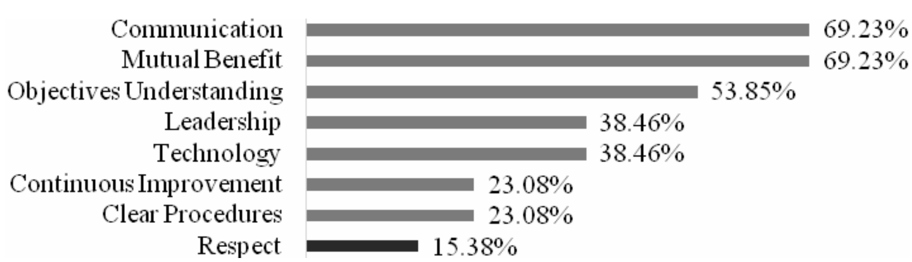

Figure 8: Essential factors for implementing IPD successfully

WILLINGNESS TO CHANGE

The vision for changing to a more collaborative model was strengthened by the company's willingness to deliver the highest engineering value to their clients and increase the level of service for their infrastructure proposals. The business developer company of the group is leading the initiative as an internal client for the other companies of design, construction and operations. The authors aimed to understand team member's expectations for change and where they had identified potential areas for improvement.

To identify participants' motivation to change their current practices, the authors asked them to comment on how they would describe a successful day in their project. Responses varied from "Improve communication and daily commitments accomplishment", "constraints removal and sharing progress with the team and getting the work done", "keep a constant work flow", "zero accidents, zero rework, high productivity", "implementing innovative processes". Common patterns among these responses suggest that stakeholders' perspective about a successful day in their projects differ from each other which means that there is a misalignment of goals and therefore priorities might be completely different. While some people concern lies on improving communication, other members' focus is more productivity oriented such as avoiding accidents and rework.

The researchers also asked the participants "If you could change something in the project, what would it be?". Responses to this question varied from "Increase client involvement and accurate communication with client", "schedule activities with the different disciplines", "define clear rules when working with the different companies in the group", "improve contract clauses in order to make it more collaborative instead of aggressive", "improve constraints analysis and planning process", "commitment compliance, improve daily planning and share it with the team", "share project goals more often", "effective communication", "involve all stakeholder earlier in the project to elaborate an integrated planning and execution program", "planning should consider all different variables that might impact it". Common patterns among these responses suggest:

- Project teams have realized the need to get the owner involved in the development and execution of the projects. A key characteristic from IPD projects is the level of commitment that owner ensures in the process. For infrastructure projects in the way of PPP in Peru where the client is the government, there is the figure of an internal client (business developer) who can play the role of the final client. However, there is a need to empower this player for facilitating decision-making.
- By requesting rules clarification, there is a suggestion to improve the company's contracts and guidelines. Though having an IPD type of contract with the government might be a difficult if not impossible fact under the current legislation, the organization can still work on an internal agreement between their companies that can facilitate key IPD strategies implementation such as sharing risk and reward, and clarify roles and responsibilities within teams.
- Even though the company has been implementing Lean tools and especially Last Planner System through the organization, basic things such as constraint analysis, still need to be reinforced by training and encouraging collaboration between the different disciplines to avoid interreferences and rework.

DISCUSSION AND CONCLUSIONS

The authors discussed points such as the understanding of the definition of "respect" by participants. It may be hypothesized that the culture of survival that still prevails in most companies might be reason for low rate of this metric in the study. In such case, it would be important to know how can we build respect in an industry that has been seriously damaged with corruption nowadays? Also, is there any relation between open communication and effective communication? While the level of communication might be acceptable, it may not be through the most effective channels. In the case study it was observed that despite the implementation of the practice of co-locating parties, communication did not flow as expected. We hypothesized that other practices such as visual management may need to be implemented to facilitate communication of co-located parties. It is also interesting to explore how trust will influence predisposition of people to share risks and rewards. Some steps for improvement have been suggested (Fig. 9) such as reinforcing the use of LPS to improve reliability and foster training programs in TVD to set and steer to targets in integrated projects.

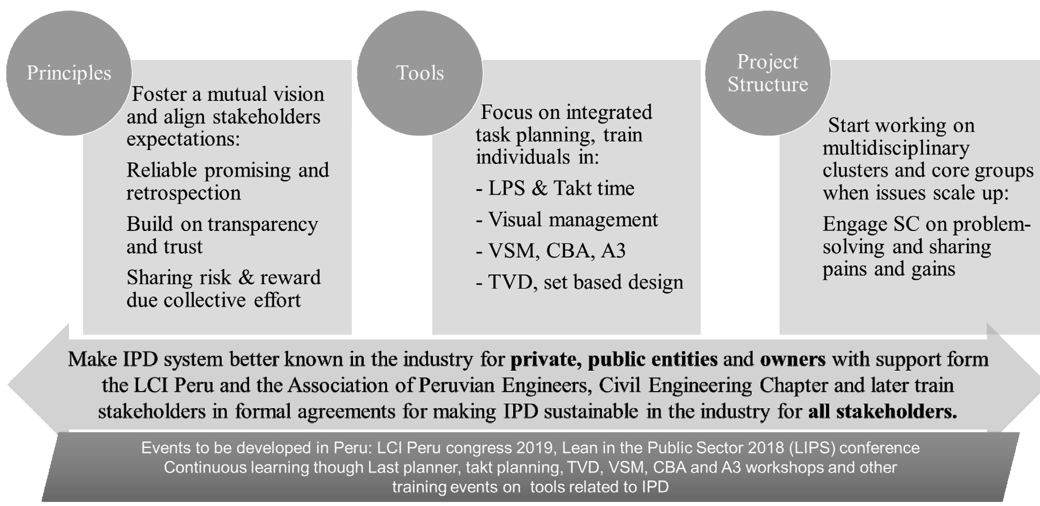

Figure 9: Steps for improve IPD implementation in Peru

The collaborative approach aims to meet higher service levels and improve the current process for design, construction and operation of infrastructure projects. The study only included data from one company, which is the most experienced using Lean construction. Results of this study should not be generalized, rather the findings should be used to give an overview of IPD implementation in Peru. Even tough Peru faces issues that seem to be characteristics of every place where construction is done, the different cultural settings (motivation and barriers) from country to country might require different triggers for generating collaboration and what might vary in fact is the process that will be adopted to achieve the required level of integration.The research reported in this paper explored practical nuances of IPD and key points where changes are required are summarized below:

- **Complexity as a catalyst for moving to a collaborative approach:** Even though a complex project may be more unpredictable and challenging, the high level of complexity of infrastructure projects may act as a catalyst to motivate a disruption in the dynamics of project teams towards more integration.
- **Lack of knowledge in regard to IPD:** Dealing with the lack of knowledge regarding IPD in the Peruvian sector requires more effort to train people to better understand the concept. The training process might increase awareness of potential use of tools that facilitate IPD. Even though the participants have started collaborating early in the construction process, the multidisciplinary teams can improve the integration practices by using tools such as A3, CBA, and PDCA.
- **Co-locating team members from early stages:** To improve efficiency of the co-location process (big room meetings), several rules exist that can be applied to the project team such as safe zone sense, importance of the opinion of every individual, and sense of equality in the status of the individuals.
- **Dealing with a culture of survival, fostering "respect":** The current state where a culture of survival prevails need to be transformed by adopting a collaborative approach which will change people's mindset with a focus on respect. Accountability, trust, and respect need to be strengthened with the support of making/keeping real commitments. However, trust and respect might imply different behavioural patterns in different institutional contexts. The company under study has started a leadership program to reinforce the concept of respect as a recognized sovereign right of people to think differently.
- **Work on basics:** According to the perception of participants, there is a need to improve reliability in the projects. For this purpose, the planning process need to be improved. It was observed that people are still following the "push" pattern of behaviour in some projects and not removing constraints properly. The authors recommend the initiation of redesigning the production system considering different requirement of the involved parties and their disciplines.
- **Commercial terms:** Participants suggested that there is a need to improve the regulative frameworks that support IPD in the construction industry. Internal agreements in the form of addendums can be used to promote collaboration.

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COLLABORATIVE DESIGN DECISIONS

Paz Arroyo[1] and David Long[2]

ABSTRACT

Decision making on projects is often done in isolated silos, lacking collaboration and communication between teams. This modality often leads to inefficiencies due to late changes in the design and the need for rework. Team moods decay when there is lack of a clearly defined decision-making process, provoking frustration and apathy. This paper presents a case study that demonstrates how the implementation of lean ideas and methods, specifically A3 reports and Choosing by Advantages (CBA), helped a team evolve their process beyond a traditional decision-making strategy. The researchers used a unique approach to observe the decision-making process as conversation for action to help the team overcome challenges. This paper quantifies the impacts of simultaneously implementing A3 and CBA in terms of saving money and reducing time in meetings. In addition, the research presents qualitative results in terms of improving the project design and creating a team capable of making efficient and sound decisions.

KEYWORDS

Decision-making, Target Value Design, Set-Based Design, Choosing By Advantages, A3 reports, Language Action.

INTRODUCTION

When decision making teams are detached from one another the integrity of projects is compromised by miscommunication, leading to ungrounded assessments, lack of shared understanding, and frustration in the team. Usually, miscommunication leads to poor design outcomes, late changes in the design to reduce cost, and rework. Lean Design methods and practices such as Target Value Design (TVD), Set Based Design (SBD), A3 reports, Choosing By Advantages (CBA) and The Last Planner System®(LPS) present an opportunity to reduce waste in the design process, reducing unproductive iterations and helping the design team define and deliver value for the client.

In particular, the decision-making process requires a transparent process in which SBD, A3 reports and CBA are well aligned (Arroyo 2014). Several studies have demonstrated case studies in which SBD, A3's and CBA were implemented mostly as independent elements (Arroyo et al. 2014b, 2015b, 2016b; Kpamma et al. 2014 and 2017;

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Parrish and Tommelein, 2009, Schöttle and Arroyo, 2016; Schöttle et al. 2017), not synergistically combined as in this case study.

In addition, the implementation of lean tools with coaches observing the decision-making process as a conversation can help teams to manage unproductive moods. The anatomy of conversations was defined by Fernando Flores (2012) and the impact of moods on the ability to learn was described by Gloria Flores (2016). These were mainly based on the observation of teams while achieving quests in role played video games.

This paper presents a retrospective reflection on a successful team that used A3 reports with CBA systematically to make design decisions in a large capital project for a major technology firm in The United States. The results of this approach with the addition of managing decisions as conversations for action was measured and documented by the design team.

RESEARCH QUESTION AND METHOD

The research questions are: 1) What is the impact of implementing A3 with CBA systematically on a project? and 2) What observations can be made when coaching the decisions of a team as conversations for action?

The nature of these questions is aligned with a case study methodology (Yin 2014). To answer these questions, a project was used as a case study for the utilization of A3 and CBA for dozens of design decisions pertaining to programing, mechanical and geotechnical systems, site safety and other design elements. The sources of evidence used were 1) direct observation, since both authors were coaching the design team to implement lean design principles and methods, 2) A3 reports, schedules, and budget documentation, and 3) Interviews with project managers and design specialists after the coaches interacted with the team. The interaction consisted of teaching, coaching, developing a system to apply lean principles and methods that worked for this project context, and specifically, coaching the decision-making process as conversations for action.

PROJECT BACKGROUND

The project described in this paper is a large and complex office building in a technology-rich area of the United States. The design team was large, multi-disciplinary, and based across multiple countries. Communication was done primarily through video conferencing and regular on-site working periods. The team had minimal or no previous exposure to lean principles. The project was complicated by aggressive schedule and budget targets, a difficult regional authority having jurisdiction, and a unique and iconic architecture.

The owner procured the design architects (two major international firms), the contractor, the construction management firm, and the executive architect. The construction manager procured the rest of the supporting engineers and sub trades, including a Lean coach and a relationship coach, sometimes in collaboration with the contractor and/or the owner. Most participants were contracted under a lump sum, fixed fee agreement and by in large worked for cost plus profit.

The owner's representatives were engaged in the decision-making process as the "decision-makers", or as advisors to higher-level decision makers based on the A3 with CBA. Not all design decisions were made with the help of the A3 with CBA process and the owner did not participate in the development of an A3 until the review cycle. The lean coach assisted the construction management firm with incorporating lean tools and methods in the design phase, including Target Value Design, Pull planning, and A3 thinking with the Choosing By Advantages decision-making process. Lean principles and tools were partially adopted by the project participants. The client was particularly concerned with making sound decisions that would be acceptable to multiple, cross-functional stakeholders at all levels within the organization.

DECISION-MAKING CHALLENGES / WASTE NOT; WANT NOT!

The primary challenge that the team faced was the lack of a collaborative decision-making process. Teams were utilizing traditional decision-making techniques that inhibited innovation despite the complexities in the building design. Their initial strategy was to assess alternatives at face value, endeavoring to present a reasonable course of action that the owner and the rest of the team would agree with and adhere to. This haphazard method lacked focus and strategy, as disparate teams addressed competing design priorities without coordination or leadership. Decision-making was not synchronized with the target project schedule, resulting in the repeated need to conduct pull plans for scheduling and rescheduling the design effort. The team was frustrated by the lack of accountability, the atmosphere was chaotic, and design decisions were poorly documented. While the project appeared to have some history with formal decision-making methods such as CBA, upon examining the few documented decisions it was clear that they were unwittingly using the CBA name but actually using the Weighting Rating and Calculating (WRC) method of decision-making.

The initial communication patterns in this case resulted in 1) hasty decisions, based on ungrounded opinions without considering all relevant facts about the performance of design alternatives, 2) misalignment between team members, 3) overturned decisions causing rework, and 4) Excessive, disconcerted information overwhelming team members. In summary, the lack of structural organization, decision tracking, and methodology for conflict resolution resulted in discernable design inefficiencies.

LEAN METHODS IMPLEMENTATION

Figure 1 shows a simplification of an overall theoretical TVD strategy and the relationship between complimentary lean methods to be used in design. TVD principles should be used to identify target values and targets costs. For every opportunity identified to improve the existing baseline design, the team should use a systematic decision-making process which includes SBD principles, developing alternative design sets until the last responsible moment. These sets are collaboratively determined by the design team based on their plan. The entire process is in accordance with The Last Planner® System (LPS). In addition, Choosing By Advantages (CBA) is used as the decision-making method and included in A3s reports to manage and report the decisions, recommendations or documentation.

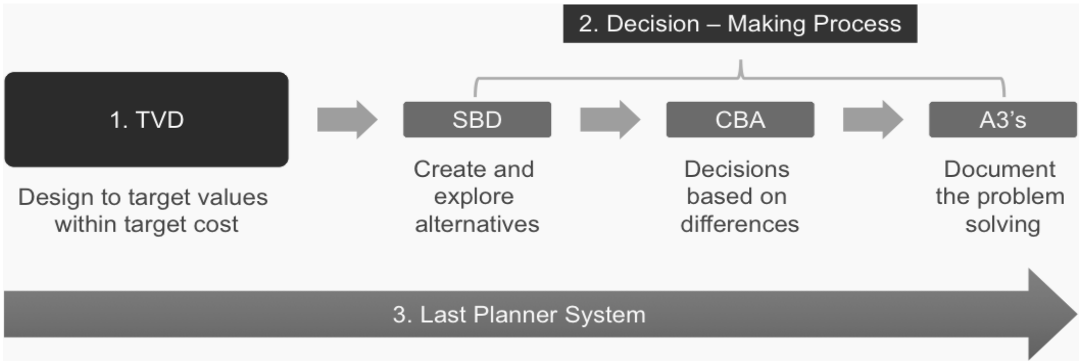

Figure 1: Lean design Methods Relationship

The following sections briefly explain a variety of lean methods introduced to the design team by the lean coaches over time. Only the project managers who were in charge of facilitating decisions had formal training in lean methodology. Lean methodology was only partially adopted by the team, however, lean coaches did attend design decision meetings through video conferences and guided decision-making processes and conversations.

Target Value Design (TVD)

TVD is a design process which seeks to achieve a target value (desired performance outcome for the whole building) at a certain cost, in alignment with the owner's value proposition. In this framework, cost is a design parameter. This is in contrast to traditional design in which the design is completed first and the cost of the building is an outcome of that design. (Ballard,2009). Current thinking applies TVD throughout the entire project delivery process, focusing on Target Value Delivery rather than limiting TVD to the design phase only.

Set-Based Design (SBD)

SBD is a design method that encourages the exploration of alternative approaches for design solutions and concurrently carries those solutions along, gradually eliminating them until the preferred solution is determined (Ward et al., 1995). This approach prevents the premature selection of an alternative that in the end could result in re-work or subpar value to the client if it is later determined not to have been the optimal choice. Ballard (2000) expanded on SBD by defining positive and negative iteration for the design team.

A3-thinking

A3-thinking is a problem-solving method used extensively in the Toyota Production System, which puts P-D-C-A (plan-do-check-act) in action (Sobek and Smalley, 2011). This structured approach to problem-solving clearly defines the problem, the desired outcomes, the hypothesized solution, and the steps to implement the solution. Using A3 reports, the team is prompted to summarize the entire issue on an A3-sized piece of paper, which allows for feedback among stakeholders. In this case study, project team members who used the A3 with CBA approach made sure to understand why decisions were being made, and implemented a standard method of documenting, both who was involved in decision-making as well as what actions each person had to take in order to complete the decision.

Choosing by Advantages (CBA)

CBA was developed by Suhr (1999), and it has been adopted in lean construction because it enables design by providing a sound decision-making method to be used in alignment with TVD and after exploring alternatives with SBD, both of which can be documented in an A3 format. CBA ranks decisions based on their respective advantage and identifies both the values and costs of each alternative, demonstrating a transparent rationale for each decision. Several studies have demonstrated that CBA is superior to traditional decision-making methods such as Weighting Rating and Calculating (Arroyo et al. 2014 and 2016; Correa et al 2017; Schöttle and Arroyo 2017) and Analytical Hierarchy Process (Arroyo et al 2015; Arroyo and Molinos-Senante 2018).

The Last Planner® System (LPS)

LPS is a commitment-based production control system usually used in lean construction projects. In this project it was also used to coordinate design activities and schedule design decisions according to pull planning (Ballard 2000).

DECISIONS AS CONVERSATIONS FOR ACTION

In his book *Conversations for Action and Collected Essays* (2012), Fernando Flores writes about using action language to instil a culture of commitment in working relationships. He defines six basic speech acts: declaration, request, promise, offer, assessment, and assertion (Table 1). Understanding the nuances of each speech act can explain dysfunction in communication and shed light on decision-making outcomes. The coaches guided the team members in using the speech acts during their conversations about each decision. For instance, the project manager declared the goals of a particular design decision; the architect requested more information about the space requirements of mechanical systems; the project manager promised to have a conversation with the client; the mechanical engineer offered to research the attributes of the alternatives before the next decision meeting; the mechanical engineer assessed how an alternative mechanical system would work in the future; and the mechanical engineer asserted facts on how different equipment operates. These conversations shape the decision-making conversation and help the team to ask questions and explore alternatives in a more collaborative fashion.

Design decisions are futuristic by nature and therefore design thinking, or an opinion that a design concept is appropriate for the circumstance, is characterized as assessment. The assessment (design) may be grounded or ungrounded.

In addition, futuristic thinking, or the “view of the future” is influenced by the mood (Flores, G. 2016), of the team. Coaches constantly observed the mood of the team, and looked for ways to cultivate productive moods.

Table 1: Speech Acts (Flores 2012)

Act	What it Does	Elements
Declare	Open a new world for action	Infers authority
Assess	Open new possibility or prepare for action	Futuristic, grounded, or ungrounded
Request	The speaker is asking a potential performer for action around a concern	Conditions of satisfaction, background of obviousness, time
Offer	Performer promises to care about something he/she perceives the listener to be concerned about	Same as request
Promise	Commit self/enterprise/team to bring a new Condition of Satisfaction	Same as request
Assert	Speaker reports facts and is prepared to offer evidence	Report of fact

RESULTS

This section presents the decisions that were made using lean principles and the results on this project. Table 2 shows a list of decisions that the team made collaboratively using SBD to explore alternatives, TVD to refer to project targets, LPS to manage the timing of the decisions, CBA to guide the decision–making process, and A3s to manage the discovery process and to validate the design team recommendations to the owner.

Table 2: List of design decisions documented.

#	Decision Title	#	Decision Title
1	Modular vs. Non-Modular IDF Closets	13	Soils Management
2	Cistern Single vs. Double Walled Construction	14	Select the Mix of Fill Material for Basement Perimeter
3	L2 Zoning Requirements for Open Office and Enclosed Studios	15	Auger Pressure Grouted vs. Precast Concrete Piles
4	Modular vs. Non-Modular Approach for Distribution Electrical Rooms	16	Access to Basement Bike Storage
5	Exhaust Locations for Basement AHU's	17	Security and Maintenance Railing at CUP Opening
6	Underground Infrastructure Support on Suspended Slab	18	PG&E Access to the Main Electrical Room
7	Cistern Sizing Evaluation	19	Location of Outdoor Fitness Area
8	Energy Pile Evaluation	20	Safety Protection at CUP Opening
9	Day 1 vs. Day 2 Lab Loads - Building System Assumptions	21	Return HVAC Zones at L1 and L2
10	Waterproof Membrane Evaluation	22	L1 Zoning Requirements for Conference Rooms
11	Vapor Intrusion Evaluation	23	First Flush vs. Pre-filtration for Canopy Drains
12	Vapor Mitigation Strategies	24	Design of Underground Utilities to Prevent Settlement Displacement

The quantitative results presented in this section are according to the client's own calculations of the initial cost of the baseline design. The design budget and value changed along with design decisions and improvements to the baseline design. In most cases the project cost decreased after a decision, but in two instances the cost of an alternative increased as the team selected the alternative that maximized value for the client. Figure 2 shows the variation of project cost with each decision made over time.

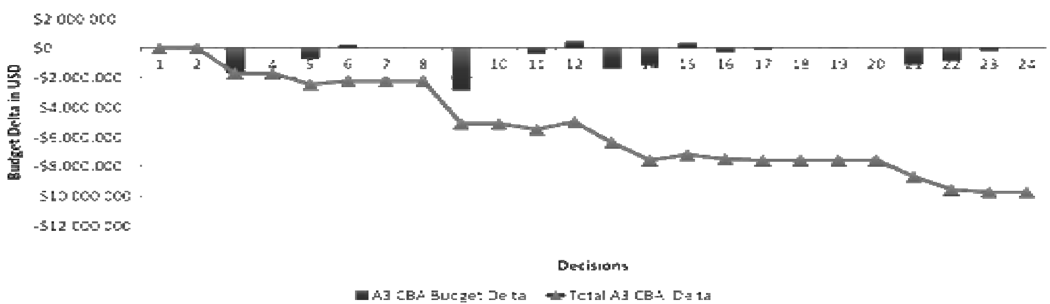

Figure 2: Project budget after each collaborative decision.

Figure 2 represents the last 24 decisions where the A3-CBA system was fully implemented. Most decisions resulted in cost savings; in total all A3's documented decisions resulted in approximately $9.7M in savings or 11% of the budgeted amount for these items. The process resulted in $96,468 in savings per meeting or $12,596 in savings per meeting hour. In terms of time invested for each decision, early A3's with CBA averaged 5.3 meetings per decision and reduced to 3.3 meetings per decision representing a 37% meeting efficiency increase. The design team members came to the meetings more prepared and developed a common language by which they more effectively communicated how to make decisions as well as why they were making the decision. Ultimately, as lean methods and conversations for action helped the team create a new collaborative practice and project managers were able to lead conversations and decisions, less intervention from coaches was required. The new process minimized future negative iterations and led to changes in habits. For example, teams began to cancel meetings when key participants didn't show, when there was missing information, or when people were unprepared.

DISCUSSION

Design teams reported increases in client satisfaction; better decision documentation; and more lasting, logical and reasonable decisions with increased design efficiency and velocity. The teams developed increased trust and respect and were better able to work together across contractual lines.

There were a number of barriers in implementing the A3 with CBA approach. Project participants expressed reluctance to adopt a new process with unproven results. There was initial confusion about A3 requirements and how they applied to the decision-making process. Early-stage meetings were time consuming and project participants felt they were "wasting time". Ironically, their dedication to inefficient work processes tended to waste more time than it would take to a new methodology. Then the A3 with CBA approach started to work, the participants began to take ownership of the decision-making process. They were more prepared for meetings, and were able to define clear roles and make commitments to move forward, even if they lacked information or learned that they did not have a shared understanding of the problem. In addition, CBA helped them to have productive conversations, avoid tangential discussions, and focus on differentiating facts from opinions. They developed a shared understanding of the criteria for judgement, and how to compare the advantages of alternatives based on the project context.

The relevance and importance of coaching became evident as the decision-making process was contextualized as a time for conversation. Decisions shaped by these conversations came to be seen as commitments to a common vision of the future. This resulted in live conversation coaching in an environment where the team was learning at a fast pace despite the project managers' limited prior training in how to guide a team through this decision making process.

The relationship between moods and decision-making became evident as team-members' moods affected the direction and outcomes of conversations. Moods are contagious. And, effective group leaders can navigate turbulent moods and encourage positive moods to allow for new opportunities, improved productivity, and satisfied clients and stakeholders. It is important that the design team has flexibility in their decision-making methods and that conversations have space to develop based on new opportunities rather than being mechanical in nature. Initially, the mood of the team was one of confusion and distrust. However, the opportunity for design specialists to discuss useful distinctions between alternatives established clarity and trust among team members and fostered a mood of resolution that allowed them to move forward and feel a sense of accomplishment and ownership of the design process.

Many opportunities for improvement are evident. We observed a clear need for increased training on decision-making methods at the earliest possible time in the project. Additionally, while lean methods improved the results of this particular teamadoption of lean methods across the project would have increased the benefits to the client. Improvement opportunities were missed.

CONCLUSIONS

This research is based on observations of the implementation of CBA with A3s in a large complex project. These observations where made while coaching the decision-making process as conversations for action. This case study answered two research questions. Firstly, that the impact of implementing A3 with CBA systematically on a project is quantifiable in measurements of 11% savings on budget and a 37% increase in meeting efficiency. The qualitative benefits reported by the team were increasing value for the client and improving their overall performance. Secondly, when coaching the decisions of a team as conversations for action we observed that implementing A3 and CBA evolved the mind-set and mood from one of confusion to one of resolution. Finally, qualitative data suggests that the results on costs savings and meeting efficiency would not be possible by mechanically implementing CBA with A3. The team's initial adoption of A3 and CBA tools were ineffective until the team was coached into the mindset of language action. The conversation process facilitates full and proper utilization of lean tools, although more research is needed to fully understand the impact of conversations and moods on the decision-making process.

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BUILDING SHARED UNDERSTANDING DURING EARLY DESIGN

Danilo Gomes[1] and Patricia Tzortzopoulos[2]

ABSTRACT

Early Design Collaboration in construction projects can be hampered by misunderstandings between team members. Consequently, design actions are not supported by all, causing delays and frustration. This paper presents a study aiming to capture (a) misunderstandings between participants at early design stages, and (b) how these individuals resolved such misunderstandings through shared understanding. Anexploratory case study was conducted to investigate collaborative interactions of a Design Team, in an Architecture Office in San Francisco (USA). Data was collected during a concept design charrette focused at the building envelope of a Medical Office Building. Results from Protocol Analysis revealed misunderstandings emerging through independent actions and wrong assumptions among the participants, which triggered breakdowns in communication and the use of metaphors to construct shared understanding. This paper proposes a conceptual framework to explain the dynamics of shared understanding in early design stages, which could be used to help design teams to map, reflect about and improve their collaborative interactions.

KEYWORDS

Collaboration, Early Design, Shared Understanding, Social Construction, Design Team

INTRODUCTION

Early Design Stages, also known as 'Project Definition' according to the Lean Project Delivery System (Ballard 2008), consist of concept design generation supported by group decision-making. Thus, early design teamwork requires social interactions between design participants facing the challenge of aligning their activities to achieve better outcomes (Valkenburg 1998). In this context, collective design activities are a matter of expression of personal commitments and persuasion aiming for conflict resolution among participants (Cross and Cross 1995). Especially at early design, conflicts can emerge due to different language and forms of representation upon participants' different responsibilities and interests usually leading to lack of shared understanding on which design factor is most important in the task (Maher et al. 1996; Kleinsmann and Valkenburg 2008). Consequently, lack of shared understanding about the design object

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and task can hamper the team's progress and can negatively influence the design outcome (Valkenburg 1998). The lack of shared understanding is linked to uncertainty and ambiguity within the design team, which is reflected in the lack of complete information to support collective design decisions (Hey et al. 2007). Designers use strategies to cope with the lack of input and progress with design activities (Koskela 2000), e.g. making decisions based on assumptions that should be checked later, but if these are incorrect, it leads to rework.

Hence, it can be said that one underlying characteristic of Early Design Collaboration is that designers usually have limited awareness and understanding of how other designers operate in the project and how their work has interdependencies with others in the design task (Cross and Cross 1995;Arias et al. 2000). Moreover, there is a poor understanding of what actions collaborators need to do when combining different design representations and how these actions can be implemented (Qu and Hansen2008). Consequently, early design collaboration needs to be informed by a better understanding of how individuals create and negotiate representations and how this influence their shared understanding during the design activity (Snodgrass and Coyne 1992; Qu and Hansen 2008).Therefore, this paper addresses the following research questions: How misunderstandings emerge in early design? What participants do in practice to avoid and resolve misunderstandings?

SHARED UNDERSTANDING

In collaborative design, Valkenburg (1998) proposed that *shared understanding* is a mutual view amongst the team members on a relevant design topic and design activity. Thus, shared understanding involves similarities in the individual perceptions of actors about either how the design topic is conceptualised, as the content of the situation, or how their *transactive memory system* works, as the process to conceive a solution (Kleinsmann 2006). *Transactive memory* is a "*set of individual memory systems, which combines the knowledge processed by particular actors with a shared awareness about who knows what*" (Wegner1987 apud Valkenburg and Kleinsmann, 2008 p. 371). In this case, shared understanding faces the challenge of integrating various perspectives emerging from different descriptions of the world and, it depends on reasoning around conflicting arguments and goals among design participants (Arias et al. 2000).

Studying military coalitions, Smart (2011) proposed that shared understanding implies similarity of understanding in relation to a particular phenomenon (i.e. goals, task, situation), involving the emergence of the abilities to form expectations and predictions regarding future states, actions and events. According to Smart (2011), *understanding* is an ability to purposefully use knowledge in highly flexible, adaptive and context-sensitive ways. In this case, to think about knowledge in use can be considered problematic, especially considering the collective nature of knowledge (Snowden 2002). Traditionally, knowledge has been considering something that is dynamically created though movements between tacit and explicit states (Nonaka 1994). Consequently, knowledge management strategies have been conceived based on the idea that all knowledge could be disembodied from its possessors and become an organisational asset

(Snowden 2002). For example, in the context of Lean Construction, Pasquire and Ebbs (2017), suggest that shared understanding, as the knowledge used in a project is something external to individuals and it should be managed as an organisational flow. However, recognisably, not all knowledge in the designers' head and conversations had, should or could be made explicit (Snowden 2002).A compelling argument on the epistemological difference between *knowledge* and *understanding* is found in Pritchard's (2014) work. According to the author, unlike knowledge, understanding is a specific kind of achievement, in which successes are accountable to ability. Hence, success should be creditable to the agent's exercise of the relevant ability (Pritchard 2014). More specifically, the author refers to a cognitive achievement, in which success (i.e. understanding) is creditable to the agent's cognitive ability. Thus, knowledge can be seen as less demanding than cognitive achievement, in situations in which to gain knowledge of causes does not require the agent to able to carry the relevant cognitive load by itself (i.e. knowledge is acquired by trusting the word of an expert) (Pritchard 2014). Understanding is more than a general conception on the relation of cause and effect, it requires a grip on how a cause generated an effect, a grip that could be given as an explanation of why the event happened (Pritchard 2014), and it can never be disembody from the actor and the situation. Hence, Smart's (2011) conception of shared understanding is key in design contexts to acknowledge the need for understanding in supporting the conception of expectations and predictions to change a problematic situation.

Therefore, adapting Bittner and Leimeister (2013) definition, *shared understanding* can be seen as the collective and dynamic ability to conceive and coordinate actions towards common goals or objectives ("meaning in use" or action perspective) of multiple agents within a group, based on diverse knowledge, beliefs and assumptions on the task, through the use of tools. Shared understanding is thus an enabler for collaboration, in which collective actions are complementary or compatible with each other, when evaluated against a common goal (Smart 2011). Furthermore, shared understanding is the expression of how agents' roles, responsibilities and capabilities (Smart 2011), are co-constructed in relation to the conception of shared goals and their perception of the aspects of the current situation. Therefore, shared understanding is a construct that is both a challenge and an important condition for team collaborative performance (Bittner and Leimeister 2013).

BUILDING SHARED UNDERSTANDING

Lack of shared understanding usually occurs because each participant interacts with their own set of assumption guiding their interpretations and actions (Hey et al. 2007). These assumptions seem to emerge from what Schön (1983) called *frames*, and Bucciarelli (1988) called *object worlds*, as underlying structures of belief, perception and appreciation, comprised of implicit understandings about what issues are relevant, what values and goals are important, and what criteria can be used to evaluate success. This are related to the concepts of common assumptions (Lloyd and Busby 2001) and common ground (Koskela 2015).

Moreover, such frames will influence the implicit pairing between the individuals' perception of what is problematic in the situation and their conception of a desired end state of goal (Schön 1983; Hey et al. 2007). Divergent frames result in conflicting set of goals, assumptions and attentional foci in a design set (Hey et al. 2007).It could be said that, early conflict between individual frames may not prevent, but rather enable the negotiation of shared frames, as long as the conflict is made explicit (Hey et al. 2007) and the participants are keen to reflect on it. One problem is that individuals may not be aware of their own implicit assumptions until they are met with conflicting perspectives (Hey et al. 2007). According to Hey et al. (2007), several activities can make individual frames explicit and, consequently, reveal conflicts among them, like,for example, collectively building a group vocabulary and defining terms, concepts and categories. When conflicts between participants' individual frames are made visible, common frames can start to be negotiated (Hey et al. 2007). When individual frames are externalised, they expand the design team object, which allows other participants to expand their engagement in what Schön (1983) calls "conversation with the materials of the situation" (Arias et al. 2000).Here, metaphors can play a key role, because they embody symbolic representations that implies socially shared ways of perceiving a situation, as well as the ability to conceive changes in it (Tomelleri et al. 2015). According to these authors, metaphors are tools that build social relationships, generating consistency between an individual's inner world and their social environment, by unconsciously establishing a sense of performance, in terms of success and failure for the collective practice.

Therefore, following this constructivist approach to shared understanding and the type of interactions identified by Valkenburg (1998), we propose a framework to describe the dynamics building shared understanding in Early Design Collaboration (Figure 1). In the next sessions, we explain how the framework was used to identify designers' interactions towards shared understanding.

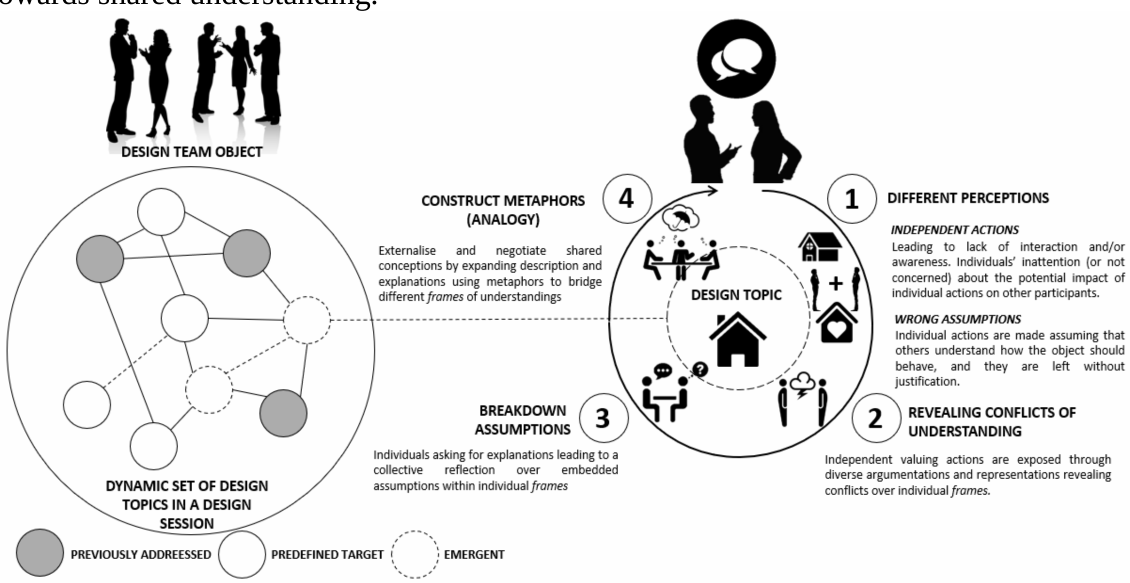

Figure 1: Dynamics of shared understanding in early design

RESEARCH METHOD

This paper presents anexploratory study which is part of an ongoing PhD research on the dynamics of early design collaboration. A case study approach was adopted, in which an in depth empirical inquiry was conducted on a contemporary phenomenon in a real-world context (Yin 2014). By focusing on understanding the dynamics presented within a setting, a case study provides a description of the phenomenon that can support the test and generation of theory (Eisenhardt 1989). The aim of this study was to understand how misunderstandings emerge between design participants during early design and how these participants resolve such situations by building shared understanding. Thus, following an interpretive approach, this inquiry focused on the ways people make sense of the world through the inter subjectivity of shared meanings (Walsham 2006).

The exploratory study involveda design team working on a charrette at the schematic design of a Medical Office Building (MOB) in Alaska, USA. The participants, which were members of an Architectural Design Office, engaged in a one-day event, taking place at the company's office in San Francisco(USA). This was the third Design Charrette on this project. In order to anonymise the participants and the company studied, the real names of the participants were substituted by their professional role and a respective number.

According to the Project Design Leaders (Architect Leader 1, AL1, and Architect Leader 2, AL2) the first two Design Charrettes included the client, structural and systems engineers, the contractor, and they resulted in the initial scheme for the concept design of the MOB. The participants who engaged on this third Design Charrette are mostly from the same discipline. There were five architects: AL1, AL2, A3, A4, A5, and one Graphic Designer: GD, which came from a different office from the same company. According to the Brief presented, they were expected to contribute in exploring alternative ideas for the building envelope. During the Charrette, the participants interacted via verbal and graphical representations to explore different design ideas.

As an exploratory case study (Saunders and Thornhill 2009), the phenomenon was assessed to interpret what is happening according tothe proposed framework (Figure 1). Hence, observations in action and access to internal documents (i.e. brief, images, design representations), supported the understanding of people's shared meanings and issues. Protocol Analysis (Ericsson and Simon 1993) was used, in which the verbal and graphical interactions during the charrette were video-recorded and transcribed by the researcher for analysis against the constructs of the framework, in an attempt to make explicit the emergence and resolution of lack of shared understanding. The transcripts were coded according to the framework's constructs identifying interactions related to: *different perceptions in the task (originated by independent actions and/or wrong assumptions);revealing conflicts of understanding; breaking down assumptions; and the use of metaphors (analogies).* Thus, coding involved the examination of each segment of the protocol to determine whether it contained an explicit reference to aspects of shared understanding.

THE EXPLORATORY CASE STUDY

The Design Charrette can be divided in three different modes of activity: *briefing, exploration and presentation.* In each of these modes, some of the interactions were identified describing actions leading to misunderstandings and the construction of shared understanding. The *briefing* activity started with the Project Design leader (AL 1) presenting the current state of design development based on the result from previous charrettes, in terms of conversations with the client and other stakeholders, as well as site analysis and initial design decisions. Following that, AL1 suggested that they should split into two groups to explore possible “design ideas” about the suggested *design topics*. Under this *exploration* mode, independent behaviour was noticed, in which the participants were exclusively involved in their own individual design activity (drawing and reflecting).At that time, there were some interactions to discuss *emergent design topics*, but less interactions in terms of contributing to shared representations (i.e. graphical artefacts).Finally, at the *presentation mode*, each of the participants presented their ideas to the group, using their sketches pinned in the wall.

It is possible to say that shared understanding was initially assumed and discussed in terms of the current state of the design task. AL1and AL2 seem to assume that everyone had similar understanding of what the design representations and images meant. Such assumption was also made about the meaning of the words used to focus and describe the selected *Design Topics*. As the *Brief* presented was conceived by AL1 and AL2, it is possible to argue that their *frame*, as their underlying structure of belief formed by AL1 and AL2 previous experiences, gave origin to certain assumptions on how and what the other participants should understand the current design situation and previous design actions. So, AL1 kick-started the activity presenting the *Brief*, as a document, showing and referencing the current "*Foot Plan*", as a design representation; hence commenting about the selected *Design Topics*, which were summarised in four keywords: *Existing Campus, Punched Window, Curtain Wall + Glazing and Materials* (Figure 2). Curiously, at that moment, the participants did not question these design objects (representation and concepts), which later revealed to be sources of misunderstandings.

Figure 2: Elements of Design Situation (1,4); (2) *Briefing* and (3) *Exploration* modes

During the exploration mode, there was a moment when A4 indicated that she had a **different interpretation** about the representations (Foot Plan + Perspective) presented earlier, which **revealed a conflict of understanding**, as is indicated in Table (1). Then, the initial assumption that everybody was interpreting the representations similarly was proved wrong. In this case, the misunderstanding may have been caused by A4 lack of understanding of the representation or her inattention to some aspects of the representation. However, after this revelation, A4 and AL1 continued working on their individual conceptions of an *Emergent Design Topic*: the "*Building Entrance*". Later in the task, during the presentation mode, this lack of shared understanding was exposed again but in depth to the whole group, which supported the **breakdown of the assumptions**. At this stage, the participants engaged in a set of questioning and explanatory actions to collectively understand the reasons behind these diverse interpretations, and what were the assumptions embedded on these perspectives (Table 1).

In another moment, during the *exploration* mode of activity, AL1, A4 and GD started a playful conversation about the idea of a "pyramid" (which was suggested by the client as a reference to pyramids in the existing buildings in the campus) and how in their view it would not fit to the current concept of the proposed building envelope design. Through this open chat, GD suggested the idea of putting a pyramid as a sculpture in the courtyard.

However, till that moment, the idea of a "pyramid" was still a loose concept in the project and the discussion of their individual views of the purpose of the "pyramid" had not been explored. Thus, GD tried to build shared understanding about this *Emergent Design Topic*: the "*Pyramid*", by **questioning and then discussing her conception** of a *Sculptural Element* with AL1. The conversation was developed and led to the collective evaluation of her conception of how a "*Sculpture*" as the proposed objectification of the Emergent Design Topic: "*Pyramid*" could be implemented (Table 1).Interestingly, in this case, in addition to the use of graphical representations she also uses gestures to describe her conception (Figure 2, Image 3).

The **use of a metaphor to bridge and convey understanding** on design topics was noticed a few times during the Charette. The most significative happened at the end of the *briefing*, when AL1 try to explain her perspective about how they should approach the main objective of the session: design the exterior of the MOB. In her concluding argument she uses two metaphors within a comparison (the "*cousin*" vs. the "*twin*" building) to make it clear that the new MOB should fit into the context of campus, but at the same time it should not look exactly the same as the existing buildings (Table 1).

Overall, when participants didn't act towards exploring the diverse and conflicting understandings that emerged during the task, shared understanding could not be constructed. For example, during the *presentation* mode, while participants had the chance to present and provide explanations about their individual perceptions and conceptions over the design topics, they lacked the initiative to collectively reflect over how these ideas could be evaluated, balanced and, eventually, merged into a group proposal.

Therefore, building shared understanding requires that participants perceive and embrace the dialectical nature of collaborative design, and work upon contradictions emerging from different perceptions founded on individual frames that manifests through diverse artefacts of interaction (i.e. verbal argument, graphical representations, organisational processes). Through such dialectical activity participants in the early design collaboration can potentially review, reposition and construct, in the sense of a bridge, their collective interpretations and actions.

Table 1: Capturing the dynamics of building Shared Understanding

Capturing the Dynamics of construction of shared understanding in Early Design Stage

Actions	Design Aspect	Fragments (Evidence)	Image
Emergence of Different Perceptions			
Initial (wrong) Assumptions:	Summary of Previous activities; Current State of Design	AL1 and AL2 sent to participants in advance: Brief + Design representation (i.e. Foot Plan and 3D perspective image)	Figure (2) Image 2 and 4
Independent Actions:	Predefined Target Design Topics of this session	*Existing campus; Punched Windows; Curtain Wall + Glazzing; and Materials*	Figure (2) Image 1
Revealing Conflicts of Understanding			
Diverse interpretations about:	Emergent Design Topic: *Building Entrance*	A4 points to the drawing and argue: "*Humm... I thought It was the last one... This makes me think....* (short pause)*... I mean... I didn't realised we were entering on this side of the building..."*	
Breaking Down Assumptions			
Reflecting over embedded assumptions (individual frames)		A4: "*... I would say from my perspective... When I first look at it I did not know where your entrance was... Just because the entry is so similar to the rest of it... I though for sure you are entering from this side, next to the building... First I thought this is your front* (showing in the drawing)...	
Asking for explanations	Emergent Design Topic: *Building Entrance**	AL2: *Like that corner?* A4: *Yes! Like this was your front…right here!* AL2: *Ow!? Ow!?* (surprise reaction). AL1: *Interesting! Ok! Ok!* A4: *I mean clearly this is you* ***big piece*** *!* (showing and pointing the element on a perspective picture)*… but I don't… just because how it was… it seems like… that wasn't noticeable like… you can see it…* AL1: *Yeah!* A3 (Pointing and making gestures over the drawing and picture): *Cause it feel like this glass is happening over that (inaudible)… maybe we should bring it up front… to have a prominence or like…*	
* Observation: unfortunately, this conflict wasn't resolved during this session (AL1 and AL2 would use all contributions to develop further the proposal)			
Constructing metaphors			
Externalise conceptions	Emergent Design Topic: a *Sculptural Element (The Pyramid)*	GD: *Maybe it could be just a sculptural object on the courtyard?!…* AL1: *That would be wonderful and…. Yes!!.. Like a fountain…* GD (laughs and add to the discussion): *… I was thinking like a black, charcoal wood* (making gestures with her hands) *in a plinth* AL1 laughs and agrees: *Yeah! That would be cool)…Like that would be really great… is in it cool?... Yeah! And that would be kind like a tiny little "pyramid"… (inaudible)… it would be like we're done.* GD: *Yes! (Inaudible)* All participants drawing in silence (30 sec). AL1 (coming back to the topic and supporting the argument): *Yeah (shaking head negatively)!... It "should" be crazy… (3 secs pause)… I like the idea of making a sculpture on it though. That is really strong.* GD: (inaudible)… *right here!... here!* (Point on the drawing, showing to A4)*… (more inaudible).*	Figure (2) Image 3
Propose a shared conception using metaphors	*Cousin vs. Twin building*	To conclude the presentation of the brief, AL1 says**:** "*So when you think of campus design, this is something that we presented to the clients. …If you think of the campus… you have your set of buildings that were done early on and then you also have the new version of what the campus can be so this is an opportunity to do something similar for their project and we have presented this project as it is the "* ***cousin*** *" building to their MOB that they already have and not the* ***"twin"*** *… so… so… that is the basic set up."*	

CONCLUSIONS

In conclusion, misunderstandings can be considered a natural emergent feature of early design collaboration, which may lead participants to engage in a dialectical construction of the activity. In this case, the emergence of diverse understandings in a design task is not a bad thing. However, if not revealed and resolved it can lead to wrong assumptions and expectations among the design team. Diverse understandings emerge and are manifested within the artefacts the participants design and choose to use in the task. When these diverse understandings are revealed and exposed in time, it can lead to an opportunity to explore and expand different ways to perceive the situation, as well as conceive different design alternatives.

However, exposing different perceptions in a design task requires participants to engage in collective explanatory interactions (e.g. asking and describing) involving reflective practices (i.e. *why am I thinking in this way?*), which help them breakdown assumptions, that may be proven to be wrong, especially about other participants' work contributions. Consequently, this means that initiatives that only focus on "exchanging information", as way to share knowledge about different perceptions and alternative conceptions is not enough. According to the proposed framework, design participants need to engage in explanatory actions (constructing "explanatory artefacts") that help them "bridge" different frames of understanding (i.e. object worlds), and collectively 'establish predictions about future states, in order to collaborate. Designers do that by using metaphors.

Therefore, this framework could be used to help design teams map and reflect about their interactions at early design. By focusing on setting the design team object (i.e. *what are the specific design topics on this task*?), individuals can expose diverse interpretations over design objects, and establish the means (artefacts) to evaluate them collectively.

Following this study, the next step on the research is to explore how the collective construction of the design object interacts with the collective construction of the project activity. This will be done to identify if different collaboration conceptions could also be a source of misunderstandings.

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LEAN LEADERSHIP TRAINING: LESSONS FROM A LEARNER-CENTERED ANALYSIS

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ABSTRACT

This paper presents an analysis of a Lean Leadership (LL) training program initiated by the company about two years ago. The program's main goal was to disseminate Lean throughout the company, which has been using Lean principles in its projects for about 20 years. So far, the LL program has reached over 280 participants. The program is constantly analysed via feedback provided by participants, however, no detailed analysis like the one presented herein has been conducted and shared. Participants of the program were requested to provide feedback about the program by answering a survey designed to capture their background and impressions the training.Data revealed that respondents with different roles, mostly related to field tasks, are attending the program and would recommend it to others. Most respondents consider themselves Lean leaders and educate others on Lean content. Respect for people, use of visuals, go and see, and use of Plan-Do-Check-Act (PDCA) have been reported as Lean tools and principles constantly used. By sharing the lessons learned about this program, the authors expect to contribute to the change management and education literature within the Lean community.

KEYWORDS

Lean leadership, training, Lean journey, change.

INTRODUCTION

"*A strong assumption within Toyota's culture is that managers are leaders and leaders are teachers*" (Liker and Hoseus 2008, p.9). This statement summarizes the strong link between the culture at Toyota as an organization and how it views its leaders and managers as teachers who mentor their co-workers and share the company'scommon beliefs, values, and assumptions. Liker and Hoseus (2008) explain the cultural bond that links people at organizations using a Venn Diagram, which conveys the message that as individuals (depicted as circles) we have our own beliefs as well as beliefs that serve a common purpose in the organizations we work for. The overlapping areas between

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different circles in the Venn Diagram represent the common purpose people develop while working for an organization. The more people share in common, the more aligned they are expected to be in the pursuit of the company's goals.

This paper presents an analysisof a current effortby a construction company to align its personnel regarding the use of Lean through the development of a Lean Leadership training program. The program was first discussed in a previous IGLC paper (Hackler et al. 2017), which explained the initial steps the company took in their journey to develop Lean leaders. The current paper focuses mainly on some lessons learned from the program, what participants seem to value in the training program, what can be improved in the future. A brief literature review of previous efforts reported in the IGLC is presented, followed by the method to gather data and the presentation of results. The paper concludes with lessons learned from the program evaluation.

LEAN PRICIPLES AND RELATED TRAINING

The IGLC as a group has hosted over the years a track on "People, Culture, and Change" which presents studies on diverse topics related to Lean implementation and education, and its related challenges. Some of these papers have been broad in nature, and discussed attempts to train a company's personnel on Lean principles (Izquierdo et al. 2011) or train their extended supply chain of project participants on Lean Thinking (Napolitano and Cerveró-Romero 2012). Along these lines, Napolitano and Cerveró-Romero (2012) suggested a model to implement Lean across an organization and in its extended supply chain by involving 41 different companies to create what they called a meta-organization. Their main idea is to spread the knowledge of Lean to their partners so that everyone plays by the same rules and understands the necessary changes to be made to function as a Lean team.

Moreover, Mossman (2015) discussed a list of skills and knowledge required from those teaching Lean (e.g., leaders, coaches, consultants) and also highlighted the importance of having Lean training programs that are: multi-disciplinary, learner-centered, and with a focus on developing people and process skills. To support the teaching of Lean to industry practitioners, Rybkowski et al. (2011) developed a workshop to teach Lean concepts and Neeraj et al. (2016) organized a list of simulations to help practitioners get more engaged with the learning process, as suggested by Mossman (2015).

Other studies have focused on training to address specific issues related to Lean implementation. Leino and Elfving (2011) described a program to implement the Last Planner System and a zero accidents program, which involved educating and engaging the workforce, and the resulting improvements obtained in terms of health and safety including an 80% drop in the lost time accident rate in about 5 years.Aslesen and Tommelein (2016) suggested that last planners display different behavioral patterns that define how they plan and control their projects, and training should be provided to steer them to be more effective in the management of their projects.

The evaluation of the training program discussed in this paper addresses some of the issues identified in the literature. The training provided, as discussed by Hackler et al.

(2017), provides participants coming from different backgrounds and with diverse types of responsibilities across the company the opportunity to engage in a Lean training. Participants are requested to read the course material for each module, and also to reflect how the material can be used in their projects and how they can effect change. The training is multi-disciplinary and learner-centered as suggested by Mossman, and addresses different concepts related to Lean. The following sections describe the method used to evaluate the program and to unearth some important perceptions and feedback from participants.

RESEARCH METHOD

The lessons learned reported in this paper are the result of a large training program under development at a company based in the Redwood City, California. The company founded in 1990 is a commercial contractor and construction manager, and has been ranked in the top 50 general contractors in the United States since 1997. It currently has 26 offices in the United States and three abroad.

The main tool used to develop the assessment of the LL program presented in this paper was an online survey deployed to current and former participants of the training. The authors brainstormed a set of questions that would capture some of the respondents' background as well as their feedback about the course modules and what they are doing with the knowledge they are gaining from the course. Finally, the survey tried to capture what can be improved in the program and how. The questions asked in the survey, which remained active for about two weeks,and the format of the answers were the following:

- Have you completed the Lean Leadership course? (Answers: Yes, I attended and completed the course; Yes, I am attending the course now;or Yes, I attended but have not yet completed the course)
- How long have you worked in the construction industry? (0-5, 5-10, 10-15, 15-20, 20+) | How long have you been with DPR? (0-5, 5-10, 10-15, 15-20, 20+)
- Which of the following options best indicates the type of work you do for DPR? (Project executive, project manager, assistant project manager, superintendent, assistant superintendent, project engineering, estimator, scheduler, procurement, project pursuit/business development, design manager, other)
- Which were the most useful modules of the Lean Leadership training? Indicate your top 3. (Lean vs. Traditional; Principles & Purpose; Focus/Alignment/Constancy, Student & Teacher, Inquiry vs. Advocacy; Respect/No Blaming People, Value Stream Thinking, Effective Measurement, Reflection, Leader Standard Work, 'Go See' Leadership, Building Teams, Advocating Lean Thinking and Mitigating Resistance)
- Do you consider your project lean?(Yes/No) | Do you consider yourself a Lean Leader? (Yes/No) | How do you use the knowledge you gained from the Lean Leadership training in your daily routines? (Open question)
- Has the Lean Leadership program helped your team's performance? (Yes/No)| Briefly explain your answer to the previous question (Open question)

- Do you recommend the Lean Leadership course to others? (Yes/No) | hy/Why Not?(Open question)
- What would you do to change the Lean Leadership course? (Open question)
- Do you educate others on Lean tools and processes? (Yes/No) | Briefly explain your answer to the previous question and describe any challenges you face when trying to educate others on Lean. (Open question)

Once the survey was closed, the authors divided the data mainly into demographics and the feedback or lessons learned obtained from the open-ended questions.

SURVEY RESULTS

DEMOGRAPHICS

A total of 85 respondents, out of 280, who have participated in the Lean Leadership (LL) training answered the survey (30% response rate). About 60% of respondents indicated that they had completed the course, and 39% were attending when data were collected for this paper, the remaining 6% have attended but not completed the course. There was a 50/50 split in years of experience. The largest number of respondents (26%) indicated that they have been with the company between 0 and 5 years, and (26%) indicated they have been with the company 20+ years, whereas 19% have been with the company between 5 and 10 years, and 21% for 10-15 years, and finally (8%) indicated 15-20 years with the company.

When asked about how long they have worked in the construction industry, participants were fairly well represented in this survey, as shown in Figure 1. About 45% of respondents have been in the industry for up to 10 years, and the remaining 55% have worked for 10 or more years in the industry. About a quarter of them have worked in the industry for more than 20 years. These numbers indicate that while some of these respondents have been with the company for a short period of time, they have been in the industry for a much longer time and are willing to keep learning.

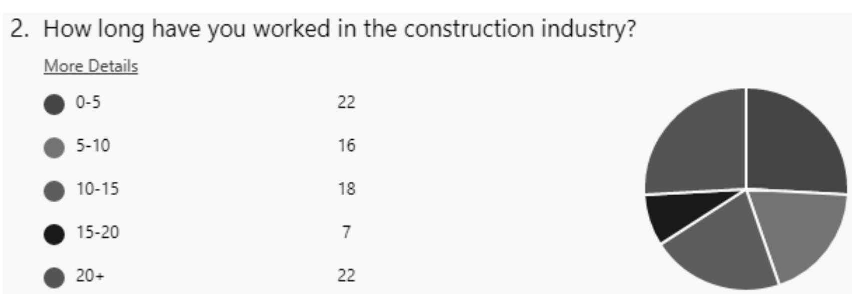

Figure 1: Time in the construction industry

Figure 2 reveals the main type of work respondents develop at the company. Interestingly, three of these categories stood out as they represent those who work close to the daily field operations necessary to deliver a project: superintendents (24%) and project engineers (24%), followed closely by project managers (19%). This figure also illustrates the diversity of roles performed by the LL training participants providing a cross section of activities in the value chain of a project. However, the feedback is mostly provided by field-related personnel and not so much by office-related ones. No feedback was obtained from people who self-identify their work with areas such as procurement, design management, and project pursuit because these activities are handled by project teams and respondents did not view these roles as their primary work within the company.

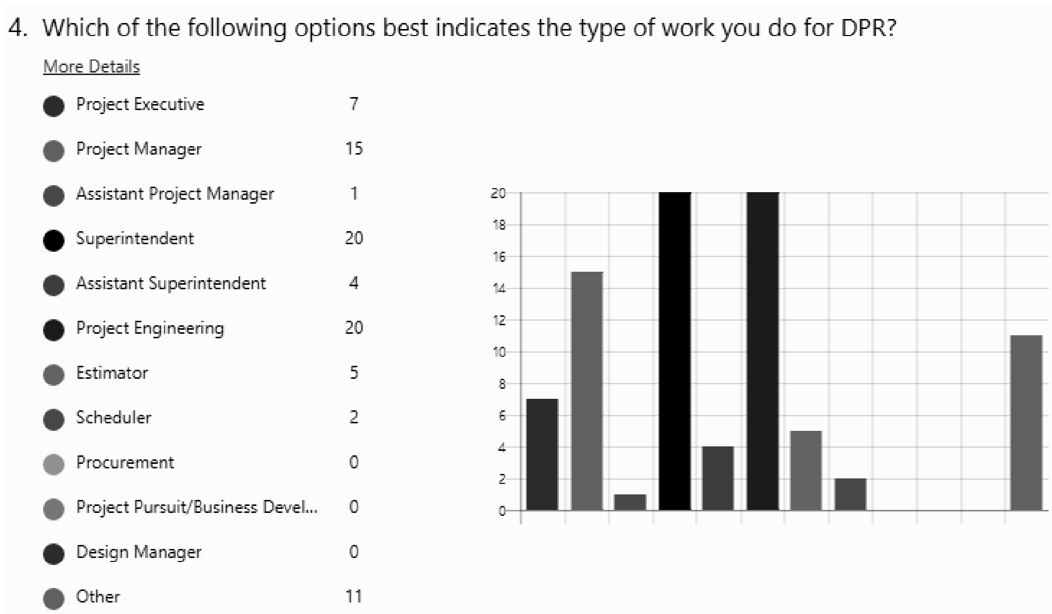

Figure 2: Type of work developed by respondents

Also, it is worth noting that the company has roughly one business development person per region (approximately 20 of them) and so far, only one has taken the course, whereas there are about 35 schedulers and 8 have taken the course. These collaborators might have taken courses and gone through training sessions elsewhere, but that was not captured in this survey.

COURSE MODULES

The LL training as deployed at the company is explained in more detail by Hackler et al. (2017) and based on the book by Gran et al. (2012). The training contains 13 modules, listed in Figure 3, and the top three modules as selected by the respondents included: Respect/No Blaming People, 'Go See' Leadership, and Lean vs. Traditional. It is worth noting that these results might be skewed because some of the respondents might not have yet covered some of the later modules shown in the sequence they are delivered in Figure 3.

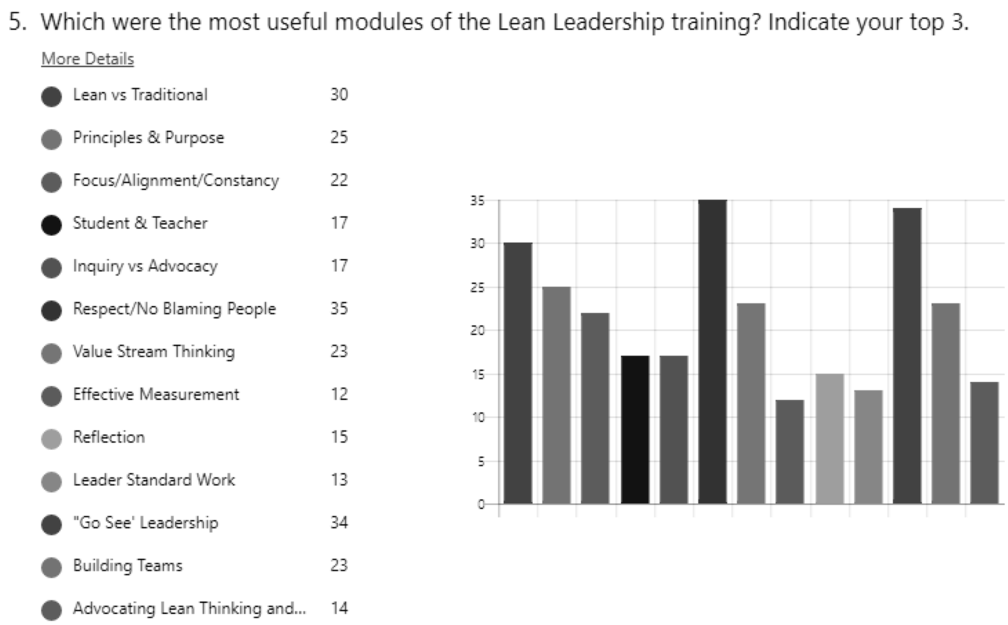

Figure 3: Preferred Lean Leadership course modules

LEAN LEADERSHIP AND EDUCATION

Respondents were asked in different questions to express their perceptions about how the program helped their teams and projects, whether they perceive themselves as Lean leaders and whether they are educating others on what they are learning in the LL course. Table 1 shows the responses indicating that 83% of respondents consider themselves Lean leaders and 85 % educate others on Lean tools and processes. However, when asked if the LL program has helped their team's performance and whether they consider their projects Lean the numbers drop to 68% and 58%.

Table 1: Lean leadership, Lean projects, and education

Question	Yes	No
Do you consider yourself a Lean Leader?	83%	17%
Do you educate others on Lean tools and processes?	85%	15%
Has the Lean Leadership program helped your team's performance?	68%	32%
Do you consider your project lean?	58%	42%

The results suggest that there is a gap to be bridged between translating the coursework to tangible actions to improve the projects, and there still much room for making projects Lean and improving their performance. The follow up questions to the ones presented in Table 1 provided some clues about the gap observed between being a Lean leader and being able to see results in their projects.

When asked about how the knowledge gained from the Lean Leadership training was used in their daily routines, participants pointed to the: need to identify and eliminate waste; use of the Plan-Do-Check-Act (PDCA) cycle to identify problems and potential solutions (P), implement the solutions identified to solve the problems (D), check how the solutions are working (C) and act to correct deviations and promote continuous improvement (A); use of visuals to promote communication and more transparent environments, and respect for people. Selected quotes from participants include:

- *I use inquiry much more and focus on process.*
- *I'm not sure I can say much of this was new to me personally. Rather, the training is giving me greater context to understand how we intend to incorporate these principles on our projects.*
- *Open Communication - Allowing open door policy where everyone feels safe to bring forward issues and feel they are heard when providing solutions. Recognizing potential problems before they arise and having options for solutions*
- *Greatly increased visual planning and communication of the plan. Daily huddles for accountability of the last 24 next 24. Use the ideas in the course to better explain my intent to the team.*
- *By consistently monitoring our project with the PDC[A] approach and encouraging feedback from our trade partners in eliminating waste and gaining value by striving for constant improvement.*
- *I've started to focus on the processes in place if something does not go as planned rather than critiquing the employee working on the task in hand. Making tasks more efficient leads to better results.*

About two thirds of respondents (68%) indicated that the LL program helped their teams performance, however, those who answered 'no' in general indicated the following reasons for their answer: they were early on the training, pushing for change is difficult, and their project team at large is not interested in Lean. Those who answered 'yes' largely pointed to issues related to: having more respect for people/partners, being able to better assess and solve issues, focusing on continuous improvement, raising awareness and alignment about Lean tools and principles helps the teams use them, using 'go and see' often. Some quotes from respondents include:

- *Lean leadership promotes a more employee friendly environment and opens communication to improving what we do everyday.*
- *Its helped me ask more questions and drill down rather than immediately try to solve a teams problems.*
- *Strive to eliminate waste, get clarity in what is being requested. Value stream thinking (draining the river to see the underlying obstacles.*
- *Project Managers and Execs are using "go see" leadership much more often.*

Respondents overwhelmingly indicated that they educate others on Lean tools and processes (85%), moreover, they indicated the challenges they face while trying to do so and what they have been doing to address that as part of a change process:

- *I utilize what is learned in the class to improve jobsite efficiency and these tools and processes are shared with the project team. Challenges on educating others is when you are working with project team members that are very experienced in construction and not as easy willing to adjust to new practices.*
- *I try to educate my team on lean principles. Sometimes I get kickback because the principles are contrary to traditional thinking.*
- *Most are open minded but occasionally you encounter resistance. By showing success using lean techniques they learn that there are better ways of doing business.*
- *I don't phrase it as in "I am teaching you lean" but if there is an opportunity to improve something that I see, I will make the suggestion.*
- *I try to lead by example everyday. Our job as leaders of projects is not to make things harder, but to make work easier and more streamlined. We have to stop blaming the subcontractors for everything that goes wrong. We are the leaders*!

Finally, almost 100% (only one respondent said ‘no’) of respondents indicated that they would recommend the LL program and offered feedback on what could be improved. Improving the videos, using examples from the construction industry and cases from the company’s own experience, having face-to-face training and/or local community of practices, and discuss topics in a quick format or faster way were the most common types of comments.

DISCUSSION AND MOVING FORWARD

As results were being analysed, the first two authors who work as leaders of the LL training program defined the conditions of satisfaction (CoS) for this program and divided them into personal CoS and Team CoS as shown in Table 2.

Table 2: Conditions of Satisfaction for the LL Program

Personal level	Team Level
Behavioral changes	Consistency among projects
Improved Quality of life (what's in it for me)	Teams are aligned around project learning
Engage in the material practice skill and implement ideas of lean	Empower LL to educate and change team dynamics and inspire breakthrough performance.
Develop 1,000 LL in the company by the end of 2019	Change perception that people are lean but team are not.
Maintain 10% drop our rate per class	Lean champions on every team – project and office.
Live in the PDCA cycle every day	

Based on the CoS presented and what the first two authors learned from the experience so far, some important changes are currently under way. While change in behavior is difficult to measure, the survey results show that over 80% of the students consider themselves Lean Leaders and educate others on Lean. However, the results also show that there is a 15-25% lower score on team performance. To drive the team performance higher, a pilot project cross-company team training was completed, and coaching is ongoing. Next, a newer company region will take the training together by having the initial kick-off, then a middle of the course check in, and a close out session all face-to-face. Additionally, to keep the effort "learner-centered", local Lean groups are starting up. One of the goals is to have a Lean champion on every team, project or office based.

To further describe some of the lean improvements that were made over the course of last year, here are the incremental changes:

- PDCA: The weekly check-in format was changed from asking each student to talk about their homework to 5 students talking about each of the homework questions. This greatly improved the discussion and allowed students to add specific points.
- 5S: OneNote for Meeting Notes was improved with better templates and real-time information from the Learning Center. This allowed the facilitators less time for setup and now 2 rounds occur in a 3-hour timeframe. This also allows makes it easier for new facilitators to see the process and focus on the people. Students now sign-up directly on the Learning Center.
- Transparency: A student scorecard in OneNote was used to show real-time weekly lesson progress, weekly check-in attendance and participation. This is driving our students to keep up with the weekly homework rather than complete it weeks after the check-ins complete. (Round 6 week 6 homework was at 25% while Round 8 week 6 was 70%).

- Better Participation: The new question format, students keeping up with homework and tracking full participation has made for better weekly check-in conversations.
- Respect for People: Instructors and students started using their webcams so that the Go To Meeting become more personal. Coaching hours/student check-in have also been added.
- PDCA: The chat box was used for a plus delta and now added to the LL OneNote.
- Continuous Improvement: Learning Center reports were created so that the student's Apply Your Learning could be easily copied to OneNote reducing facilitator setup time.

CONCLUSIONS

The last year of LL has been a huge PDCA cycle for all of us involved in teaching Lean. We found that people have truly enjoyed the course by continuing to sign up and dedicate 9 weeks to the course on top of their daily responsibilities. They have walked away truly believing in PDCA, we had multiple students say that was their biggest takeaway from the last round of LL class. We have also known that LL participants are making big changes moving forward when using the PDCA cycle, they do not feel hesitant to stop, improve then move forward, typically right now people are scared to pause when they see issues with processes. Another big change is that managers are finding fault at processes and not people, knowing that processes will fail at some point. Teams are promoting a learning mentality when it comes to improving, causing teams to be open to continuous improvement.

Moving forward we are sticking to what has worked which is PDCA and asking the students (our customers) what they think will improve the course. For 2019, we will replace some of the content purchased from an outside vendor with our own employee's videos. We will choose one chapter and then ask our customers if they prefer our employee's examples or the examples given in the existing modules. If they like the changes, our plan will be to replace all content with internal examples. We will continue to drive toward a learning culture and want to see the numbers of people that say they are lean (82%) to match the number of people that say their project are lean (60%), if we are able to change this number then our workers are teaching and educating others and promoting the lean culture of learning.

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LANGUAGE, MOODS, AND IMPROVING PROJECT PERFORMANCE

David Long[1] and Paz Arroyo[2]

ABSTRACT

Compared to other industries, the construction sector has lagged in improving productivity. Effective performance, of which productivity is an indicator, is facilitated by conversation that clearly identifies necessary steps to achieve common goals. The type of language used in productive conversation can be referred to as the language of action; similarly, the term “linguistic action” denotes a domain of effective speech to facilitate action. However, even when linguistic action is employed, teams may struggle to communicate effectively when the speech or moods of individuals, or the environments in which they are operating, are not conducive to either productive action or dialogue. This paper proposes direct relationships between linguistic action, positive moods and team performance. It observes that the ability to recognize and influence moods suggests that team performance can be improved by fostering positive moods in the work environment. Two research questions are explored: 1) What research has connected Linguistic Action and mood to increased performance? 2) What are potential new opportunities for connecting Linguistic Action and mood to performance on projects?

KEYWORDS

Linguistic Action, Productivity, Performance, Language Action, Learning Behaviors, Lean, Moods.

INTRODUCTION

The lean construction community has long recognized low productivity issues in the global construction industry. Construction related spending accounts for 13% of the world’s GDP, yet the sector’s annual productivity growth has increased only 1% per year for the last 20 years (McKinsey report 2017).Although this report provides a healthy dose of cautionary disclaimers it outlines seven ways to tackle ten root causes of poor productivity. The adoption of lean principles in project management has been shown to increase productivity, primarily as a result of applying The Last Planner® System (LPS), a commitment-based production process control method. LPS recognizes the positive effects of making and securing reliable promises, and as a management philosophy streamlines decision-making and production processes. Ballard and Howell (1994)

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illustrated the connection between commitments kept on projects, measured by "Percent Planned Complete" (PPC) in LPS, and increased productivity. Macomber and Howell (2003) connected both the linguistic action perspective (LAP), and research from Flores (2012), to improved project management. Flores (2012) identified the five "speech acts" (Fig. 1) of effective conversation (Declare, Assess, Request, Offer, Promise and Assert) and how they can be applied in the work environment to frame discussions as "conversations for action." The LPS uses the speech act of "promise" to establish commitments, thus reducing variability and increasing productivity. The direct connection between increased fulfilment of commitments, as measured by the Percent Plan Complete (PPC) in the Last Planner System, and increased productivity was shown by Ballard and Howell (1994) and again by Liu et al. (2010). Understanding commitments as promises, one of the speech acts in Flores (2012), establishes the direct connection between linguistic action and increased productivity.

Flores, G.P. (2016) further advanced the work of Flores, F. (2012) by observing the connection between moods and learning; moods that are unproductive or moods that are conducive to learning are identified, and the nature of mood and learning, as well as their connection to collaborative team performance, is explored. Commitment (promise) in the function of the LPS exemplifies how Flores's "speech acts" can be used to improve performance on construction projects. Although the remaining four speech acts are mentioned in the literature, there is not much discussion about how to explicitly apply them to improve project performance. Even less has been said to connect project performance and mood, and there is no discussion of the methods by which moods can be improved to positively affect construction project outcomes. The literature on speech acts from the linguistic action perspective in construction reflects a variety of authors' attention to the relationship between performance, the use of linguistic action and the potential effect of mood on projects.

RESEARCH QUESTION AND METHOD

The research questions are: 1) What research has connected Linguistic Action and Lean to increased project performance? 2) What are potential new opportunities for connecting Linguistic Action and mood to performance on projects?

This paper shows the results of a review of previous research studies exploring "linguistic action" in the lean construction literature; past IGLC papers were given particular attention in the analysis.

LANGUAGE ACTION

In his book *Conversations for Action and Collected Essays* (2012), Fernando Flores writes about using "action language" to in still a culture of commitment in working relationships. Expanding on the linguistic action work of Austin, J. (1975) and Searle J. (1969), Flores defines six basic speech acts: declaration, request, promise, offer, assessment, and assertion (Table 1). Understanding the nuances of each speech act can explain dysfunction in communication and shed light on action outcomes. In related research, Macomber and Howell (2003) borrowing from Flores, F. (2012), observed that projects are a network of commitments, while (Ballard, G. and Howell, G., 1994) used percent planned complete (PPC) to measure and illustrate the direct relationship between commitments made on projects and improved productivity. Beyond being a “network of commitments,” a project should also be considered as a “network of conversations” built on all five speech acts defined by (Flores 2012) to further improve productivity.

Table 1: Speech Acts and Actions

Act	**What it Does**	**Elements**
Declare	Open a new world for action	Infers authority
Assess	Open new possibility or prepare for action	Futuristic, grounded, or ungrounded
Request	The speaker is asking a potential performer for action around a concern	Conditions of satisfaction, background of obviousness, time
Offer	Performer promises to care about something he/she perceives the listener to be concerned about	Same as request
Promise	Commit self/enterprise/team to bring a new Condition of Satisfaction	Same as request
Assert	Speaker reports facts and is prepared to offer evidence	Report of fact

MOODS

In Flores, G.P. (2016.) *Learning to Learn and the Navigation of Moods,* Gloria Flores makes the distinction between moods that are either unproductive or conducive to learning. In addition, moods affect the possibilities that people see for their future. She observes that moods are contagious and invisible and that moods can be cultivated. She also states that moods are not emotions, that moods are in the background and are not about a particular event. Humans are historical beings whose possibilities are shaped by historical occurrences. She states that moods are triggered by assessments that are usually automatic.

She presents unproductive moods, and examples of assessments people make when falling into these moods. Here we present these moods with examples of assessments we have heard and observed in construction projects:

- **Resignation:** There is nothing I can do to make this project better; even if I work hard, these subcontractors will not do their part.
- **Arrogance:** I have experience in this type of project, and I know what I have to do. I do not want to waste my time planning.
- **Confusion:** I don't understand what is going on. No one is letting me know what I should do. I am just going to keep myself busy.
- **Frustration:** I have tried to change this project to be a more effective and productive team, but everyone goes back to work in the same old way.

- **Impatience:** There is no value in planning. This is a waste of everyone's time. We should be working on site!
- **Distrust:** I do not trust these subs. These guys are just unreliable. I cannot ask for their help. We will need to add more contingency to this job.
- **Overwhelmed:** There is so much to design in this project and people are not even talking to each other! We will make mistakes for sure.
- **Powerless:** I don't like how things are, but there is nothing I can do to change the system.

She further presents moods conducive to learning. In this paper we are presenting these moods with examples of assessments that we have heard or observed in construction practice that lead to productive conversations.

- **Wonder**: I do not understand the whole design but I wonder if there is a better way to create the value for the client.
- **Serenity/Acceptance**: The future is uncertain, there will be surprises, but our team will be able to get through it.
- **Ambition**: I see opportunities to improve and I am willing to convince others to try them. I am committed to taking action and lead the way.
- **Resolution**: I see opportunities to implement lean in this project and I will take action right now.
- **Confidence**: We have been successful in complex projects in the past and I know we will be able to do it again.
- **Trust**: I am confident that the team will deliver what we need to succeed in this project.

With regard to navigating moods, Gloria Flores (2016) observes: "we can not avoid falling into unproductive moods, but we can learn not to be trapped by them". This "freedom" from moods can be practiced through conscious awareness of one's own mood and the mood of others, exploration of what assessments trigger unproductive moods and the standards that give rise to those assessments, changing the standards that give rise to assessments that trigger unproductive moods, and actively cultivating productive moods.

RELEVANCE OF LANGUAGE ACTION AND MOODS

Projects are organizations. They are groups of people assembled to take action towards accomplishing a common goal. Skilful conversation and language informed by Flores' speech acts strengthens communication and thereby facilitates action.

Proper understanding and use of the speech acts is critical to projects. Confusing speech results in unwanted, improper or insufficient action, such as when a request is confused with an order ("Will you finish foundation concrete this week?"), or a declaration is confused with a request ("We are not on schedule. I think we need to bring more people."), or when a promise is unfulfilled. These miscommunications result in poor planning and an environment of unreliable workflow. Lean construction principals and The Last Planner System seek to reverse this trend.

The Last Planner System, a commitment-based production process control system, brings an awareness of the conversations needed to make commitments, concentrating on the speech acts of offer, request and promise. Any implementation of the speech acts is an improvement over traditional project coordination conversation, but further emphasis on the remaining speech acts, assessment and assertion, would be an even greater improvement. Additionally, formally recognizing the role of productive and unproductive moods is necessary to coordinate action with optimal skill and efficacy.

The speech acts and the role of moods are in play in conversations whether or not the team acknowledges their presence. For example, a simple commitment such as a promise to finish the foundation concrete requires the use of the speech act "promise." Similarly, other conversations, such as requesting work from another subcontractor or requesting concrete from the concrete provider, require the use of the "request" speech act. There are several identifiable elements at play during conversation; for instance, an effective promise involves a speaker, a listener, a specified time for fulfilment, conditions of satisfaction, a background of obviousness, future action to be performed by the speaker, the performer´s ability to fulfil their promise, sincerity, shared concerns, and possibilities for the future (Flores, 2012). Alternatively, an effective request requires the performer and listener to make assessments and assertions in preparation for a promise, such as the declaration by the owner that the job must be competed under a certain cost (declaration), that the drawings indicate a concrete additive is required (assertion), the number of concrete trucks needed (assessment), or the quality of the rebar installation (assessment).Moreover, conversational interactions benefit from the understanding that moods are always present and provide context for communication through feelings such as distrust as in "I do (or do not) trust the subcontractor", or irritability as in "the foreman angered me so I'm not listening to them anymore". The inherent nature of speech acts and moods suggests that consciously recognizing their effectiveness creates an opportunity to improve conversations.

Other studies have also explored how moods can be influenced, are contagious, and impact event outcomes. The clinical study (Kadom et al., 2017) measured the impact of improved mood on adverse procedural outcomes during image-guided interventions. The authors noted "The procedure room is a two-way street in which the patient can affect the healthcare professional and vice versa" suggesting that negative moods are contagious. The team found that improving patient's mood from negative to positive reduced the occurrence of adverse procedural outcomes. Interestingly, once in the positive mood range, further positive improvement of mood did not show additional reduction in adverse procedural outcomes. One of the authors recommended training for procedure-room workers in coping strategies as well as in techniques to help patients reverse negative thought processes.

A functional MRI study of the human brain, in which participants were asked to make positive facial expressions during the scan, demonstrated how moods can be influenced (Kohnet al. 2013). Participants' moods were recorded before and after making positive facial expressions. Participants with elevated mood activated the areas in yellow in their brains; (Fig. 1.) the more positive the mood, the stronger the activation of these areas. The results of this study clearly indicated that making positive facial expressions (inductions) for one-minute intervals in between breaks (baseline) altered brain function in a positive and measurable way among participants. To put it plainly, the act of smiling actually made them happy. There is clearly a reciprocal relationship between moods and facial expression: not only does mood inform expression, but facial expression also affects mood, even when artificially produced.

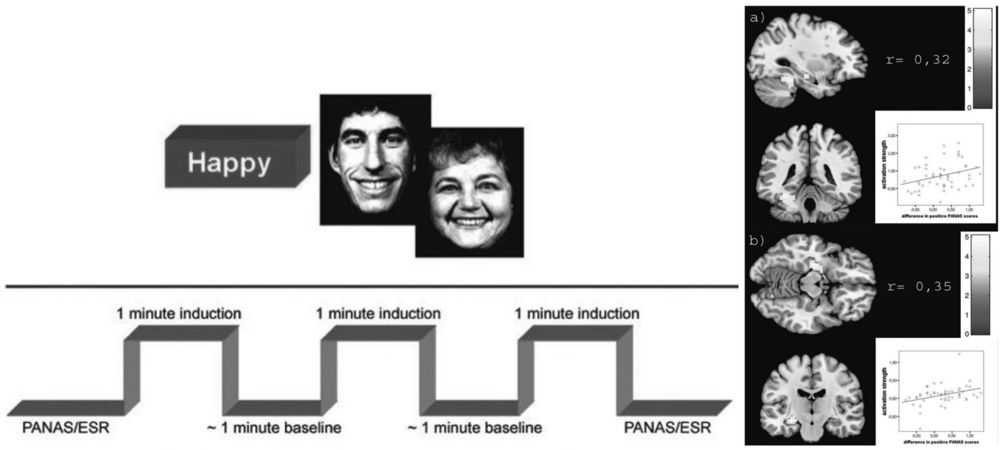

Figure 1: In the upper half of the figure two sample images of the facial stimuli used for support in the mood induction are displayed. On the right is a functional MRI showing the activity in the brain as a result of the positive stimuli. (Kohn, N. et al 2013)

SUMMARY OF PREVIOUS STUDIES

A literature study, primarily of IGLC papers was conducted in which the terms “language action,” “linguistic action,” and related terms were searched. Each paper was independently searched for the terms at the top of the table and their occurrence in the papers recorded.

Table 2: Literature Review

Authors	Year	Title	LPS	Conversation	Speech Acts	Language Action	Linguistic Action	Commitments	Network of Commitments	Declare	Offer/Promise	Request	Assessment	Assertion	Moods
Andersen, L.	2016	'Design and Engineering – Material Order'	X	X	X		X			X	X	X	X	X	
Austin J.L.	1955	How to do Things with Words		X	X		X	X		X	X		X	X	X
Azambuja, M.M.B. , Isatto, E.L. , Marder, T.S. & Formoso	2006	The Importance of Commitments Management to the Integration of Make-to-Order Supply Chains in Construction Industry		X	X	X	X	X	X	X	X	X			
Ballard, G. and Howell, G.	1994	Implementing lean construction: stabilizing work flow	X	?				X							
Ballard, G. & Howell, G.A.	2003	'An Update on Last Planner'	X				X	X	X		X	X			
Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N., Brown, S.	2017	Reinventing Construction: A Route to Higher Productivity	X												
Cleary, M. , Rooke, J. & Koskela, L.	2010	On a Road to Promises That Work					X	X	X		X	X			X
Feliz, T., Reed, D., Draper, J. and Macomber, H.	2014	Leveraging Software for Learning-in-Action Using Commitment-Based Planning	X	X	X	X	X	X	X	X	X	X	X	X	X
Flores, F.	2012	Conversations for action and collected essays: Instilling a culture of commitment in working relationships		X	X	X	X	X	X	X	X	X	X	X	X
Flores, G.P.	2016	Learning to Learn and the Navigation of Moods: The Meta-Skill for the Acquisition of Skills		X	X	X	X	X	X	X	X	X	X	X	X
Howell, G., Ballard, G. and Demirkesen, S..	2017	Why Lean Projects Are Safer													
Howell, G. & Macomber	2006	What Should Project Management Be Based On?		X	X	X	X	X	X	X	X	X	X	X	X
Kalsaas, B.T. & Sacks, R.	2011	'Conceptualization of Interdependency and Coordination Between Construction Tasks	X		X	X	X	X			P	X			
Knapp, S. , Charron, R. & Howell, G.	2006	Phase Planning Today	X	X				X	X		P	X			
Liu, M., Ballard, G. and Ibbs, W.	2010	Work flow variation and labor productivity: Case study	X	X				X	PP C						
Macomber, H. & Howell, G.A.	2003	Linguistic Action: Contributing to the Theory of Lean Construction	X	X	X	X	X	X	X	X	X	X	X	X	X
Macomber, H. , Howell, G.A. & Reed, D.	2005	Managing Promises With the Last Planner System: Closing in on Uninterrupted Flow	X	X	X	X	X	X	X	X	X	X	X	X	
Rooke, J. , Koskela, L. , Howell, G. & Kagioglou, M.	2012	Developing Production Theory: What Issues Need to Be Taken Into Consideration?		X		X	X	X	X	X	X		X	X	
Senior, B.A.	2012	An Analysis of Decision-making Theories Applied to Lean Construction	X			X	X								
Slivon, C.A. , Howell, G.A. , Koskela, L. & Rooke, J.	2010	Social Construction: Understanding Construction in a Human Context	X	X			X	X							
Viana, D.D. , Formoso, C.T. & Isatto, E.L.	2011	Modelling the Network of Commitments in the Last Planner System	X	X	X	X	X	X	X	X	X	X			
Vrijhoef, R. , Koskela, L. & Howell, G.	2001	Understanding Construction Supply Chains: An Alternative Interpretation	X	X	X	X	X	X	X	X	X	X			
Zegarra, O. & Alarcón, L.F.	2013	Propagation and distortions of variability into the production control system: Bullwhip of conversations of the last planner	X	X	X	X	X	X							
Zegarra, O. , Alarcón, L.F. , Pereira, P. & Cachadinha, N.	2013	Weekly tracking of stability of the flow of conversations into the subprocesses of last planner system	X	X	X	X	X	X			X				

As can be seen from the summary of previous studies (Table 2), the lean construction community has discussed connecting the linguistic action perspective to lean methods and project performance. However, less has been said about the connection between mood, learning behaviour and improved project performance. While the connection between improved project performance and communication makes intuitive sense, design and construction teams do not explicitly talk about how language is used on projects or how the project team's mood affects their work. There are numerous examples of conversations that are detrimental to the progress of the project, and regular project participants can easily identify with them, but standard methods of recognizing and changing language habits on projects have not been developed or even seriously considered.

CONCLUSIONS

The design and construction industry has not yet solved its low rate of increase in productivity. There have been productivity improvement approaches outlined, and while the components of their observations are sound, they address extrinsic obstacles to progress rather than investigating interpersonal dynamics that can and should be optimized. Changing the norms of communication, the use of language and the recognition of moods on projects could revitalize the construction industry by increasing more than just productivity but also overall project performance and drastically improving the workplace culture. How project managers and team members use or don't use language in the working environment directly impacts their ability to establish an environment of positive moods conducive to increased performance. The efficiency and follow-through of project tasks, and good intentions on the part of communicators alone is not enough to prevent misunderstandings - particularly when teams lack the sensibilities to differentiate between speech acts and a systematic method for approaching conversations. Based on a review of relevant texts that emphasize the connections between productivity, language, and mood, evidence indicates that shifting to a positive mood is synonymous with a shifting to a mood of high productivity and high performance. More experimentation and research should be done to explore how these observations can improve systems and methods in the construction industry and how to effectively shift teams toward high performance by steering them into positive moods.

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TOWARDS FACILITY MANAGEMENT PARTICIPATION IN DESIGN: A UCSF CASE STUDY

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ABSTRACT

The discipline of Facility Management (FM) emerged in the 1970s triggered by the concomitance of (1) increasing complexity in the workplace and (2) understanding of an interdependence between users' behaviors and building design. Despite the existence of FM, a number of buildings today still fail to deliver value during the occupation phase. Although various causes contribute to such failures, this paper focuses on the lack of strategic involvement of Facilities Managers (FMs) in design. It uses the University of California, San Francisco (UCSF) as a case study to describe how an organization has-in the course of its Lean journey-learned the importance, not only of considering FM requirements during design, but more importantly of actively engaging FMs early in the design process. Benefits experienced by UCSF are multiple. One is that FMs understand, perhaps better than designers, the complexity of the programs housed by UCSF buildings and the constraints this complexity imposes on the design requirements. This helps FMs advise on trade-offs between their preferences for simple (e.g., easy-to-maintain) systems and the programs' needs for complex systems.

KEYWORDS

Facility Management, Case Study, Design Management

INTRODUCTION

The discipline of FM emerged in the 1970s due to concomitance of (1) increasing complexity in the workplace and (2) the understanding of an interdependence between building users' behaviors and building design.

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Information telecommunication technology drastically changed how office work was organized in the 1970s. This shift in how information was distributed and shared, along with other technological breakthroughs, made the built environment more dynamic. As a result, customers became more vocal and what they valued became more varied. FM was created to operate and "steer" the building upon delivery by the Design and Construction (D&C) team, so that it would continue to deliver customer value for many years.

The understanding that people are influenced by the environment in which they evolve dates back many years (e.g., Nightingale 1857) However it is not until the 1980s that the discipline of evidence-based design (EBD), which focuses on the relationship between buildings and user behaviors, was introduced by Ulrich (1984). FM was tasked with observing and managing the interdependence between the building and its users (the terms "occupants" and "users" are used interchangeably in this paper).

Despite the existence of FM ever since, buildings still fail to deliver value during the occupation phase. Although various causes contribute to building failures, this paper focuses on the lack of strategic FM involvement in project delivery, and specifically on FM involvement in design. It provides a case study to illustrate how such involvement may occur.

The paper is organized as follows. The first section lists definitions of FM encountered in the literature as well as the tasks FM encompasses. The intent is to show that (1) the discipline of FM encompasses many activities and (2) no consensus exists on how to do FM. The second section highlights similarities between the emergence of FM and the emergence of EBD. The intent is to invite the Lean community to explore FM with EBD eyes. The third section describes the UCSF case study. The intent is to encourage owners to reflect on how they integrate FM in design and the impact thereof on FM's satisfaction with the building's operability, maintainability, and adaptability to future needs once constructed. The fourth section presents the conclusions of this research.

FM DEFINITIONS AND TASKS

Various literature reviews on FM exist. Bascoul (2017) consolidated a list of 17 definitions of FM, based on literature reviews by Tay and Ooi (2001), Shohet and Lavy (2004), Noor and Pitt (2009), and Waheed and Fernie (2009). From these definitions, trying to determine what is actually managed by FM gives different answers, such as:

1. "Buildings, systems, equipment, furniture" (Becker 1990).
2. "The buildings and infrastructure" (Barrett and Baldry 2003).
3. "Buildings and accommodation, services and resources" (Regterschot 1990).
4. "Services and support infrastructure" (Atkin and Brooks 2015).
5. "Building assets as workplaces" (Varcoe 2000).
6. "Non-core company assets" (Nelson and Alexander 2002).

This paper adopts Atkin and Brooks' (2015) definition: "FM is creating an environment that is conducive to the organization's primary processes and activities, taking an integrated view of its services and support infrastructure, and using them to achieve end-user satisfaction and best value through support for, and enhancement of, the core business."

The authors chose this definition for the following reasons: (1) the importance put on FM for the success of the organization, (2) the consideration of both end-user and business (which are not the same, as Finch (2010) notes), and (3) the emphasis on best-value as opposed to cost effectiveness.

Regarding FM tasks, the scope of FM is so large and varies so much from one organization to another that it is hard to define (Chanter and Swallow 1996, Waheed and Fernie 2009). Unsurprisingly, Noor and Pitt (2009) write that "there is no universal approach to managing facilities." FM role has received many names:

1. "Hybrid manager," "business leader" (Alexander 1994).
2. "Teacher," "housekeeper," "manager," and "juggler" (Aune et al. 2009).
3. "Jack of all trades" (Tay and Ooi 2001).
4. "Innovation leader" (Noor and Pitt 2009), "user-technician" or "super-user" (Aune et al. 2009).

Overall, the literature review suggests that FM has traditionally been considered as a support department rather than a core department, that must be cost-efficiency driven, and that is not directly contributing to meeting the business objectives (Chanter and Swallow 1996, Grimshaw 2007, Noor and Pitt 2009). In this respect, Clayton et al. (1999) write: "Maintenance, remodeling, replacement of components and daily facility operations consume a large portion of the cost of doing business." More recent publications also show that FM is ready for a paradigm shift. This paradigm shift can only happen by acknowledging the value that "FM bring(s) towards organizational effectiveness" (Noor and Pitt 2009).

The next section links the emergence of FM to Florence Nightingale and EBD.

EMERGENCE OF FM

Although some FM literature reviews links the emergence of FM in the US to the creation of the Herman Miller Research Corporation, Finch (2010) links the origin of FM to Florence Nightingale.

While Nightingale is more frequently associated with nursing than FM, one cannot downplay her understanding of the relationship between the built environment and patient recovery. In her Notes on Nursing (1857), Nightingale makes four recommendations with regards to the built environment in order to accelerate patient recovery. Hospitals should have (1) outside air over recirculated air, (2) daylight over artificial lighting or dark rooms, (3) wall and floor finishes that are easy to clean, and (4) variety (in aesthetics) (Finch 2010).

Florence Nightingale's observations are a landmark in the EBD timeline (Rybkowski 2009). EBD is defined as "the conscientious and judicious use of current best evidence, and its critical interpretation, to make significant design decisions for each unique project.

These design decisions should be based on sound hypotheses related to measurable outcomes" (Hamilton 2006). The discipline of EBD was formalized later, by Ulrich (1984).

Thus, FM and EBD have as a common characteristic that they both look at the interdependence between buildings and users. FMs' unique knowledge could play a key role to guide EBD efforts in project delivery. Participating in EBD is one of many ways to strategically involve FMs in project delivery. The next section explores additional opportunities.

CASE FOR FM INTEGRATION

This section captures arguments found in the literature on the value of integrating FM in the delivery of projects during programming, design, planning, and construction. Arguments in favor of FM involvement in the commissioning phase and the use phase are not captured in this paper, since they are abundantly covered in the literature.

PROGRAMMING PHASE

The early involvement of customer user groups (including FMs) has been acknowledged to be critical in the programming phase of construction projects. Because FM maintains buildings, it constitutes a user group that has specific needs as well. In addition to being a user group, FM has two areas of knowledge that can be valuable to the design and construction team.

First, FM knows building users (their behaviors, preference, processes, and activities), since FM interacts with them at the operational level. This is the reason why Aune et al. (2009) compare FM with "super-users" because they "see" the users.

Second, FM has knowledge about how buildings have been satisfying users' needs in the past. Thus, FM can be the "feedback loop" and present lessons learned on former projects to inform the project definition phase, thereby preventing architects and engineers from repeating errors (Aune et al. 2009) and driving them to further innovate.

DESIGN PHASE

Numerous studies have pointed out the importance of involving FM in design. Kalantari et al. (2017) list 13 such studies, and Bascoul (2017) adds 3 more: Mitropoulous and Howell (2002), Aune and Bye (2005), and McAuley et al. (2016). The next paragraphs summarize the arguments given in favor of FM involvement in the design phase.

A first argument is informing the design of maintenance considerations (Aune and Bye 2005) or "maintenance practicality" (Assaf et al. 1996) and thereby drive down building life cycle cost (Meng 2013). Accessibility of equipment, location and sizing of maintenance catwalks, selection of mechanical systems depending on their reliability, location and sizing of janitors' and storage spaces are examples of decisions made in the design phase that FM could inform.

A second argument is increasing building efficiency. Energy efficiency can increase if FM better understands the design intent before occupancy (Aune and Bye 2005)

A third argument is avoiding negative design iteration. Mitropoulous and Howell (2002) investigated design iteration encountered on an office-space renovation project. Through interviews with project team members, they identified: the conditions that created design iteration, causes for design iteration, the effect of design iteration on design, and their effect on cost and time. They concluded that most of the design iteration was due to late discovery of existing conditions. Yet, awareness of existing conditions is part of FM's tacit knowledge, hence the value of integrating FMs in the design phase might have avoided some negative iteration.

A fourth argument is a better translation of customer needs (Meng 2013). This converges with the arguments in favor of FM involvement in the programming phase.

The value of FM involvement in design certainly goes even beyond these arguments, because FM "hold(s) tacit and experience-based knowledge" (Aune and Bye 2005). This makes FM specifically suited to reminding architects whether or not their performance expectations are reasonable, since "designers may sometimes expect their buildings to operate in ways that are not practically feasible" (Kalantari et al. 2017).

PLANNING PHASE

FM strategic involvement in the planning phase is critical for facility upgrades (Bascoul et al. 2017). FM knows how equipment and systems function. It possesses tacit knowledge about existing conditions that may or may not have been captured in as-builts (as it often happens in successive "small" upgrades). It also has accumulated knowledge about how systems are fine-tuned, and the extent to which systems are sensitive to perturbations. FM can inform the construction team about the feasibility and the risks associated with the construction means and methods proposed. FM may also be able to recommend strategies on how to tackle the job.

CONSTRUCTION PHASE

FM involvement in the construction phase is valuable (Enoma 2005, Aune and Bye 2005) and necessary because FM involvement in the programming- and design phases is insufficient to guarantee that what they specified in programming and design has been understood by the design and construction team and will not be altered. This notwithstanding, FM is often no longer consulted in the construction phase, although design changes still happen. Finishes are a case in point. FM have tacit knowledge about the maintainability of finishes and how the products used evolve and last with time. However, substitution with other products and manufacturers still happen during construction for various reasons, hence the necessity of keeping FM informed and involved during this phase.

The next section describes UCSF's Lean journey and how it started to integrate FM in project delivery increasingly early.

UCSF CASE STUDY

Given that FM involves many tasks and UCSF operates many facilities, UCSF has different FM departments with different functions. This section only refers to FM that is responsible for maintaining buildings.

UCSF'S LEAN JOURNEY

UCSF has been using Lean for delivering projects since 2007 (Bade and Haas 2015) and has been successful at it on complex projects exceeding $2 billion and many others.

When UCSF began developing Mission Bay in the late 1990s, it used design-bid-build contracts and Construction Management (CM) at risk delivery methods. UCSF initiated its Lean journey by addressing the root cause of poor project performance: the misalignment between the operating system, the organization, and the commercial terms (contract). These three elements constitute the Lean Triangle (Lean Construction Institute 2017). UCSF developed a Construction Management (CM) at risk with design-build subcontractors and an incentives contract for the $254 million Smith Cardiovascular Research Building. Then, it developed a design-build contract for the $123 million Dolby Regeneration Medicine Building with "lean elements."

A critical component of Lean project delivery is the early involvement of key project stakeholders. Yet, UCSF being a large organization, has projects with many stakeholders. The difficulty that arises then is answering the questions: "Whom to involve in project delivery?" and "When to involve them?" UCSF has identified FM as a key project stakeholder.

EVOLUTION OF FM PARTICIPATION IN DESIGN

Figure 1 depicts the evolution of FM integration in project delivery at UCSF. On the upper half of the timeline, the shaded triangles of the Lean Project Delivery System (LPDS) schematic indicate when FM gets involved in project delivery. The triangles represent the five phases of the LPDS, from left to right: (1) project definition, (2) lean design, (3) lean supply, (4) lean assembly, and (5) use. On the lower half of the timeline, the evolution of FM integration is illustrated using five UCSF projects: (1) Genentech Hall, (2) Helen Diller Family Cancer Research Building, (3) Smith Cardiovascular Research Building, (4) Mission Hall, and (5) Block 33. The dates below the horizontal bars indicate the start and end of construction (the dates for the start of the project definition phase would have been a better indicator of UCSF's evolution with FM integration but these were not available at the time of this writing. They would have allowed readers to compare these dates with UCSF's changes in contracting practices and team selection processes.)

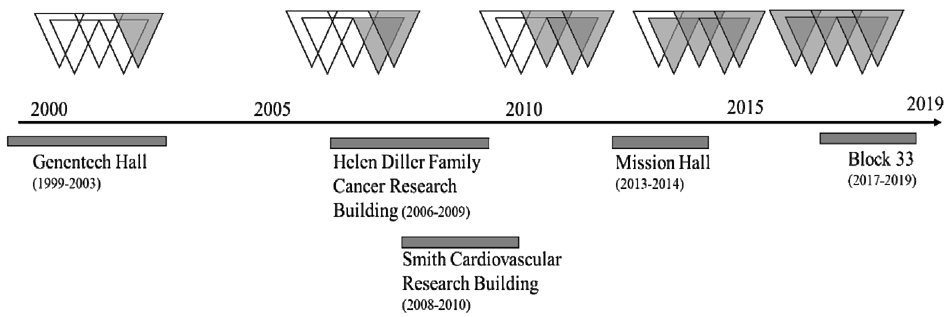

Figure 1: Evolution of FM Integration in Project Delivery at UCSF

Construction of **Genentech Hall,** UCSF's first building on Mission Bay, started in 1999 and was completed in 2003. The $161 million five-story building houses programs in structural and chemical biology as well as molecular, cellular, and developmental biology. It also houses the Molecular Design Institute, Nikon Imaging Center and the Center for Advanced Technology.

At the time, UCSF had not started its Lean journey and FM was involved in the project use phase only. FM at UCSF gave the researcher examples of input that the project team could have requested from them but did not, due to a lack of active participation of FM in the design process. These include: needs in space (e.g., janitor closets, shops, storage rooms, etc.) or the type of water system to use. Concerning the latter, FM indicated they would have recommended the use of a Reverse Osmosis/Deionized water system as opposed to a deionized water system as delivered. Following this project, as UCSF started its Lean journey, FM started to be brought in earlier in project delivery.

Construction of the **Helen Diller Family Cancer Research Building** started in 2006. Occupancy started in 2009. This five-story building houses researchers investigating basic biological mechanisms causing cancer, including brain tumors, urologic oncology, pediatric oncology, cancer population sciences, and computational biology. Although UCSF had already initiated the development of new contracts for integrated project delivery teams, FM at UCSF reported that their involvement remained limited on this project. For example, they mentioned that the building was delivered before being fully commissioned, which FM would have recommended against had they been consulted.

Construction of the **Smith Cardiovascular Research Building** started in 2008 and was completed in 2010. The building houses nearly 500 research scientists and clinicians who work on the development of new treatments for cardiovascular diseases. This project is a landmark in UCSF's Lean journey: project team members met in the "big room" and were collocated in one large trailer. FM became more involved in the design phase and started to be recognized as important project stakeholders to consult when making design decisions.

Construction of **Mission Hall** started in 2013. The seven-story building was completed in September 2014. In terms of contractual relationships, UCSF had a design-build contract with the architect and the GC, which the owner selected on best value. All project team members were involved early on the project, which supported the implementation of the Last Planner™ System in the design phase. Furthermore, UCSF provided the competing design-build teams with the Technical Performance Criteria book version 1.0. In version 1.0, FM weighed in, but it was involved only after the project was awarded to discuss specific FM-related issues. In the first year of building occupancy, the energy profile of the building differed from customer expectations. In fact, FM was not familiar with the installed underfloor mechanical system. FM therefore had to learn how to operate it. Mission Hall was the first building at UCSF to be delivered with a two-year warranty.

Construction of the building on **Block 33** started in 2017. The project will provide space split between two programs. The building will house academic and administrative office space (including desktop research, dry core and computational laboratories), and ophthalmology clinical space, called the "Center for Vision Neuroscience."

Contractually, the project is delivered under a Design-Build agreement which is UCSF's new Integrated Project Delivery (IPD)-like contract, binding the Architect to UCSF, and the GC to UCSF. The contract is qualified as "IPD-like," because it is not a multi-party agreement ("true" IPD contracts presumably are multi-party contracts). However, the use of multi-party contracts is legally impossible for UCSF due to its public status and the contracting regulations that apply to public entities.

For this project, UCSF created the Technical Performance Criteria book version 2.0 as part of its project definition process. This book documents UCSF's expectations about the building from a performance perspective. It is meant to capture what UCSF's project stakeholders value, and to translate what they value into design criteria. Unlike the Technical Performance Criteria book version 1.0, version 2.0 is the result of close collaboration between FM and a design consultant, and active engagement of relevant project stakeholders to unveil operational and physical criteria, understand space requirements, define room layouts that promote efficiency and well-being, and understand past failures and successes by visiting existing spaces and learning from precedents.

LESSONS LEARNED

UCSF sees value in FMs' active participation in the design of facilities. Beyond the reasons commonly mentioned in the literature (i.e., ensuring maintainability of buildings), FM's active participation in design allows them to understand the complexity of the programs housed by a facility, well before building commissioning. This understanding is critical at UCSF, since the organization operates many high-end facilities, or in other words, facilities housing sophisticated systems and/or equipment, which performance is critical to allow the organization to meet its business objectives (e.g., hospital, laboratory, power plant, etc.).

Complex programs in high-end facilities require that FMs make trade-offs, e.g., between their preference for simple and easy-to-maintain systems and programmatic requirements that can only be met with complex systems.

CONCLUSIONS

While FMs may prefer systems that are simple, maintainable, reliable, cost effective, and that they are familiar with, the design of high-end facilities involves one-of-a-kind interdependent systems that require training and expertise to maintain. Thus, when FM is involved late in the design of high-end facilities, conflicts are likely to arise between FM's requirements and the developed design, causing design iteration (at best) or FM's dissatisfaction. Conversely, when involved early, FM can better understand the programmatic requirements of a project. This, in turn, helps them specify maintenance requirements that are compatible with programmatic requirements. While UCSF has benefited from engaging FM earlier in their projects, of note is that their experimentation and learning when and whom to best involve from FM in project delivery is still ongoing.

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APPLICABILITY OF VALUE STREAM MAPPING AND WORK SAMPLING IN AN INDUSTRIAL PROJECT IN INDIA

Lavina Susan Pothen[1] and Shobha Ramalingam[2]

ABSTRACT

Poor productivity and inefficiencies in the production process are alarming issues in the construction industry that also erode the value proposition of projects. Value Stream Mapping (VSM) and Work Sampling (WS) are two important techniques in the 'Lean' philosophy that aim at reducing and minimizing 'waste' in the life cycle process of activities and thereby aide in maximizing productivity. In this paper, we discuss the implementation challenges and benefits of these two techniques in an industrial project in India through an action-based research methodology. While VSM was adopted for Vacuum Dewatering Concrete Flooring works, tour based WS was done for block-work activity. VSM helped to visualize the entire process and reduce time overrun by 2.5 days. Alternative materials were cost estimated and compared to reduce cost overrun. The WS technique helped the contractor to assess the productivity rate and identify reasons for below average productivity. Subsequent corrective action plans and recommendations led to reduce non-value added wastes and improve performance. This study lays a foundation for practitioners to systematically adopt these lean techniques in practice and thereby optimize the process, reduce wastes and enhance productivity.

KEYWORDS

Value Stream Mapping, Work Sampling, Lean Principles, Process Optimization, Industrial Project.

INTRODUCTION

In order to stay competitive, firms in the Architecture Engineering and Construction industry will have to constantly review their process and continuously improve their performance. Construction industry is inherently plagued by poor productivity. A

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McKinsey study reports that over the past 20 years, productivity has increased by only 1% in construction (McKinsey TR, 2017). Lean methods and techniques aim at providing viable solutions to this alarming concern in the industry by identifying and eliminating waste in the process that do not create value for the product, the process and the end customer (Ingle and Waghmare, 2015) and thereby improving productivity. In this study we focus on two lean tools, namely, Value Stream Mapping (VSM) and Work Sampling (WS) and provide a brief overview of the same below:

VSM is a lean tool to visually map the process and identify both the value adding and the non-value adding activities (wastes) in the current state of the production process (Tapping et al., 2002). Subsequently, a future state map is generated by eliminating wastes or by finding alternative solutions through kaizen efforts to optimize the process. The new implemented process is then observed to aim for the next higher level of productivity improvement. Howell and Ballard (1998) contend that a value stream map can be a comprehensive model for a project to reveal issues that are hidden in current approaches and raises the possibility of maximising performance at the project level. VSM method follows a 5-stage process (Rother and Shook, 1999) that includes: selection of a product family, creating a current state map, identifying waste and developing a future state map, proposing an action plan and implementation of the action plan.

WS is yet another lean tool that can administer the management of site resources, time and labour. In WS, a series of instantaneous observations as 'snap shots' of work in progress is taken randomly over a period of time (Jenkins and Orth, 2003) to measure productivity. This method provides information on the amount of time workers spend performing productive, supportive, and non-productive work. This technique thus provides valuable information regarding areas of low productivity, which in turn can inform for the needed corrective action (Thomas and Napolitan, 1999). Work sampling was shown to provide important information about the characteristics of delays (Thomas and Daily 1983).

In summary, VSM and WS are both elemental time studies. While VSM maps the time taken to perform a task and WS describes how much time is spent on the task productively (or non-productively). The strengths of these two lean techniques, however, interest us to explore the organizational inefficiencies present at construction sites, particularly in India, where the lean principles and methods are still in its nascent stage. To this end, a study was undertaken to understand the implementation of VSM and WS in an industrial project and assess its impact with respect to cost, time and overall productivity.

METHODOLOGY

RESEARCH SETTING

ABC is a leading construction company in India. Over the years, ABC firm has pro-actively taken strategic decisions to implement lean principles and techniques with the support of Lean consultants. The firm strives to achieve the following Lean goals: a) Advance Constraint finding and resolution to complete the project as per schedule, b)

Conduct productivity study for future plan and to set up standard for ongoing works, c) Creation of better work environment for everyone, d) Conduct time motion study to remove any kind of non-value adding waste, e) Commitment tracking from civil contractors as per execution phase schedule and f) Root cause resolution to streamline the execution activity.

ABC firm has three business verticals, namely, Construction Materials, Construction Contract and Real Estate. The study was conducted on an Industrial expansion project that falls under the Construction Contract vertical, spread over a plot area of 300 acres. The project scope consisted of infrastructure facilities like internal roadways, power infrastructure and units like manufacturing plants (5#), warehouses, utility building and switchyard. The manufacturing plants in the facility have an area of approximately 20,000 square meters each. The study was conducted on specific construction activities executed in manufacturing plant-4 for VSM analysis and in manufacturing plant-1 for WS study.

DATA COLLECTION AND IMPLEMENTATION METHODS

Data was collected from a single site and on specific activities in a project through an action-based research approach. 'Action Research', coined foremost by Kurt Lewin, is a methodology that can be undertaken by a focused team of practitioners/researchers to solve an immediate practical problem in a real setting using data feedback system in a cyclical 5-stage process that includes: a) diagnosing (identification of primary problem), b) action planning (establishing targets for change using a guided theoretical or empirical framework), c) action taking (implementing planned actions through intervention of practitioners/researchers), d) evaluating (outcomes) and e) specifying learning (through reflection) (Stringer, 1999; Baskerville, 1997).

The first author spent two months on the site and was part of a team that explored the implementation of VSM for vacuum dewatering concrete flooring (VDF) activity in the manufacturing plant-4 of the facility and WS for block-work activity in manufacturing plant-1. The methodology adopted is explained below.

VALUE STREAM MAPPING

VDF was a critical activity that was scheduled to be executed on site. It was diagnosed and decided to map this activity using VSM technique. The objective was to optimize cost and time in the VDF execution process. VDF in Manufacturing plant-4 had FM2 (FM-Free Movement) class of flooring suitable for high abrasion and heavy traffic movement as per recommendations from the technical report of concrete industrial ground floors by the concrete society (TR34, Concrete Society). The first author and a project manager took turns to visit the site as per a scheduled plan in May 2017 and observed the process step-by-step in order to map the entire sequence of activities (work flow). The process was captured through photographs, videos and hand-written notes. The sequence was further transcribed and documented chronologically. The captured photographs, videos and the transcribed texts were analyzed the next day. With the collected data, a flow chart was prepared that depicted the entire process and a current state map of the activity was created. Subsequently, planning the next action step, a committee comprising of a team of experts including in-house experienced contractors, site engineers, concrete technicians and the project manager analyzed the sequence of activities to identify wastes in the process through active brainstorming sessions (kaizen efforts). Alternative methods and materials were suggested to overcome cost and time over-run. Based on recommendations of the committee, the future state map for the activity sequence was planned and implemented on site. The findings are explained in the subsequent section.

WORK SAMPLING

Four activities were identified by the firm for work sampling. These included:

- PEB Erection of Primary Members in Plant 1.
- PEB Erection of Secondary Members in Plant 1.
- PEB Roof Liner of Plant 1.
- PEB Block-work of Plant 1.

Tour based work sampling was conducted for the four activities in Plant 1. The activity was observed and diagnosed for a period of 30 days. Planning the next action plan, the first author stayed on site from 9 am to 5 pm, for a month in June 2017 and recorded the activities manually in an observation table pre-designed in the firm under 3 categories - Value Added activity (VA), Non-Value Added but Necessary activity (NVAN) and Non-Value Added activity (NVA). The work sampling information was therefore manually recorded on worksheets and the data was imported into a Microsoft Excel spreadsheet. Pie-charts were generated to illustrate time spent by job site workers on the identified categories. As a policy decision, the firm decided to take up activities for further improvement whose NVA was above 20%, which meant the labour productivity for those activities were below average. After reviewing the data collected, it was found that the block-work activity alone fell under this category. For the remaining three activities, the contractor was operating at above average productivity level and hence, out of the 4 activities, the block-work activity was taken up for further improvement. The findings and recommendations to reduce the NVA in the block-work activity are discussed in the subsequent section.

FINDINGS

Discussed below are the consolidated findings from the VSM and WS implementation process on the selected activities in the project.

VSM

The floor area of manufacturing plant-4 was 140m X 160m. For casting of the floor, surface preparation was done initially for an area of 2160 sq.m (60m X 36m). The floor was divided into equal sized bays, each spanning 60m by 4.5m. From the documented data, the time taken for each activity was identified and cross-checked with the project team members and the contractors to foremost prepare the current state map. According to the sequence steps and activity times, the process of VDF took 27 days to complete.

Each activity step was subsequently micro-analysed during the brainstorming session. While most of the activities required the time as planned, channel fixing and transferring of the reinforcement bars to the site required 2.5 days which delayed further execution. Experts identified this as an activity not necessarily required to be in the sequence process and therefore tried to improvise this particular step by bringing it out of the main flow. Thus, it was proposed that the reinforcement mesh (which was not dependent on the earlier activity, metal rolling, in the sequence flow) be prepared earlier and stored at a location closer to where concreting would take place, which in turn would save time for the transportation of the mesh. This reduced the entire process time for the activity by 2.5 days and the new cycle required 24.5 days (noted as 25 through approximation) to complete the VDF flooring process. This decision was implemented on the site during the action taking phase. This also saved time for the execution team. Figure 1 graphically depicts the current state and the future state map of VDF activity. The red rectangular box shows the areas with Kaizen burst situations.

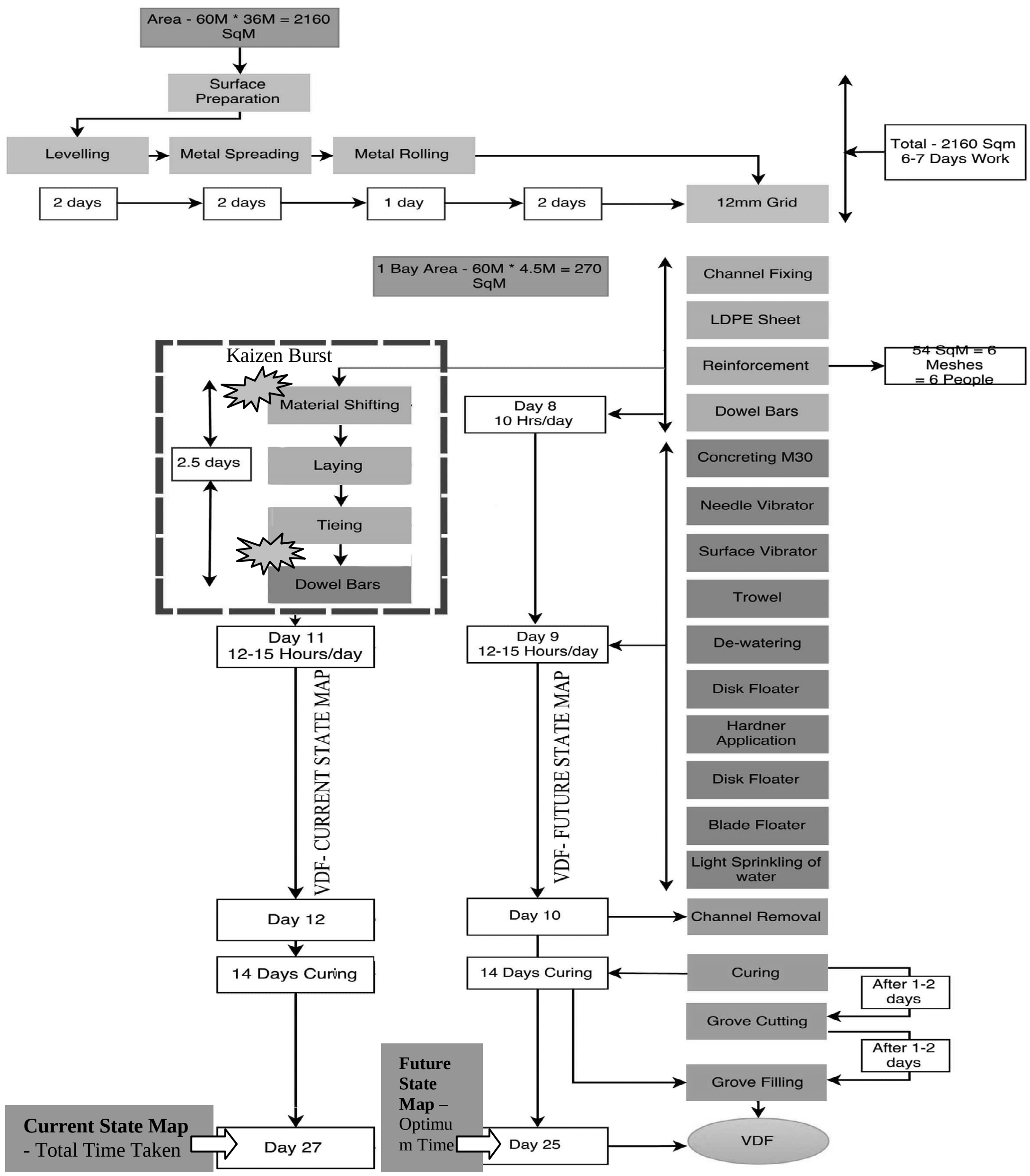

Figure 1: VSM and the Current and Future State Map of VDF activity

Value steam mapping helped in visualizing the entire work flow and identifying areas of improvement to optimize the schedule.

Figure 2 shows some of the photographs taken on site after implementation of the recommendations.

Figure 2: (a) Surface Levelling, (b) Reinforcement Mesh prepared in advanced, (c) LDPE Sheet and Reinforcement Mesh., (d) Concreting

Once the process in the future state map was applied in real time the following observations, recommendations and action plans were suggested in the evaluation and learning phase to further improve the activity and optimize the process with respect to time and safety as shown in Table 1 below:

Table 1: Recommendations and action plan for Vacuum Dewatered Flooring

Observation	Recommendation	Action Plan
Manpower and material shortage as resource availability. In an ideal situation for the VDF process, alternative bays of flooring (60m X 4.5m each) should be cast at site, but due to manpower shortage only one bay of 60m X 4.5m was cast in a day for this project.	Contractor should ensure that mobilization of resources is done prior to the activity. There is a need for more manpower to utilize the mesh that is already binded at site prior to the start of the activity.	Need to explain the scope and timeline schedule to the sub-contractor in-charge of the labourers to complete the concerned activity and make use of the reinforcement mesh binded at site.
During the application of the hardener on the bay, the labourers at site were not wearing safety goggles.	Some people are sensitive to resins, hardeners, vapour etc. Therefore, it is advisable to use hand gloves/ goggles and suitable protective clothing during the application of hardener on the bay.	The labourers to be provided with suitable clothing and the supervisor at site should ensure they use it while they are at work.
The traditional VDF process gave a tolerance of 3mm-5mm.	Concrete floors can be constructed by using cutting edge technology of laying floors with Laser Screed (Small line Laser Screed machine, keeping in mind the scale of the project). A tolerance of 1mm was achieved through this process.	The contractor should contact specialized agencies who use state-of-the-art machinery for laying the Industrial Floors. In most of the cases they would recommend Steel fiber reinforced concrete as an alternate to traditional mesh reinforcement.
Reinforcement mesh took up to 2 days for preparation.	Steel fibre reinforced concrete can be used as an	

	alternate to traditional mesh reinforcement.	
Delay in Concrete Supply for the process of concreting at site.	ABC Firm has an in-house RMC plant. If the in-house concrete supply gets delayed, due to any reasons, then material preplanning should be done, or material should be catered by external agency	During the signing off stage the management team should ensure there is abundant supply of concrete for the activity to be conducted.

A techno-commercial comparison was done with alternate materials for cost and quality optimization that included comparison between reinforcement mesh Vs steel fibres Vs glass fibres for VDF flooring as shown in Table 2 below:

Table 2: Comparison of alternate VDF flooring materials

Sr. No.	**Item**	**Unit of Measure**	**Quantity**	**Unit Rate (USD)**	**Total Cost (USD)**
VDF with Reinforcement					
1	Concrete M30 for 200mm thickness	Cum	3888	98.15	381611.49
2	Fe500 Reinforcement (31kg/m3) i.e. 10@200c/c	Tons	138.8	950.84	131976.43
				Total	513587.92
VDF with Steel Fibres					
1	Concrete M30 for 200mm thickness	Cum	3888	98.15	381611.49
2	Steel fibres (15kg/m3)	Tons	67.2	1073.53	72141.06
				Total	453752.55
VDF with Glass Fibres					
1	Concrete M30 for 200mm thickness	Cum	3888	98.15	381611.49
2	Steel fibres (2.5kg/m3)	Tons	11.2	6901.25	77293.99
				Total	458905.49
Note:					
1	Floor Casting Methodology Remains same in Both Case				
2	Plant Size Considered: 120m X 162m				
3	Expansion Joint, Dowels, Hardener, other allied element remains same in all cases				
4	Floor Load Capacity Considered 7.5 Ton/m2				
5	Floor Specification is FM2.				
6	Tax as applicable.				

WS

Tour based work sampling was conducted at random time periods during the day for a period of one month during the action taking phase. The job site workers were not made aware of this study, to avoid possible hawthorn effect. The observations through tour sampling of PEB block work at plant-1, was initially noted under VA, NVA and NVAN categories in the standardized template of the firm as shown in the Figure 3 below.

Activity	Blockwork at Plant-1		VA				NVAN			NVA		
Location	Date	Actual Productivity	Placing Morter & Blocks	Layerwise placing of Blocks with proper masonry bond	Checking alignment & final fixing with morter	Others	Tranportation of Blocks	Dressing or cutting of Blocks	Others	Idle/Breaks	Talking	Others
PLANT - 1	02-May-17	200sqm/day	-	-	-	-	3	2	-	2	-	-
	03-May-17		-	-	-	-	3	2	-	1	-	-
	04-May-17		1	-	1	-	1	1	-	4	-	-
	05-May-17		2		1		2				2	
	06-May-17		-	-	-	-	-	-	-	-	-	-
	08-May-17		2	2			2	1			3	
	09-May-17		2	2	2			1		4	2	
	10-May-17		2	2	2		2	1		1	2	
	11-May-17		2	2				2		1		1
	12-May-17		4	2			5	2		2		2
	13-May-17		4	2			4	1		1		
	15-May-17		2	2			2			2		
	24-May-17		1					1				1
	25-May-17		1	1			4	2		2		2
	26-May-17		1	1			4	1				
	27-May-17		1	1			3			2		
	29-May-17		1	1				1				1
	30-May-17		1	1			5	3		2		2
	Sum		27	19	6	0	40	21	0	24	9	9
	Total		52				61			42		
	% Contribution		33.5483871				39.35483871			27.09677419		

Figure 3: Work sampling data sheet for block-work at plant-1

Data was analysed through pie-charts to understand the percentage contribution of VA, NVAN and NVA in overall productivity. Table 3 below lists some of the identified activities in each category.

Table 3: VA, NVA and NVAN activities in Block-work

Value adding activity (VA)	**Non-Value adding but necessary activity (NVAN)**	**Non-Value adding activity (NVA)**
Placing Mortar & Blocks	Transportation of Blocks	Idle time, Breaks
Layer wise placing of Blocks with proper masonry bond	Dressing or cutting of Blocks	Talking
Checking alignment & final fixing with mortar	Others including inspection, approval	Others

Work sampling technique helped to identify the non-productive time and minimize it during the evaluation phase. Figure 4 below shows the percentage contribution of the activities using Pie-charts. 4(a) shows the consolidated percentage of VA (34%), NVA (27%) and NVAN (39%) activities, 4(b) shows the percentage contribution of each activity in NVAN, and 4(c) shows the percentage contribution of NVA. From the study, it was observed that the most common NVA was idle time and that was caused due to lack of effective supervision.

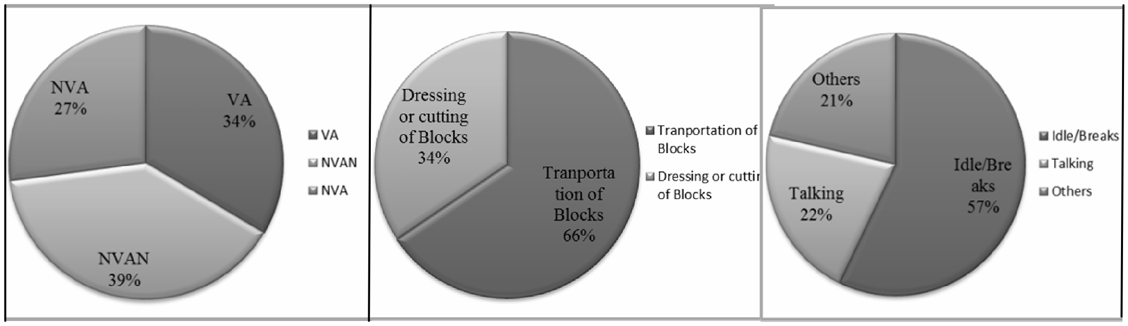

Figure 4: (a) Consolidated Percentage Contribution of Work, (b) Percentage Contribution of Work (NVAN), (c) Percentage Contribution of Work (NVA)

Based on the analysis, further recommendation and action plan were provided during the learning phase for improving productivity as shown in Table 4 below

Table 4: Recommendations/action plan to improve productivity of block-work

Recommendation	Action Plan
Proper guidance should be given to the job site workers during the execution of an activity.	Tool box meetings can be conducted every day to make the workers aware of productive time waste impact.
Time wastage can be reduced by proper supervision.	Proper supervision should be conducted to increase productivity by improving value added time for the specific activity.
Work front availability must due to completion of predecessor activity.	Proper planning of work must be executed in the job site. Provide number of skilled laborers to avoid delay in work.

CONCLUSION

The objective of the study was to understand the current scenario of on-site and labour productivity in a construction project and to analyse the benefits through the implementation of Lean techniques including VSM and WS. Value stream mapping technique for VDF proved to be beneficial to visually map the process and optimize the operation with respect to cost and time. In specific, it helped to measure the time taken for supporting activities such as channel fixing and transporting of wire mesh and adopt alternative method to optimize the process. Similarly, Work sampling helped to identify and reduce/eliminate non-productive time spent by workers and allowed the contractor to improve the productivity of block-work activity above average level. Thus, we contend that by adopting similar approaches, project managers will be able to take key decisions to enhance productivity and optimize performance. However, the study offers insight from a single project and therefore suffers from limitations for a broader and comprehensive generalize-ability. Future studies could also explore the combined effects of these lean tools in construction projects as prevalent in other sectors, such as for instance, Barnett et al. (2015) adopts work sampling to value stream map an activity in healthcare domain for process improvement.

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IMPACT ON THE DESIGN PHASE OF INDUSTRIAL HOUSING WHEN APPLYING A PRODUCT PLATFORM APPROACH

Shamnath. Thajudeen[1], Martin. Lennartsson[2], and Fredrik Elgh[3]

ABSTRACT

With a glulam-based post-beam building system, a variety of building solutions is offered on the market for multi-story buildings. The building system must be adaptable to the demands of each project. However, short lead-time, efficient manufacturing and assembly must be ensured. The use of product platforms has been acknowledged as an enabler to manage external (customer) and internal (production) efficiency. The building system cannot be locked to a set of standard components as a high level of customisation is required. A set of methods and tools is needed to support the design work and to ensure that solutions stay inside the boundaries of the platform definition. The aim of this work is to map the state-of-practice in the design phase for a glulam building system from a platform theory perspective and outline a path forward for applying a sustainable platform development in companies where a component-based product platform does not suffice. Empirical data were gathered from an on-going product platform development including interviews and document analysis. The results show the lack of definition in platform-based product development from a theoretical perspective and need for development of support methods for design that align with different production strategies.

KEYWORDS

Product Platform, Industrialised house-building, Engineer-to-order, Glulam.

INTRODUCTION

The industrialized house building sector strives towards standardized and controlled processes in the design phase (Viklund, 2017). The demand for industrialized timber house buildings is getting increased attention (Jansson, 2013), where the glulam-based post and beam building system has been acknowledged as a feasible option for multi-

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storey buildings with timber (Tlustochowicz et al., 2010). Glulam is a structural timber member composed by at least two parallel laminations which may include one or two boards side by side having thicknesses from 6 mm up to 45 mm (BS EN 14080:2013). The building system composes of modular structures of main load-carrying members such as prefabricated beams and posts made of glulam with floor panels, wall and roof elements. The glulam system offers many advantages over other building systems such as element and volume types as well as being an attractive and versatile system for market demands (ibid). The changes towards industrialised house-building will have an influence on design, production and onsite work as a result of an increased use of prefabricated structural elements (Roy *et al.*, 2003). The customization possibilities are highest in Engineer-to-order (ETO) based companies since customer involvement is allowed early in the engineering phase of the specification process (Hicks *et al.*, 2000). The design phase of construction, in general, suffers from inefficiency in deliveries where time, cost and quality are not consistent with contracts (Tilley, 2005).

A platform, as a method of sharing components and processes allows the companies to develop differentiated products efficiently through a flexible and responsive processes (Robertson & Ulrich, 1998; Meyer, 1997). For companies applying a product platform concept, prefabricated solutions could be a path forward to efficiently comply with customer demands. The automotive industry, e.g. Scania trucks, has introduced platform approach as a successful strategy for cross-product and process reuse (Robertson & Ulrich, 1998). The practice of a platform-based product development approach could be a path forward, concerned with the design and also support customers, purchasing, in-house production and site assembly that is capable of meeting the demand and exhibits less lead time in whole construction processes (Jansson, 2013). One of the main reasons for less development in the house building industry is the high amount of customization requirements from the customer (ibid). Several research studies have pointed out the benefits of adopting prefabrication (Höök, 2008), modularization (Jensen, 2010) and standardisation (Roy *et al.*, 2005) in the house building sector, but applying a product platforms approach linked to the design phase is not well-developed.

However, a platform-based product development and implementation of a methods that supports a platform concept creates a research gap in the field of glulam based multi-story timber house building sector where demands from clients must be fulfilled within a narrow timeframe. The aim of this work is to map the state-of-practice in the design phase for a glulam building system from a platform theory perspective and outline a path forward for applying a sustainable platform development in companies where a component-based product platform does not suffice. The impact on the current practice and future state of the design phase has been analysed and discussed. The scope is delimited to the design phase where a single case study has been carried out.

RESEARCH METHODOLOGY

The Design Research Methodology (DRM) was adopted for this study (Blessing & Chakrabarti, 2009). DRM is a four-stage iterative process used for conducting research in the engineering design field to develop innovative solutions that solve practical problems and allows a theoretical contribution. Research clarification is the initial stage where the researcher tries to find support or evidence to formulate the goal. In the Descriptive Study phase, the researcher has a clear goal and the empirical data collection and analysis can be done to gain deeper knowledge by accessing the current state. The prescriptive study is the third stage where the researcher starts the systematic development of new support for the improvement of an existing problem. The researcher then proceeds to the final stage which is the Descriptive Study II (DS-II) stage to investigate the impact of the support method and its ability to realize the desired situation.

DRM is used as a framework for the whole research project and this paper covers the two initial phases where a literature review was done in the research clarification phase followed by the collection and analysis of empirical data from the case company as part of the first descriptive study phase. The research approach was qualitative in nature with literature studies combined with a case study strategy. Multiple sources of evidence were scrutinized with semi-structured interviews and document analyses. The interviews were carried out with five respondents, Managing Director, Design Manager, Structural Engineer, Design Engineer and Project manager with open-ended questionnaires. Besides, the documents analysed included the structural calculations, 2D drawings, 3D models of buildings, excel spread sheets and activity plans for different projects etc.

LITERATURE REVIEW

There are four types of product specification processes according to Hansen (2003) for meeting the client needs which depend on the four production strategies engineer-to-order (ETO), modify-to-order (MTO), configure-to-order (CTO) and select variant (SV) as shown in Fig. 1. ETO companies offers highly customized products where the product specification process starts based only on norms and standards, e.g. Construction industry. The MTO companies produce customized product based on technical platforms (Jensen, 2010), e.g. Manufacturing industry and according to Hvam et al. (2008), the MTO or ETO processes are appropriate when the product is complex or more creativity in design is required. CTO products are produced based on modules and the standard parts are evaluated according to a set of predefined rules, e.g. Software industry. The last one, select variant, is a process in which a standard product fulfill the customer's needs e.g. Automotive industry. To achieve the benefits from the use of platforms, the company has to postpone the customer order decoupling point (CODP), the point where customer meets suppliers, to a later stage of the value chain (Bonev *et al.*, 2015).

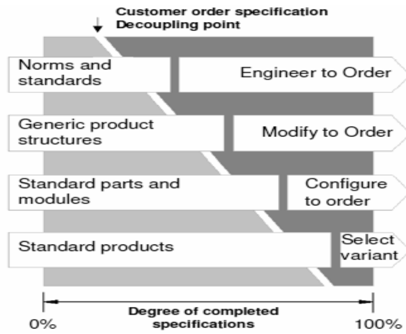

Figure 1: - Product specification process (Hansen, 2003)

The use of product platforms has been acknowledged as an enabler to manage external (customer) and internal (production) efficiency. Robertson & Ulrich (1998) define the fundamentals of platform which consists of four parts - components, processes, knowledge and relationships. Components are the building blocks used when designing a product and designing component-specific tools for manufacturing. The processes include the tasks involved in the different phases such as design, production process and assembly. Knowledge is described by the technical and design knowledge, knowledge transfer between projects, production and assembly knowledge including testing. Relationships concern interactions internally between team members, and externally with organisations, networks with suppliers and the broader supply chain. These assets are critical in the development of platform strategy for any business settings. A platform contains a core of technology and is defined as *"A set of common components, modules or parts that form a common structure from which a stream of derivative products can be efficiently developed and produced"* (Meyer, 1997). A platform approach can be of two kinds, where the first one is module- based (discrete) and characterized by sets of components being clustered into interchangeable modules that together form the product (Elgh *et al.,* 2016). The second one is scalable platform supporting adaptation by stretching or shrinking the product instances following variations in design variables. Both approaches, support the generation of product families, which is a group of different products generated from a common set of components (modules) and have a number of common characteristics (Hvam et al, 2008). The product development and production strategy based on platforms have been successfully implemented in industries such as automotive, electronics and software etc., but not well developed in house industry.

Customer involvement in the product development of house building and the ETO production strategy hinders the implementation of a fully parameterized platform (Jansson *et al.*, 2014). The introduction of platforms within house-building causes contractors to move from ETO towards MTO oriented production, which Winch (2003) describes as a transition towards mass customization. The implementation of product platforms by standardisation of the products and process has been considered as a challenge in the construction sector (Jansson, 2013).

The practice of reusing processes and technical solutions leads to the design of product platforms for house building (Jansson *et al.*, 2014). The design process is challenging and has multi-disciplinary tasks in all the product development projects.

Normally, the design process starts with conceptual design by the architectures and continues through design development which including systems design, and detailed design (Jansson, 2013). Viklund (2017) studied the advantage of integrating the platform in the design phase of industrialized house building. By predefining building systems and technical solutions in product platforms, parts of the design process can be integrated and used for platform development (Jansson *et al.*, 2014). Standardised processes for repetitive work to better utilise resources as well as ensuring that knowledge of the product and the building system is captured within the system itself, not only by persons working in it (Jansson *et al.*, 2008). By controlling the design process in house-building and making that process more efficient, a higher quality of product development is achieved which supports to avoid the re-planning of design work (Jansson *et al.*, 2013). The repetitive processes in design offer a foundation for treating those processes as commonalities in the process platform asset (ibid). The literature review indicates that a strict platform theory does not fit in this context and is difficult to adopt for companies working with a combination of production strategies.

SINGLE CASE STUDY - STATE OF PRACTICE

The case company is a glulam producer with the world's oldest glue-wood factory and is one of the leading glued-wood manufacturers in Europe. The factory was founded in 1919 and employs 137 peoples. The total production capacity is 55,000 m^3 annually with a turnover of 28 million EURO. The company is part of a Scandinavian industrial group that manufactures building products and systems to the construction sector. The group has production facilities in 50 locations and employs approximately 3,400 peoples.

THE BUILDING SYSTEM

The building system was launched in 2007, which was one of the major innovations in post and beam building system. It is ideal for a hybrid building system where materials such as concrete, steel components are also used with timber during the construction to create a strong building base. The building system allows an 8-meter span, that enables space for architects. To have the proper stabilization of the buildings, the stair-wells and elevator shafts are constructed of concrete and all the connections between posts and beams made by steel components. The offer includes an engineered structure, designed from static considerations, for the multi-storey building including support frames with posts and beams, connectors for post and beams, intermediate floor element insulated with mineral wool and roof elements. The assembly and erection of elements have been carried out by either customers or with the support from a partner contractor.

The process mapping and flow of information during the structural and design phase are shown in fig. 2. The main tools used are software such as Stat-Con, Truss-Con, Mathcad for structural calculations, Finite Element Method (FEM) programs such as RSTAB, RFEM and excel sheets for summarizing the loads by structural engineers. Tekla structure and AutoCAD are used for drawing and modelling 2D and 3D design by design engineers. Parametric CAD models in Tekla structures are also used for a few projects to expedite the modelling. The structural calculations start with the help of documents and standard references such as drawings from customers, standard reference by law and permanent loads according to the scope of the project. The total loads acting on the foundation must be calculated and transferred to subcontractors who deal with the concrete foundation works. Then, the calculations for posts are done initially, then the beams and then the trusses by considering the permanent loads of posts, beams, trusses etc. The next step is to calculate the total load on the concrete structure (elevators and staircases). A predefined spread-sheet is used to put in the standard loads for wind, snow, permanent etc. which automatically generates the output of required loads that need to be designed. Stat-con structure is used to calculate the dimensions of posts and beams. Mathcad is used for the calculations of floor elements and detailing of all the steel brackets and connectors. Once the dimensions are extracted for posts and beams, the structural engineer starts with the calculations of floor elements and other components. An AutoCAD drawing is generated with all the values of loads and parameters that should be references for the design engineer to model the entire building in Tekla structure. As shown in figure 2, the finished drawings from Tekla structure will be forwarded to the different stakeholders in the project such as suppliers, customers, production and on-site assembly operations.

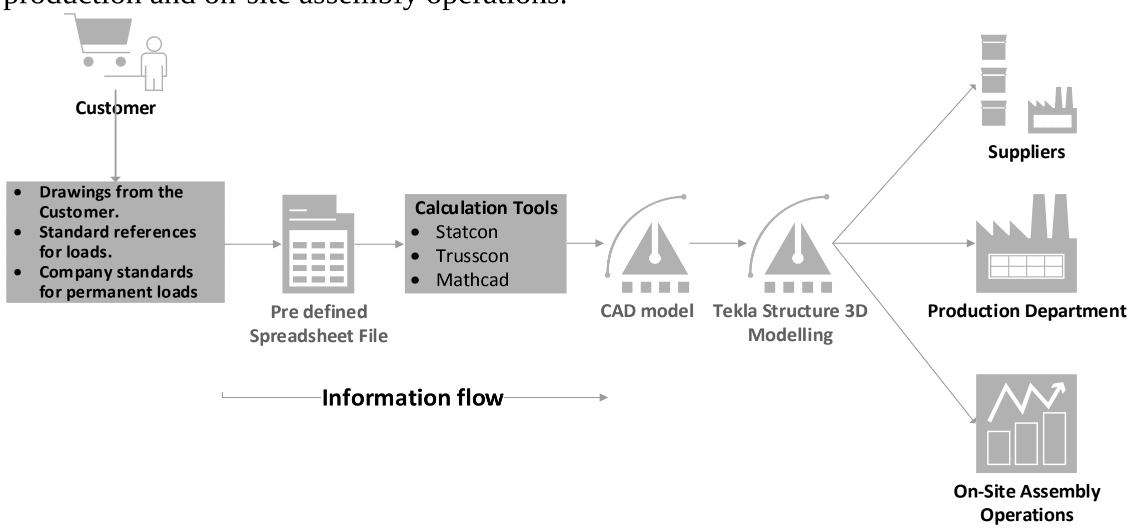

Figure 2: The Design process at case company

CASE ANALYSIS AND DISCUSSION

The company is working both with the ETO and MTO where customised buildings are developed upon customer requests based on norms and standards linked to the building system. The products offered by the company based on the building system are customer specific and have been executed accordingly to the demands from the customer. Robertson & Ulrich (1998), define components, processes, knowledge and relationships as the collection of assets for house-building platforms that combine to form the product.

For the components, the company has partly defined the components that can be derived from the building system. No product family has been developed from the building system and it includes some standardized components such as steel connections, joints, foot of columns connector and standard fittings for connection between column and beams.

The processes in the design phase has not been standardized and the sequence of work is not clearly defined which makes it difficult to manage many projects at same time. The traditional way of executing the projects has been identified at the company and processes are not well-developed either in technology nor product development. The people working within the structural and design phase develops their own methods individually to simplify their works, by finding the similar tasks or repetitive tasks, e.g. custom components by a design engineer, excel platform by a structural engineer.

For the knowledge asset, the individual learning is happening between the projects, for example, the design engineer working with the projects is learning from previous projects and manage to develop better solutions for future projects. The company has developed a parametric CAD model to a certain level that can be used for a different project to some extent, but they are not developed completely to have access for all designers. The designers are using a components library customised for projects where they execute the design process of many components used in the projects and reuse the components as much as possible to reduce the lead time. The current library is not fully defined, developed and organized as it has some brackets, column footings only. The design engineer has been following an approach and make some assessments individually during the design of building components which support the production and assembly team to make sure that the components can be easily produced and assembled at the site during erection e.g. sequence marking on floor elements and connectors. However, it has not been well-documented or supported with guidelines and without means to share.

For the final asset, the relationships internally and externally, they are not well-aligned and no protocol to follow currently. The main external support is from sister companies with the guidance, recommendations from partner company for acoustics expertise and sub-contracting company who provides dynamic calculations for different project that need special skills. The company does not have a formal system to collect and analyse customer feedback. Most solutions are developed within the projects. However, according to Lessing (2006), It is important to separate the development of a product platform from individual projects. The platform assets have been related and analysed to identify the issues and understand the current state of platform definition at the case company. The current platform is not structured enough to follow for stakeholders and defined boundaries and components are missing which mismatch with theory. The view and understanding of platform-based product development among the respondents appear far from the theory as they were not familiar with the term and concept of platform.

APPLYING PRODUCT PLATFORM APPROACH

To meet the increasing demands of building system from the market, the company could develop a platform approach that supports both external stakeholders such as customer, suppliers and internally in design, production and site assembly operations in an efficient way. The gap between the theoretical review and practice was in terms of design support methods of platform development. As an act to improve, the support methods such as design planning, collaborative design, design optimization and requirement iterations should be developed. As Jansson et al., (2014) argue, the design support methods for daily engineering works are required to link the gap between the standardized platform and the project specific parameters and applying the methods can highlight different assets in the platform. It is significant to develop support guidelines in the design phase that helps to evaluate and guide the solutions that developed can also be efficiently manufacture and assembly concern to design for manufacturing (DFM) and design for assembly (DFA). The effective planning and efficient management of the design phase is important to consider by investigating all the included tasks and deliverables.

A platform perspective facilitates value focus for both the customer and the producer, i.e. adding support for the stakeholders to decide what to standardise to create value for customers and move further from the traditional construction to lean construction (Maxwell & Aitchison, 2017). Currently for the case company, both the knowledge and the relationship assets are not emphasizing this issue, adding a risk when applying a platform approach. For example, this could help the company to reduce non-value adding works, variability, less lead time and unnecessary wastes which basically is, the lean way of design and manufacturing (Jansson et al., 2008). This could also benefit to differentiate the repetitive activities and unique activities within the design to develop the requirement iterations in a smart way. The design collaboration could be achieved through regular daily meetings within the design and other departments and acts according to the plan. Also, the design optimization by implementing a feedback management system should be developed for the continuous improvement from both internal and external sources which is highly critical for the company (Jansson, 2013). The feedback reports from the client should be analysed and modifications implemented to the engineering work process. The development of a well-defined platform will offer the customers to choose their products which are defined within the platform boundaries that outline the product family. Fig. 3 shows the representation of a desired product platform support essential for the company.

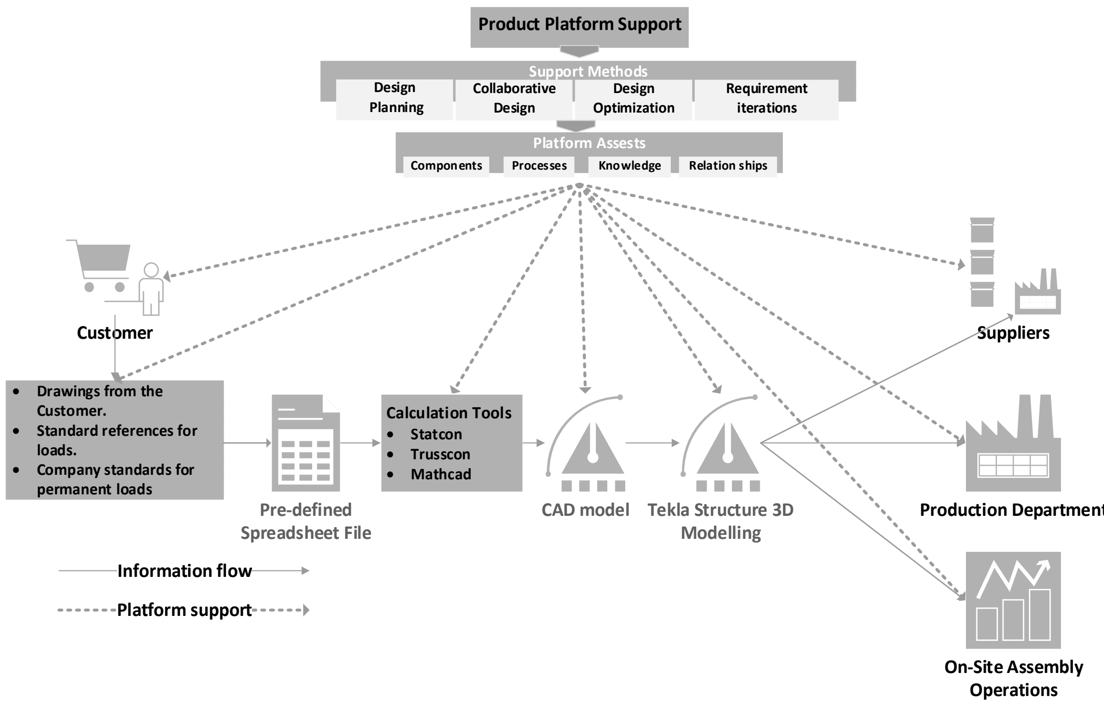

Figure 3: Platform support in detailed design phase

The definition of support methods will help to align the platform assets which makes a high impact on the design phase, which was the objective of this study. It is recommended to adopt a strategy where step by step development of the process in some parts of the system, evaluate, improve them slowly could result in an incremental development of the product platform. The development of well-defined product platform approach could support the case company to identify the product structure, distinguish the components into different process flow to avoid interactions within the design phase, support those with different methods and tools and finally improve and optimize the individual flow.

RESEARCH OUTLINE AND CONCULSIONS

This study indicates a lack of theoretical knowledge in the area, how the combination of different production strategies could work well and align with the companies operating in same sector as case company. It is significant for the case company to develop their business model based on the principles of product specification process illustrated by Hansen (2003). From the product concept described, it is evident that the company cannot stay completely in a specific production strategy as some components of building system can be standardized and have a modular approach, some parts comes in configured approach and some parts are yet to be in engineer-to-order that should be altered and customize according to customer needs. Some standard components and modules can be derived to a certain extent with the help of the platform support methods to generate solutions, evaluate and ensure that they are fulfilling the requirements from client and can be easily be produced in production and assembly at site. It shows that the theory is not well-defined and completely applicable on the case company, implies a mismatch and outline the research gap on this field. From the analysis of state of practice at case company, it is clear that they cannot develop a fully predefined and fixed platform system for all the products as the projects are customer-driven. The combination of manufacturing strategies suits better for these types of companies in the construction sector where some subcomponents from the building system suits for configure-to-order, few parts fits in modify-to-order process and rest to fulfil the unique needs of customers. The future research shows the path forward to develop the knowledge in theoretical field that defines the methods and criteria's to be considered when transforming companies into a product platform strategy that also contributes the scientific knowledge in the field.

The case company has the potential to achieve high levels of product variety, reduced time to market, better operational efficiency and responsiveness to the market needs with the support of product platforms. The impacts on the design phase when applying the product platform in the glulam-based building system have been analysed based on the platform knowledge perspective, which are the main platform assets defined by Robertson & Ulrich (1998) and support methods described by Jansson et al. (2014) together constitutes a path forward for sustainable platform development for the case company. The objective of this paper was to investigate the state-of-practice in the design phase from platform theory perspective. The mapping of processes revealed the lack of definition in platform-based product development from theoretical point of view. It seems to be challenging to strictly apply the definition of platform approach in these kinds of companies working with a combination of production strategies. The results point out the need of knowledge development including methods and tools, supports the design phase and to ensure that solutions offering to customer are within the boundaries of the platform.

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EXPLORING PRODUCT DEVELOPMENT IN INDUSTRIALIZED HOUSING TO FACILITATE A PLATFORM STRATEGY

Martin Lennartsson[1], Fredrik Elgh[2]

ABSTRACT

Industrialized house-building companies are offering unique products by adopting an engineer-to-order (ETO) strategy. Client satisfaction is achieved by adaptation of product solutions and swift introduction of new technology in combination with cost-efficient production and short lead-time for completion. Product development is executed in collaboration with the clients and changes in requirements are frequent. The use of product platforms, where external and internal efficiency are well-balanced, has been acknowledged as a strategic enabler for mass customization and increased competitiveness. However, ETO-companies struggle with adopting the common product platform approach, set by pre-defined modules and components. Predefinitions may cause an imbalance between product development and a lean production system. The aim of this work was to analyse current strategies and support to master the balance of external and internal efficiency in product development within industrialized house-building to facilitate the development of a product platform strategy. Data were gathered from a single case study and an on-going product platform development and includes interviews and document analysis. The findings show that product development is guided by a technical platform, but there is an imbalance where external efficiency is prioritized over the internal efficiency.

KEYWORDS

Product development, Industrialised house-building, Engineer-to-order, Product platform

INTRODUCTION

Industrialized house-building is a complex field, consisting of several constructs that need to be integrated and continuously developed (Lessing et al. 2015), where the building system is a key asset (Johnsson 2011). Further, Lessing et al. (2015) stress that industrialized house-building needs to be managed strategically and not on a building

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project level. The challenge for house-building companies is to balance standardisation and customisation to reduce uncertainty in the supply chain (Gosling et al. 2013).

Construction is identified as a sector employing an Engineer-to-order (ETO) production strategy (Gosling and Naim 2009). In recent years, there has been an increasing focus on the platform concept in the construction sector (Johnsson 2013; Jansson 2013; Jensen et al. 2012; Thuesen and Hvam 2011). A generally accepted definition from Robertson & Ulrich (1998) describes product platforms as "The collection of assets [i.e., components, processes, knowledge, people and relationships] that are shared by a set of products", not only including artifacts in the concept. Through product platforms, companies achieve high levels of product variety, a reduced time to market, improved operational efficiency and responsiveness to market needs (Meyer and Utterback 1993, Muffatto 1999). Improved customer value is targeted by adaptation of product solutions and swift introduction of new technologies combined with cost-efficiency and lead-time reduction. The use of a product platform, where external and internal efficiency are well balanced, has been acknowledged as a strategic enabler for mass customization and increased competitiveness.

However, ETO-companies struggles with adopting the common platform approach building upon pre-defined modules and components. By applying the core competences of ETO (Konijnendijk 1994), Johnsson (2013) scrutinized product development platforms in house-building concluding that coordination between market and manufacturing is a crucial capability when engaging in platform organisation. Jensen (2014) investigated platform architecture and modularity within construction and the results show that for an ETO-based context and integrated product architecture it is difficult to apply platforms. Still, by approaching the problem from a modify-to-order/configure-to-order perspective platform theory can be applied by incremental development. From a platform perspective, Jansson (2013) studied the design phase and stresses that when an ETO strategy is applied, the balance between distinctiveness and commonality is crucial to master.

The aim of this work is to analyse current strategies and support to master the balance of external and internal efficiency in product development within industrialized house-building to facilitate the development of a product platform strategy. Empirical data were gathered from a case study of an industrialized house-building company and includes interviews and document analysis, where the product development process was scrutinized from a platform strategy perspective.

METHOD

To achieve the aim of the paper two data collection methods were used: interviews, and analysis of internal documents from the case company. A case study is appropriate since it involves studying a phenomenon in its natural context, targeting rich descriptions of the phenomenon (Miles and Huberman, 1994). A set of semi-structured interviews regarding the current product development process was conducted. The questions were separated into different domains: product and technology development before and after order point; demands; information sources, tools and models; process development and; platforms. Five respondents (technical manager, structural manager, HVAC coordinator, electricity coordinator and design coordinator) with key responsibilities were chosen to obtain a comprehensive representation of the current practice. To support the data collected from the interviews, internal documents describing the current platform strategy for product development was scrutinized. The primary source is the technical platform, where product families and house models are described. Types of documents include, drawings needed to produce standard configurations, but also design templates and standard operations (STD), which describe a variety of issues, e.g. technical solutions, bill of material and way of working. Further, the data analysis was guided by the theoretical framework and the representations from Robertson and Ulrich (1998) and Krause et al. (2014).

CASE DESCRIPTION

The studied company is focusing on products such as, schools, kindergartens, elderly homes and offices, which demands knowledge of their client operations. The company applies an industrialized house-building strategy and off-site construction with up to 90 % of completion in a factory and follows the process described in Johnsson and Meiling (2009). Thus, a fundamental idea is to maintain a high level of standardisation in the production. The building system is based on volumetric elements in turn-key contracts, meaning that the company is covering all disciplines and the entire construction process. However, clients are often municipalities and other public actors having large budgets and also the capacity to either set a narrow frame of demands, making it hard to fit the building system, or to continuously alter the demands on the projects. In consequence, the company is an appropriate choice to investigate internal and external efficiency. The on-site assembly and kindergarten project is illustrated in fig. 1.

Figure 1: On-site assembly of volume elements and a finished kindergarten project.

THEORETICAL FRAMEWORK

PLATFORM THEORY

Beside Robertson and Ulrich (1998), other definitions of product platforms can be found. McGrath, (1995) describes the concept as “A collection of common elements, especially the underlying core technology, implemented across a range of products”. Thus, adding technology to be a fundament, which can be connected to the building system concept (Johnsson 2011). Simpson et al. (2006) add a competitive aspect by saying “*group of related products that is derived from a product platform to satisfy a variety of market niches*”. Meyer and Lehnerd (1997) include a market aspect and propose “*A set of* *common components, modules, or parts from which a stream of derivative products can be efficiently developed and launched"*. Both Simpson et al. (2006) and Meyer and Lehnerd (1997) include competitiveness as a key element. Thus, when combining customized product offers with a platform approach, the challenge is to stay competitive, in other words, balancing external and internal efficiency.

Further, Krause et al. (2014) proposes a toolkit to use in design to keep the external variety high at the same time keeping the internal variety low. Four principles outline the basis of the proposed toolkit: Clear differentiation between standard components and variant components, reduction of the variant components to the carrier of differentiating properties, one-to-one mapping between differentiating properties and variant components and, minimal degree of coupling of variant components to other components.

Platforms are generally described to be of one of either two kinds: (1) the module based (discrete) characterised by sets of components being clustered into interchangeable modules that together form the product, or, (2) the scalable platform that becomes adaptable due to letting some of the design variables vary (Simpson 2004). Modularity is proposed as the main enabler for customization (Hvam et al. 2008). Bonev (2015) states that modular architectures are a major enabler for being able to reduce the internal variety of organizations through standardization, while having high external variety towards the market. This is typically done by using a set of common components which are shared between product variants at the same time as varying distinctive components (variant components) to produce product variants which are differentiated by the market. André et al. (2017) introduce a design platform that should support the development of customised products, where coherence across all disciplines is emphasised.

Within the IGLC community several studies regarding modularisation have been reported including, Lennartsson and Björnfot (2010) proposing modular building services, Björnfot and Stehn (2004) argued that modularity support the practice of Lean Production in construction and Bertelsen (2005) try to allocate work groups using a modular mindset. Jensen et al. (2009) used modularity principles to develop a flexible building system within industrialised housing. Further, both Jensen et al. (2013) and Kalsaas (2013) have investigated configurators and their applicability as knowledge carriers.

PRODUCT DEVELOPMENT WITHIN INDUSTRIALIZED HOUSE-BUILDING

Lessing (2006) defines industrialized house-building as a thoroughly developed process with a well-suited organization for efficient management. The production system is process-oriented with defined value streams, repetitive operations and experience feedback (Johnsson and Meiling 2009). Thus, a move towards industrialized house-building means a shift from strictly project based production to a more process-oriented production (Jonsson 2017). Competitiveness is driven from factors such as flexibility, delivery time predictability, quality level and cost (Jonsson and Rudberg 2014). The process is vulnerable to misinformation and a core competence is to master the difference between commonality and distinctiveness (Jansson 2013).

RESULTS

The results presented are a synthesis of the gathered data. First an overview of the product development process is presented, and then the four assets of product platforms introduced by Robertson and Ulrich, (1998) is highlighted.

PRODUCT DEVELOPMENT

The current state of practice in the case company is that they have developed a modular product methodology, in terms of a Technical Platform (TP), see Fig. 2. There is no explicit product development process at the company. Rather, product families and house models, based on the building system and previous house models, are developed to meet the needs from the market. Thus, the product development is managed by sellers and architects. Consequently, customizations are allowed by the client, where a rule of thumb is to keep the balance on 75/25 catalogue house/customization, but there is no distinction when a remodelled standard becomes a variant.

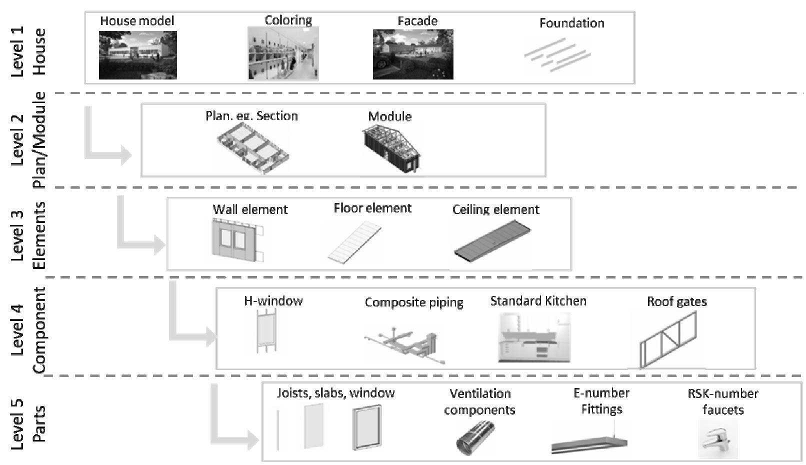

Figure 2: The Technical Platform (TP) and the five levels, house, module, elements, components and commodities.

Though the primary focus is on the house models, development also includes details and technical systems, where development is carried out as illustrated in Fig. 3. It follows the principles from Lessing (2006), meaning that customer specific solutions are derived from existing house models and implemented into the projects. Validation and prototyping is done in real projects, as the technical manager stress "*we are a construction contractor*". If similar solutions have been used in multiple projects, these can be incorporated into the TP. Assessment of solutions is based on the building system definition.

COMPONENTS

In fig. 2, the TP is illustrated from top level 1 describing the house down to level 5 which is based on parts. The superior level is described by parts from the next subordinate level. The platform is dependent on the developed house models and how these can be decomposed. Technical demands are divided into 10-15 technical departments, which are defined by the company but also the client. Technical development includes all parts of the TP, which should be updated on demands, norms and rules of the construction sector.

Development is initiated reactively, e.g. a problem is reported or demands on cost-cuts or regulations emerge and an (1) investigation is started that covers all departments, followed by (2) resource allocation and (3) drawings update in the CAD-system. The development project is guided by the impact and the consumption of resources. No other software, beside energy calculations, to model the products than Revit is used. The TP is vulnerable to volatile and changing demands that initially are not clearly stated and specified. For instance, demands on energy, which also varies for different municipalities. To comply with these demands the internet and databases are used.

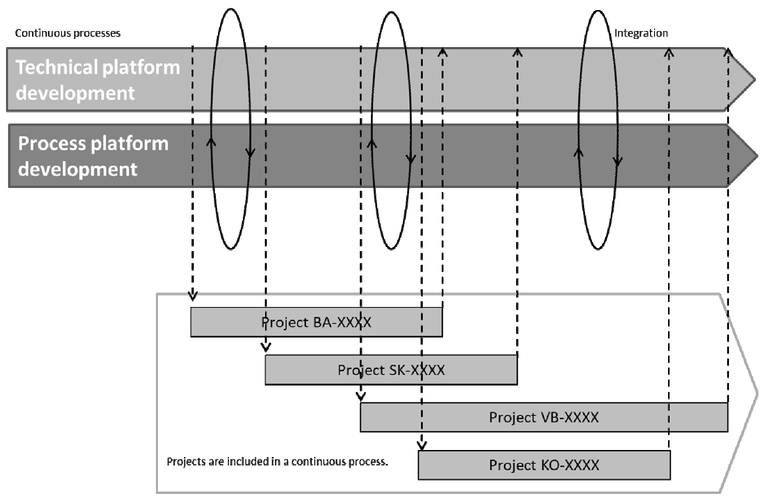

Figure 3: The development of the TP (Green flows) aligned to the on-going projects (Grey boxes). Company internal illustration inspired by Lessing, (2006).

PROCESSES

To manage operations, the company has defined an overall process, describing marketing, sales, project management, tendering and purchasing, but also continuous improvements and the development of the TP. The domains have assigned responsibilities and their own subprocesses. For the production process, it is well-described in terms of value flows and order of the work stations and focus on waste elimination and Lean production. However, when taking the TP into consideration, the production layout and process is prioritized over the ability to configure products.

KNOWLEDGE

The use of design templates and standard operations (STD) lay the foundation of know-how, but there are also test reports and energy simulations that add to the experience. However, according to the technical manager, the TP is not really defined or fully documented. No metadata is attached to the documents that offers possibilities of better alignments or revision management. Consequently, an overview and holistic approach is missing. Instead, the TP is functioning as a knowledge repository and a substantial part of the contents reside within minds of the staff. The document analysis shows that the number of documents within the TP has been allowed to increase uncontrollably, resulting in a folder structure exceeding 1.5 million documents. This is a result from the fragmentation of the TP and the unclear interfaces between the levels of the TP resulting in an increase of variants and evidently the number of documents as well. A similar situation prevails in production where knowledge is buried in the heads of the staff and the reward goes to the problem solvers, which aligns with Löwstedt (2017) and the current state of the construction sector.

PEOPLE AND RELATIONSHIPS

This asset has not been the primary focus of this paper. However, the interviews with the HVAC coordinator and the electricity coordinator show that development across disciplines is scarce meaning that development is carried out individually. Supplies and material deliveries are not planned according to the structure of the TP, rather than when long lead times demand early purchasing, e.g. windows.

DISCUSSION

The current state of practice in the case company is that they have developed a modular product methodology. With the TP, the company wants to be competitive using a product platform in the business model, which should bring order to the product development of what can be agreed with the clients. The assets [components, processes, knowledge, people and relationships] described by Robertson & Ulrich (1998) are fairly well-described in the case with (1) a modular structure of the product, (2) a well-described production process, and (3) know-how. The fourth asset [people and relationships] was not in focus. Still, the way some of the product development is carried out, i.e. lack of cross-disciplinary coordination, improvement areas can be identified.

However, when scrutinizing the way that the company manages the balance between distinctiveness and commonality (Robertson and Ulrich, 1998) it becomes evident that there are parts missing. The expansion of the number of documents in the database along with the testimonials from the interviews where a holistic view is missing. When analysing the tool-kit provided by Krause et al. (2014) with the collected data, it can be concluded that; (1) there is no clear distinction between standard components and variant components, (2) no reduction of the variant components to the carrier of differentiating properties, (3) one-to-one mapping between differentiating properties and variant components is missing and (4) the degree of coupling of variant components to other components is unclear.

The results align with the findings from, Jansson (2013) stressing that when an ETO strategy is applied, the balance between distinctiveness and commonality is crucial to master and that it is difficult to apply platforms for an ETO-based context and integrated product architecture (Jensen, 2014). Technical solutions that are developed in specific projects often have integral product architectures that are difficult to re-use in continuous improvement processes (ibid), which matches the situation in the case company. Jansson (2013) proposes a framework to develop a platform strategy for industrialised house-building where experience feedback from the supply chain is utilised and incorporated into the platform, a strategy that follows the principles of Lessing (2006) and the current way of working with improving the TP of the case company (fig. 3).

The ambiguity in the description of the TP leads to the fragmentation and an unrestrained growth of the document database. For products within the ETO-oriented production strategy working with fluctuating requirements this is not surprising and similar findings have been observed previously (Jansson 2013; Jensen 2014). As André et al. (2017) stated, for platforms in an ETO-context, coherence across all disciplines in needed, which aligns with the basic principles of lean where long-term strategy and holistic view are cornerstones. Modularisation offers an entry to efficiency but active work in all domains is necessary. From both the platform perspective but also from a lean perspective the management of knowledge is a liability since it represents a cornerstone in both fields.

The indistinctive product development and supporting organisation combined with the prevailing culture in construction prioritise projects which clash with the fundament of the industrial housing case. Johnsson (2013) suggests that contractors with a wider scope could focus on standardization of processes rather than products which is consistent with the situation of the ETO process where very few components can be produced before being ordered, which is necessary for creating economies of scale in production (Jensen 2014).

Properly applied, the TP should facilitate lean both in design and production. Fundamental lean principles such as lead time reduction, variability management, and continuous improvements are enhanced from a well-defined platform. However, since Lean is applied in the production, there is a risk linked to the current state with a multitude of variants accepted by the sales department, i.e. having a modular product structure without boundaries is a risk when the number of variants is allowed to expand (Höök 2008) and applying lean principles on non-standard operations might be counterproductive. Conversely, increasing pre-definitions, the risk is to move too far away from the demands of the clients and the market, leading to an imbalance between buildability and client satisfaction (Jansson 2013), including product definitions (Brege et al. 2014), design boundaries (Jansson 2013) and the production (Lennartsson 2012). Thus, there is a risk bundled if Lean is introduced without any evaluation.

CONCLUSIONS

The aim of this paper was to analyse current strategies and support to master the balance of external and internal efficiency in product development within industrialized house-building to facilitate the development of a product platform strategy. The data analysis through the lens of the assets provided by Robertson & Ulrich (1998) identifies several gaps between the state-of-practice and theory on platforms, both generically and regarding research within the industrialised house-building sector. The instrument used to balance external and internal efficiency is the Technical Platform. The results show that customised solutions outside the boundaries of the TP are allowed, e.g. a large number of variants in the product offer and a sliding document database. Having a large portion of public clients with specific demands reinforce this situation. The absence of a holistic view on the operations obscures the potentials of modularisation prescribed in the TP. In conclusion, there is an imbalance where external efficiency is prioritized over the internal efficiency, which clashes with Bonev (2015).

PATH FORWARD

The results show that the case company needs to become better in the management of distinctiveness and commonality from a platform strategy perspective. In alignment with the TP and lean philosophy regarding knowledge handling, the file system database needs to be mapped and sorted out in terms of what information is included in the different drawings and files, identification of systems running across different levels of the TP. The range of documents can then be reduced, and redundant variants can be excluded. Further, an increased integration between the different parts of the platform should be facilitated.

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STAKEHOLDER VALUE EVOLUTION, CAPTURE AND ASSESSMENT IN AEC PROJECT DESIGN

Vijayalaxmi Sahadevan[1] and Koshy Varghese[2]

ABSTRACT

The success of a design lies in its ability to fulfill client values. However, the ambiguity in identification of values by clients renders the task complex and challenging. The investigation of the dynamics involved in stakeholder definition of the project values entails the need for research methods used in social sciences. This paper first presents the process of client value generation and evolution based on an ethnographic study of the architect selection process of two institutional buildings. The study consists of participant and non-participant observations of the project conceptualization and architect selection process. It is observed that along with client requirements incorporated in architectural design, the design delivery efficiency criteria of the architect have equal considerations in architect selection. Therefore, the values in Architecture Engineering and Construction (AEC) design can be categorized into Project Design Delivery Values (PDDVs) and Architectural Design Values (ADVs). The paper proposes a framework for the evaluation of design of a built facility using suitable Multi-Criteria Decision Making (MCDM) technique.

KEYWORDS

Choosing by Advantage (CBA), Set Based Design (SBD) and Target Value Design (TVD), Value in Design

INTRODUCTION

As per the Transformation Flow Value (TFV) theory, it is imperative that AEC project design be viewed through the lens of value in addition to transformation and flow (Ballard and Koskela 1998). Product design and development in general is getting more customer focused (Boztepe S. 2007) with growing impetus on definition and measurement of client satisfaction. However, in the AEC industry the definition of client requirements in itself is challenging due to the presence of diverse perspectives of project

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performance of multi stakeholder client bodies (Thomson 2011). A study on the design process for residential and commercial projects in India revealed that the strategies and the durations of the design of a particular organization was dependent on its design objectives (Joe et al. 2017). This property of variability in outcomes is one of the basic differences between designing and building leading to the unpredictability of the design process (Ballard and Zabelle 2000).

Understanding client value in construction is challenging owing to the extended time taken for completion of projects and the presence of stakeholders with conflicting objectives. Due to the multidimensional, subjective and dynamic nature of value, arriving at an agreement on a set of values for an AEC project is a challenge. It can be stated that, the success of a design lies in its ability to fulfil client values. However, the ambiguity in the identification of values by clients renders the task complex.

This paper presents the process of client value generation and evolution which are based on an ethnographic study of the architect selection process of two institutional buildings. Section 2 presents findings from the literature on value in design. Section 3 describes the scope and methodology of the exploratory study. The accounts of the ethnographic study and its findings are presented in section 4. Section 5 presents a framework for assessing the value in design as a method for choosing between design alternatives. The final section summarizes the current work and recommends scope for further research.

LITERATURE REVIEW

Despite ongoing efforts by researchers to develop a theory of value in the construction industry, a common definition has not materialized. Value has been defined variedly in literature (Derek et al. 2003). Traditionally, the values in an AEC project have been related to time, cost, quality, safety, environment, function, etc. However, studies show that investment in a good design produces economic and social returns. These studies provide evidence in the areas of healthcare, education, housing, business, crime prevention, civic pride and cultural activities. However, value and cost are not linearly related and returns of the cost expended on design are usually intangible (MORI 2002). Unlike product design, design brief in AEC is not limited to initial requirement definition but includes a constant dialogue between stakeholders (Thomson 2011).

Literature has reported a number of tools and techniques for value capture in the AEC industry. Researchers at the Loughborough University have developed the technique to deliver value integrating stakeholder judgement into the design process known as VALiD®. It consists of a platform for understanding, defining and assessing the value proposition. The technique calls for workshops for aiding the stakeholders to have a common vision and understanding of set of values for an AEC project (Thomson et al. 2006).

Quality Function Deployment (QFD) is another tool that has been adopted successfully in the manufacturing industry for capturing client requirements. Literature has also reported the application of QFD to address client requirement capture in construction. However, the role of QFD is limited to the pre-design phase and is market focussed. The complicated nature of construction projects renders the process of development of QFD matrices large and complex (Pheng L. S. 2001). Further, client requirement capture in QFD are predominantly static in nature and the model does not provide for the stakeholder subjectivity. Similarly, the concept of value in design is often confused with Value Engineering technique, which predominantly focuses on value for money in terms of construction techniques and materials, rather than stakeholder aligned requirements.

The Technique of Target Value Design (TVD) is believed to have the potential to address this dynamic nature of values through stakeholder interactions throughout the design process. TVD is a process that aims at providing best value to the owner through pain share gain share mechanism, between the stakeholders. Although TVD has the potential to reduce the likelihood of cost overruns, it has not been widely adopted in the construction industry. This is due to the inherent difficulties in measurement of value and design quality and the need to perform frequent cost-benefit analysis (Orihuela et al. 2015).

Literature reports number of tools and indices for assessing design quality. Design Quality Indicator (DQI) developed based on a research project in UK, is one such toolkit for measuring the quality of a built facility and to aid in the decision-making process during design (Gann et al 2003). Other tools include the Post-Occupancy Review of Buildings and their Engineering for post occupancy evaluation (Leaman and Bordass, 2001), Housing Quality Indicator (HQI) for housing projects (DTLR, 2000) and Building Research Establishment Environmental Assessment Method (BREEAM) which provides measures of energy use in construction.

Literature confirms that stakeholder requirements in AEC projects are pluralistic and complex in nature. Moreover, the iterative, explorative and reflective nature of design suggest limitations in effective applications of the existing tools in managing design requirements (Thomson 2011). In order to develop a strategy for value assessment, the emergence of stakeholder requirements through the design process needs to be studied.

SCOPE AND METHODOLOGY

This work explores the process of client value generation and evolution which are based on ethnographic study of the architect selection process of two institutional buildings. Ethnographic study typically involves spending extended periods of time on the field that one researches, employing participant and non-participant observations, memoing, interviewing and reflecting their own role in the research setting. However, due to its time consuming nature, recent approaches employ techniques that are participatory and that can be tailored to the specific research objectives and settings (Pink et al. 2010).

In the current study, the two institutional buildings were chosen based on convenience sampling. The total area of both the institutional buildings is approximately 500 acres and the scope of work covered development of the master plan for the entire campus, including detailed design of academic zone and common bulk services and development.

In both the projects, the proposed master plan was to be designed for a capacity of 20,000 students, to be developed in three phases over a span of 20 years.

The ethnographic study consisted of participant and non-participant observations of the project conceptualization and architect selection process. The first author was a part of the team involved in the drafting of design brief for the project, studying and analysing the proposal documents submitted by the architects. The second author was a member of the committee involved in design evaluation. In addition, semi-structured in-depth interviews of nine key informants and document analysis were conducted. The key informants in this study were the committee members consisting of architect consultants, engineering consultants, directors of the respective institutions and other members who are experts in the field of engineering, project management or architecture.

The main objective of the interviews was to study the difficulty in specifying stakeholder requirements in the design brief. The key informants included committee members The overall objectives of the ethnographic study were threefold: (i) to study the stakeholder understanding of value in design and the current practice of value capture, (ii) to study the dynamics of stakeholder values through the design process and (iii) to derive a set of stakeholder values for a typical institutional building. The interview transcripts, documents and memos were analysed using content analysis using open coding. The outcomes of the study are discussed in the next section.

OUTCOMES OF THE EXPLORATORY STUDY

The documentation and analysis of the exploratory study a number of outcomes were observed with respect to the constraints in the selection process, design process and design requirements. This section discusses these outcomes. Due to space constraint single interview intercept has been included with respect to each outcome.

CONTEXT AND CONSTRAINTS OF THE ARCHITECT SELECTION PROCESS

The design and construction of the two Institutional buildings are funded by the Government of India and the selection and employment of architect consultant is governed by General Financial Rules (GFR), which is a part of the Ministry of Finance, Government of India. The GFR has been formulated to standardize the procurement of consulting services across government agencies with mandated levels of objectiveness and transparency (MoF 2017). According to the GFR rules, the architects are evaluated in three broad stages: the eligibility, the technical and the financial bid.

The selection framework entails a procedure that mandates 'Combined Quality cum Cost Based System' for architect evaluation. In this system, the pre-qualified architects are evaluated based on the design proposal and financial bid carrying weights in the ratio of 80:20. The intent of keeping the above ratio is to select an architect deemed most competent for the work rather than evaluating them solely based on price. A higher weight for the technical bid was deliberated for the process instead of equal or nearly equal weightage. This is to avoid an architect from winning the bid by quoting a very low price, despite of a poor performance in the technical bid. The overall procedure for architect selection consists of the steps illustrated in figure 1.

Figure 1: Steps in Architect Selection Process

Step 1: The process of architect selection begins with the publishing of Expression of Interest which gives information regarding the scope and pre-qualification criteria. The criteria evaluate the experience and competency of the participating architectural firms.
Step 2: The interested architects submit applications out of which only the technically competent architects are qualified based on the given criteria for technical evaluation.
Step 3: The pre-qualified architects are provided with the Request for Proposal (RFP) containing the design brief.
Step 4: The submitted design proposals are assessed to determine how well it caters to the requirements as mentioned in the design brief. The technical evaluation thus consists of an initial shortlisting of design proposals of prequalified architects. The shortlisted architects have to present a modified design by incorporating the suggestions from the stakeholders. At the end of the technical stage the architects are scored based on their design proposals.
Step 5: The financial bid of the top three architects of the technical stage is opened. The architect with the highest combined final score (technical score + financial score) is awarded the work.

EARLY INVOLVEMENT OF KNOWLEDGEABLE PROJECT STAKEHOLDERS

The director of institution 1 has served on committees for setting up of a number of new campuses in India among other responsibilities. The director elaborated on the owner's role in specifying design requirements as follows:

"The requirements have to come from the owners and if they don't have the capacity, they have to get good advisors to work with them. Either hire or appoint people with experience to understand academic building requirements to understand design and construction and appoint few advisors, to work with them."

The design brief is prepared by a committee consisting of the director and other experts in the area of architecture, engineering and project management to develop a design brief. The committee in this case represents the clients of the project. The early involvement of various experts can bring the knowledge and expertise of diverse fields together. The following paragraph describes the emergence of social value characterised by interdisciplinary interactions that evolved through such dialogues between stakeholders.

SOCIAL VALUE OF INSTITUTIONAL BUILDINGS

A senior retired officer of a public works agency, who is a committee member, spoke about social value in institutional buildings:

"We can't have a department functioning solely on its own, independently without interacting with others. In the whole campus this interdisciplinary interaction has to be brought in. How are we going to bring it, is for the architect and for us to discuss and bring it (in design). That's a challenge."

The design of institutional buildings should cater to the needs of fast growing interdisciplinary research. Apart from labs, the functional planning of the campus and individual buildings should cater to creating environments and opportunities for interactions of students and faculties to the maximum. Interdisciplinary interactions form the social value of a built facility.

As the design progresses, retrospection and reflection through dialogues between project stakeholders aided in specifying requirements such as provision of cafes and positioning of departments to facilitate interdisciplinary interactions. It was observed that stakeholders usually go back and forth with design solutions arising from differences in perspectives and finally arrive at a consensus through mutual agreements on trade-offs. The following paragraph discusses how iterations in design are essential in avoiding ambiguity in providing design requirements.

DESIGN AS AN ITERATIVE PROCESS

The director of institution 2 expressed his difficulty in giving requirements for design.

"The problem is to decide, to what level we should specify the requirements, because if you specify too much, then we will probably remove all the freedom which the architect should have in the design."

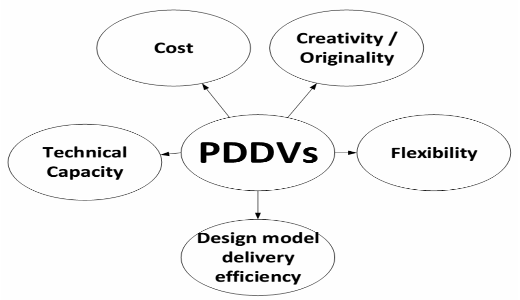
Clients articulate their values in the form of requirements in the Request for Proposal (RFP), which is a document that solicits proposals through a bidding process. The RFP gives brief details on the project background, site details and requirements, facilities to be planned, scope of work, etc. With the progress of the design, clients becomes more and more aware of his requirements. There is a collaborative effort in the form of dialogues between the client and the designer to improve the design to best meet the stakeholder values. In ideal situations, it is imperative that a design should undergo a number of iterations until any further meetings do not add value to the design.

Through the process of iterative dialogues between the stakeholder groups a number of values were captured and further these values evolved into detailed design requirements. These design values can be either subjective or objective in nature which are discussed in the following section.

PROJECT DESIGN DELIVERY AND ARCHITECTURAL DESIGN VALUES

The pre-qualification of the architect is based on the criteria such as organisational strength of the applicant, experience of work and financial capability. Apart from this, during the final presentations of the design proposal the committee tries to understand the design delivery capabilities of the architect. This is assessed based on the firm's history of successful design delivery, cohesive functioning of the design team, BIM platform, coordination and integration with lead consultant office, organizational setup for quick response, etc. These criteria point to Project Design Delivery Values (PDDVs), which are said to have significant influence on the performance as an architect consultant.

In institutional buildings, in addition to traditional values of time, cost, safety, quality and sustainability, there are a number of other architectural design considerations which have direct impact on the users of the facility. These values are Architectural Design Values (ADVs) and can be either subjective or objective in nature. From the study of the various stages of architect selection process the following set of PDDVs and ADVs were derived.



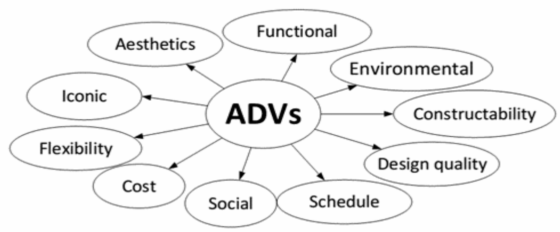


Figure 2: Project Design Delivery Values **Figure 3: Architect Delivery Values**

Figures 2 and 3 illustrate a set of stakeholder-aligned values for both the institutional projects. PDDVs reflect the project management capabilities of an architect and gives indications about the delivery performance of an architectural team. Technical capabilities of an architect are criteria such as previous experience, organizational, technological and financial capabilities of the firm which are purely objective in nature and form the eligibility criteria for competing in the bidding process. The other PDDVs include cost, creativity and originality, flexibility in making changes to the design and the efficiency with which the architect delivers the design documents.

The PDDVs are considered objective in nature as some criteria can be judged based on the quality and scale of the team's previously delivered projects and others that can be tied to the contractual agreement. These values can be associated with the character and commitment of the architectural team. The study of the technical evaluation process revealed ADVs, which are related to the technical and quality aspects of the designs. These values are related to the stakeholder requirements for the built facility as specified in the RFP. ADVs are inherent in the architectural plans and features of a building design. These values are tailored to the specific project and need careful consideration of client behaviours and demands.

As discussed in the previous sections, design values have different levels of abstractions. A few of these values, such as aesthetics, are predominantly subjective in the initial stages and evolve into objective specifications with the progress of the design process. The next section explains this aspect with an example of functional value of design.

VALUE ASSESSMENT

Values as derived from the design brief are usually abstract which evolves into more detailed design requirement with the progress of design. As a result, although values that appear to be subjective during the initial stages of the design, can be broken down into more objective details. Figure 4 illustrates the different abstraction levels of 'functional' value of design.

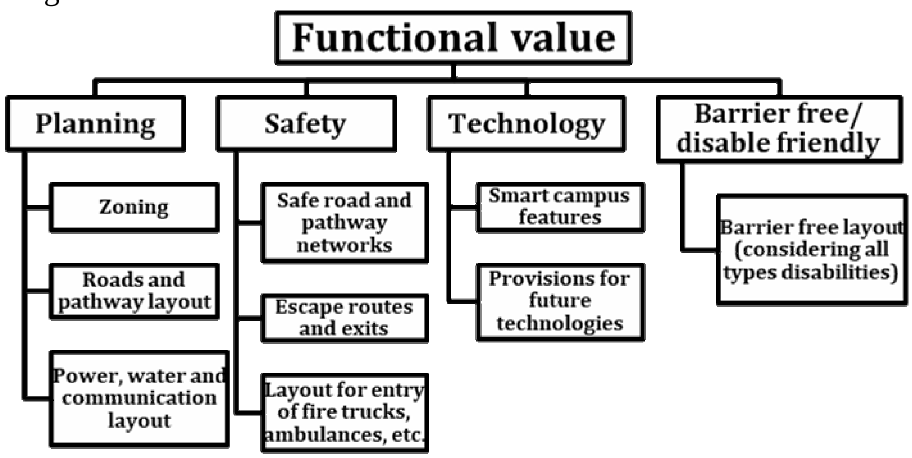


Figure 4: Abstraction levels of ADV value

The abstraction levels are derived from the architect selection process through design iterations and stakeholder dialogues. It is clearly observed that at lower levels, the values are more objective in nature. This paper proposes a framework for assessing the value of a design alternative based on the parameters obtained from the ethnographic study.

DESIGN AS A MULTI-CRITERIA DECISION MAKING PROBLEM

In the ethnographic study a number of instances emerged where the incorporation of one value was conflicting with another. The discussions between project stakeholders during the technical evaluation revealed a number of instances of conflict between design values. The inception of any technical institute is subjected to a number of uncertainties such as, the type of research that the institute will pursue in the future. During the design of the master plan however, specification of requirements is essential in order to provide for research facilities. In the current study the master plan is to be planned keeping in view the provisions for the next 20 years. This calls for flexibility in design. In many institutes the concept of flexibility is met through open buildings or modular designs, wherein the labs can be easily customised to cater to future requirements. However, this solution can constrain designs with specific aesthetic design requirement.

Similarly, the site of one of the institutes was characterised by the presence of a number of water bodies, rocky outcrops, marshy areas and paddy fields. The consideration and preservation of these features pose major constraints in designing the layout of the master plan and the total buildable area.

Due to the above trade-off problem, arriving at a consensus on design alternative can be challenging, especially with the presence of multiple stakeholders with diverse expertise and objectives. Multi-Criteria Decision Making (MCDM) techniques are used in ranking and choosing from available alternatives based on weights given to the criteria which are sometimes conflicting (Ho 2008). MCDM techniques have been applied to a wide range of areas such as business, production, energy and environment, economy, etc. (Mardani et al. 2015). The AEC and lean design management literature has reported the use of Choosing by Advantage (CBA) for decision making processes. CBA developed to compare advantages of alternatives. The technique is again based on criteria of alternatives and stakeholder preferences for the advantages. The application of CBA in SBD and TVD have also been discussed in lean literature (Arroyo 2014).

The current work proposes that choice of design alternatives be viewed as an MCDM problem, wherein given multiple design alternatives, the best design can be chosen considering design values as criteria. The following section describes a framework for evaluating and ranking the design alternatives.

FRAMEWORK FOR EVALUATION OF VALUE IN DESIGN

The proposed framework in this work uses MCDM technique to choose between design alternatives. The figure below represents the steps involved in the framework.

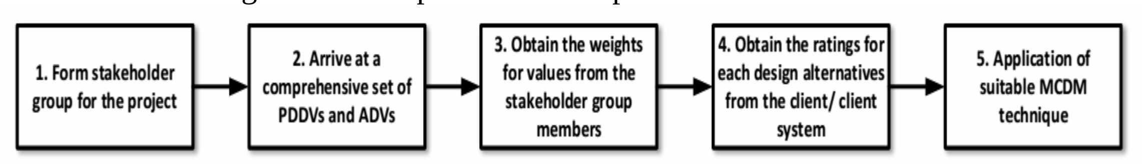


Figure 5: Framework for evaluation of value in design

The steps involved in the framework are as explained below.

Step 1: Form a stakeholder group consisting of representatives/experts from domains which are part of the entire lifecycle of the project.

Step 2: Arrive at a comprehensive set of aligned PDDVs and ADVs depending upon the type of project and the stakeholder group aspirations. The set of values utilized in arriving at criteria can be used as inputs for the questionnaire survey to obtain ratings from the client system in step 4 of the framework.

Step 3: Experts from diverse areas tend to have differing opinions and objectives, because of which all values will generally not assume equal weights. Weights given to PDDVs and ADVs reflect the relative importance to aid in the evaluation and ranking of the design alternatives.

Step 4: The ratings given against a particular value could be subjective or objective in nature. The ratings for each value are solicited from the client in the form of a questionnaire survey that considers the PDDV and ADV criteria derived in step 2.

Step 5: This step involves the choice and application of suitable MCDM technique. The technique chosen should facilitate group decisions. The choice of MCDM technique will depend on whether the user aims to choose, rank or classify the alternatives.

SUMMARY AND SCOPE FOR FURTHER RESEARCH

The paper initially provides an account of the study that was conducted to understand the process of definition design values of two institutional buildings through an ethnographic study. The study reveals the significance of the presence of diverse experts and their involvement in defining the design brief. The study gives accounts of the capture and evolution of a comprehensive set of design values through iterative dialogues between stakeholders. Two categories of design values, viz. PDDVs and ADVs, for construction project designs were identified. Further, the study witnessed the evolution of PDDVs and ADVs into objective detailed design requirements.

The outcomes of the study provide a foundation for a new framework for assessing a design based on these values. The framework mainly considers stakeholder group preferences for evaluating and ranking design alternatives using appropriate MCDM technique.

The proposed framework can be modified to suit any type of AEC project to aid in decision-making between design alternatives. The scope for incorporating this framework into design visualisation tools requires further exploration. While the technique would aid in assessing and hence choosing between designs, its application can be further extended to provide automated value assessment of design for software that explore and generate multiple design alternatives.

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GUIDELINES FOR PUBLIC PROJECT DESIGN DEVELOPMENT

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ABSTRACT

The project development and budgets (PDB) process of public enterprises is carried out in a piecemeal fashion by stakeholders. This situation contributes to several inadequacies of constructions, mainly related to costs and deadlines. The present work aims to propose guidelines to the PDB process of public enterprises based on the Target Value Design (TVD) process and the identification of practices used in the investigated institutions. The study was carried out in four public institutions in Brazil, through qualitative research. The study approach was subdivided into three stages: process investigation based on the TVD; elaboration of guidelines for the process; and evaluation of these guidelines. As a result, the paper presents 13 guidelines distributed in three axes: project budgeting process; planning and process control; and BIM process. The present study demonstrates feasibility in the guidelines application, as evaluated by the investigated ones, thus allowing them to be used to construct integrated PDB processes models.

KEYWORDS

Integration, Process, Target Value Design (TVD), Project Development Process.

INTRODUCTION

In Brazil, public enterprises are contracted through public bidding, which according to Law 8.666 / 1993 (Brazil 1993) allows the bidding to be carried out from a basic project, which is classified as a "set of necessary elements and sufficient, with an adequate level of precision, to characterize the work or service, ... object of the bid. " This brief description of basic design does not make clear the requirement for an executive-level project.

Research on public works projects reports that project failures and changes in projects during the project are pointed out as the main causes that impact on cost increases of works (Santos; Starling; Andery 2015).

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In another study carried out by synthesizing data from the literature, it was verified that 47% of the inadequacies of deviations from costs and deadlines in construction projects are directly related to the following categories: management (lack of planning and control of costs in the pre and post-contract - incorrect estimate of material - among others); project and documentation (defects, errors and omissions in the project - alteration of the project - delay in the elaboration and approval of the project - among others) (Muianga; Granja; Ruiz 2015).

As it is observed in the literature, the architectural and engineering (AE) projects are pointed like preponderant items for assertiveness in the anticipates costs in budgets of real estate ventures. This context is the main justification for the present study.

From the discussion of inadequacies in public constructions, some collaborative aspects in the process of developing projects and budgets are related, such as: integration of technical teams; improvement in process description; use of BIM; anticipation of actions in the project process; improvement in the computerized communication system (Neves et al. 2017).

The proposal for the development of the study is characterized by the investigation process of the context of project development in public enterprises, through case studies, using theoretical process Target Value Design (TVD).

Seeking to frame the research problem, an essential question arises based on the presented aspects: How to improve the projects development process of projects of public enterprises? As objective, the present study aims to elaborate guidelines for the participants in the development of projects of public enterprises.

TARGET VALUE DESIGN

The discussion of value in this process is defended by lean thinking, which is based on the principles of lean construction proposed by Koskela (1992), among which it is possible to highlight: increasing the value of the product / service by systematically considering the requirements of customers; and focus on overall process control.

The TVD is based on lean thinking and uses 17 theoretical elements that relate stages of the development process of AE projects with the objective of guarantee the value established by the client. The process considers the participation of the customer (owner or responsible) and the suppliers in the stages of development of real estate products, besides emphasizing the importance of budget cycles to guarantee the established cost (Ballard 2011).

TVD aims to have a construction done within a desired budget, according to a detailed estimate. For this, value, cost, schedule and constructability are established as basic components of the project criteria (Forbes; Ahmed 2011).

The TVD presents fundamental points such as: the client's decision about financing the undertaking; the determination of the total cost; integration between teams of designers, suppliers and customers; and routine budgets throughout the process. (Ballard 2011)

In Brazil the approach to TVD is still limited, and it is necessary to diffuse its elements, thus enabling the process of knowledge about a rigorous management method for the development of products in civil construction, involving developers, architects, engineers, builders and suppliers (Oliva; Melo; Granja 2015)

The Last Planner System (LPS) and Building Information Modeling (BIM) are considered catalysts for the TVD process and are not mandatory. However, it is emphasized that, in order to achieve higher levels of collaboration, these catalysts become mandatory (Oliva; Granja 2015).

Target Cost (TC) has a strong relationship with TVD, considering that the two methods aim to reduce costs, ensuring quality, reliability among other attributes, thus generating value for customers (Miron; Kaushik; Koskela 2015). Oliva et al. (2016) suggest that TVD should be reviewed in the light of the original theory of TC to better adapt to the new applications to be carried out in real estate projects.

The benefits of TC application increase over time as the company gains in productive efficiency and increases its cost sensitivity. In addition, it strengthens the method of collaborative work (Jacomit; Granja 2011). The main functions, or construction systems, can be adjusted based on the TC, through the identification of ideas for cost reduction through a systematic process of balance between cost and performance (Ruiz; Granja; Kowaltowski 2012).

The LPS can be applied in the design process, aiming to plan and control the products obtained through the strategic, tactical and operational levels, thus making possible the increase of the reliability of the process through the completion of tasks. In this way, it composes levels of planning based on the commitment of the participants (Ballard; Howell 1998; Khan; Tzortzopoulos 2014).

In short, a project process can evolve from new methods and processes, aimed at its development in an integrated way and stimulating the autonomy and participation of stakeholders, prioritizing the simultaneity of the projects, as well as the systematization and documentation of the process (Fabricio 2002; Barros Neto; Nobre 2009).

METHOD

The present research is classified as qualitative, being one of the objectives of this type of research the performance in social issues (Poupart et al. 2008). The research strategy adopted was the case study, when the phenomenon to be studied is contemporary, and it happens in a context of real situation (Yin 2001).

As a delimitation of the research object, 04 public institutions were studied, being composed by sectors of project development, budgets and construction supervision. The research covers the linear chain of activities that are components of the public enterprise production system, which was subdivided into three stages: investigation of the process in the light of TVD; elaboration of guidelines for the process; and evaluation of these guidelines.

INVESTIGATION OF THE PROCESS IN THE LIGHT OF TVD

In the present study, TVD is considered a fundamental reference, therefore, previous bibliographic research was performed according to Neves et al. (2016). The systemic search on the subject was carried out with the aim of identifying the works with greater representativity and seminal authors. Based on this search, the data collection instrument was elaborated and had as theoretical foundation the 17 elements proposed by Ballard (2011), as well as the TVD catalysts according to Oliva and Granja (2015). This instrument was subdivided into 03 parts: basic project development (26 questions); TVD catalysts (03 questions); and respondents' contributions (03 questions).

The selection of the case studies was carried out from the outline of public institutions that maintained common organizational structures, such as: AE project development and budgets sector; and construction supervision sector. Therefore, 04 public institutions were studied, involving a total of 17 participants: 03 clients; 05 managers; 03 designers (architects and engineers); 03 budgeteers; 03 works inspectors[5].

Since this is a qualitative study, a delimitation is necessary in cases that were willing to contribute to the present study. Therefore, contact was established with the participating institutions. The sectors studied are responsible for the development of projects, budgets and construction bids. In this last case, each institution has only one architecture and engineering sector. Institutions use similar production procedures.

The institutions investigated work in the public segment in the states of Ceará and Santa Catarina, being denominated: Institution A; Institution B; Institution C; and Institution D

After data collection, the interviews were transcribed with the purpose of allowing re-reading, supporting the process of data organization and subsequent analysis. This phase was performed according to a protocol elaborated from Bardin (1977), which was structured according to the following sequence: preliminary reading; selection of specific texts; segregation of text samples; construction of coded reference; and data correlation. The NVivo software was used for data analysis. In this way it was possible to understand the projects development process of public enterprises, considering all phases involved.

ELABORATION OF GUIDELINES FOR THE PROCESS

Based on the previous stage, it was possible to elaborate the guidelines for the public enterprises projects development, these being structured from TVD, through three axes: process of projects and budgets; planning and process control; and use of BIM.

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5 According to Law 8.666 / 1993 (BRAZIL, 1993), in public institutions there is a restriction of external participation to the institution, making it impossible for the builder to participate in the process. Thus, it is necessary to adapt the TVD to public institutions. Therefore, for this study, it was possible to adapt the participation of the constructor, which was replaced by the "Working Inspector", participant responsible for monitoring and inspecting works of the institution. The works inspector is considered a technical servant who has the knowledge and experience in relation to the works. It is important to remember that this adaptation is only possible in public institutions that have a complete technical team to develop projects.

EVALUATION OF THE GUIDELINES FOR THE PDB PROCESS

The elaborated guidelines were submitted to the evaluation in one of the studied institutions, each one being evaluated under three aspects: feasibility; expectation of application; and conflict with Law 8.666 / 1993.

Institution A was chosen for the evaluation by concentrating the largest amount of data collected. The evaluation model was collected through a meeting with members of the institution.

The evaluation process was conducted by the researchers through rounds of discussion, in each round being collected the opinions of the servers. At the end of the meeting, answer sheets were collected, drawn up based on the evaluation aspects, properly completed by the participants.

RESULTS

GUIDELINES FOR THE PDB PROCESS

The need to adopt integrated project development processes is raised by the servers themselves, as well as planning and controlling activities, and adopting new technologies. Thus, based on the aspects raised in the present study, the guidelines were elaborated and based theoretically on the works of Ballard (2011) and Oliva and Granja (2015), relating the TVD elements and their catalysts to the gaps observed in the study. In this way, the guidelines were distributed according to the following axes: process of projects and budgets; planning and process control; and use of BIM.

GUIDELINES ON PROJECT AND BUDGET PROCESS

It is observed that "budget error" and "project error" stand out as the main causes pointed by the interviewees for the inadequacies in public works related to costs. Some of the respondents reported that budget errors often happen because of project errors.

In Institution B, the participant "WI" demonstrated not to know many of the aspects pertinent to the process reported by the participants in the technical area, "designer" and "budgeteer". In general, the WI only has effective participation in the post-bidding phase, that is, after the effective contracting of the company contracted to carry out the work.

From the results, it is evidenced that the institutions do not recognize the Definition of Financial Resource (DFR) phase as a strategic process, because, according to the reports, the determination of the cost of the enterprise is made by the history of works previously carried out by the institutions themselves.

This decision on the cost of the project is established as the guiding parameter of the PDB, which only knows the cost of the work at the end of the project development. For institutions, this requires adaptation to the allocated resource, or requires that the project be adjusted to the pre-determined resource.

The DFR process considers only the participation of the architect and does not consider the involvement of engineering designers, budgets and construction supervisors. In this way, the process eliminates the possibility of discussion among participants with experience in other areas of engineering, either for the definition of construction costs or to discuss the problems generated by system specifications inconsistent with the projects and only discovered during the construction.

The fact that there is no documentary process in the DFR phase weakens the later phase, since it allows the project to be modified during the development process to fit the needs of the client.

Table 1 presents the consolidation of the guidelines on the project process and budgets.

Table 1: Guidelines on the Project Process and Budgets

	Guidelines - Project and Budget Process
1	Implement a process of integrated development of projects and budgets, also considering the DFR phase, among the participating members, these being: clients; managers; architects; design engineers; budgeting; and WI. This action must be preceded by selection of participants and duly registered. It is important that the technical team share the same physical space in their work routine.
2	Standardize and systematize the DFR and PDB processes, as well as the documentation pertinent to these processes.
3	Conduct presentation to participating members about the needs of customers as well as the benefits planned for the venture. This action should also include guidance on possible cost constraints and deadlines of the enterprise.
4	Define the costs for execution and operation of the project still in the DFR phase.
5	Use creative costing-goal process tools to optimize and reduce costs.
6	Develop budget and work schedule in advance, starting at the DFR stage and subsequently developed during the project and budget process.
7	Establish cost goals and schedules for each project discipline. This action must be carried out through updates of estimates by area throughout the project and budget process, and it is necessary to evaluate the predetermined targets.

GUIDELINES ON PLANNING AND CONTROL OF THE PROCESS

According to the research participants, there is no long- and medium-term planning for the project and budget activities, but two of the interviewees reported that there is a computerized work routine control system. In this system the servers supply the short-term schedules. This system was presented to the researcher, as well as the access link was made available as a form of supporting evidence.

Other reports indicate that short deadlines for process development can lead to project errors, as project changes throughout the process or work can lead to higher project costs.

Table 2 presents the consolidation of the guidelines on planning and process control.

Table 2: Planning and Process Control Guidelines

	Guidelines – Planning and Process Control
8	Implement planning and control system in the projects and budgets development process considering: long-term planning; medium-term planning; and short-term planning.
9	Program the short-term planning in an integrated way, considering the participation of the management and operational teams, so that the planned activities are controlled, as well as exist the feedback of the long and medium planning, aiming the learning and evolution of the system.

GUIDELINES ON THE USE OF BIM

It appears that the use of BIM, in part of the institutions, still does not constitute a policy. However, the isolated actions by some architects in working with BIM reflect the innovative stance of these servers.

The participant of Institution D reports that the conceptual project in the FS phase is carried out through BIM modeling of the preliminary study in the LOD[6]-100, as well as the documentary process of approval of the FS is performed, being in two formats: the analysis matrix, recorded in printed process; and BIM model, registered in BCF (BIM Collaboration Format), that can be visualized in other tools of software directed towards the client.

The participation of the "budgeteers" in the FS phase in BIM does not exist, according to the participant of Institution D, who affirms that there is no such function in the sector, which is assumed by the engineer or architect. The same one affirms that, with the use of BIM, there is a clash between the quantitative generated in the model and the budget base presented in the official tables, being this a limitation generated.

According to the "Designer" of Institution A, the implementation of BIM in the institution is developed through three axes: 1) pilot project in joint with the architecture and budget teams; 2) capacity activities through training, with the objective of bringing professionals closer to the BIM methodology; 3) implementation of BIM process in the projects and budgets development.

The participants reported some possible future contributions with the use of BIM, these being: reduce project production time; reduce design errors; because it considers an efficient work tool, soon there is an increase in the information confidence; reduce divergences between project and budget; improve the process in a general way; facilitate the projects and budgets preparation; improved level of detail.

Table 3 presents the consolidation of the guidelines on the BIM use.

[6] LOD (Level of Development) is defined as a classification for elements modeled in BIM, facilitating communication between project participants. LOD 100: elements are not geometric representations. LOD 200: elements are geometric representations, considered components, but they present approximate information.

Table 3: Guidelines on BIM use

	Guidelines – BIM use
10	Select a key team of servers, architects and engineers, for training and qualification in BIM, aiming the development of pilot model. The main purpose of said model is to provide data for structuring process standardization in BIM.
11	Prepare standard specifications to meet the technical information needs of BIM. This booklet should consider the complete chain of information on the components, elements and building systems commonly used by the institution.
12	Establish work cost parameterization based on BIM models from the LOD 100 and LOD 200 classification, considering that these classifications are pertinent to the financial resource definition phase, being characterized as conceptual studies or preliminary studies.
13	Adapt the function of employees, architects and engineers to the new working paradigm established by BIM, considering that the models provide the quantitative from the parameterized geometric basis. This adaptation is directly correlated with the budgeteer, which should contribute to the process assuming a new role. In the latter case, the learning process is the function adjustments basis.

It is important to note that a final guideline was proposed for the present study, but this was eliminated after the evaluation, as presented in figure 1. The aforementioned guideline was listed as "14" and has the following purpose: "To structure reference base of composite costs in BIM, with the purpose of contributing to future adaptations in the official tables of costs and indices of civil construction".

GUIDELINES EVALUATION

Figure 1 presents the consolidated result of the guidelines evaluation carried out by the participating members of Institution A.

Guideline	Is it viable?	Application Expectation	Conflict with Law 8,666/1993	Comments
1	Yes	2 Years	No	1
2	Yes	6 Months	No	2
3	Yes	2 Years	No	3
4	Yes	2 Years	No	4
5	Yes	2 Years	No	05*
6	Yes	2 Years	No	6
7	Yes	Over 2 years	No	07*
8	Yes	1 Year	No	08*
9	Yes	1 Year	No	09*
10	Yes	2 Years	No	10
11	Yes	2 Years	No	11
12	Yes	2 Years	No	12*
13	Yes	Over 2 years	No	13
14	No	-	-	14**

Figure 1: Guidelines Evaluation

Following the observations made by the participants during the evaluation: 01- It is an extreme urgency guideline for projects carried out by internal teams, and can be implemented more easily; 02- Important and necessary guideline, especially in public service and legal demands, however, will require time and dedication from the team; 03- It should be included as a preliminary project step (needs program / feasibility studies) and duly registered as part of the work routine, avoiding future and recurring changes; 04- It is not clear if sufficient information will be available to elucidate execution and operation costs in an initial project stage (financial resource definition). Only if you work with building standards; 06- It depends on the level of budget detail / construction schedule; 10- Process in progress, but linked directly to guideline 2, for long-term implementation; 11- Process in progress, however, it is linked directly to guideline 2, for long-term implementation. The especifications would be the end result of the process, being desirable for the whole institution, not just for the BIM implementation. Thus, it would allow greater integration between project, budget, process control, transparency and efficiency; **14- Impracticable. It demands a great effort on the team commitment. It is believed that it will be a market transformation through the culture change with the use of BIM**.

Some points were raised during the evaluation, mainly regarding doubts about the implementation or application of the guidelines in question, according to the observations: 05; 07; 08; 09; 12; and 13. However, it is considered that only through a model implementation process, based on the guidelines, would these questions be elucidated.

CONCLUSIONS

This study aims to propose guidelines to the participants in the project development of public enterprises, considering that the said process shows weakness in the preliminary definition of costs, which begins to reflect in the whole subsequent process. The research contributes to the discussion about aspects that directly affect the quality of projects developed in public institutions in Brazil.

Public institutions commonly estimate the cost of new projects by considering the cost history of similar existing buildings, or use information based on the Basic Unit Cost (BUC), a cost indicator for the construction industry in Brazil. Therefore, this integration proposal is not only a theoretical discussion, as observed in the results of the research, but also reflects a need pointed out by the servers investigated.

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USING BIM AND LEAN FOR MODELLING REQUIREMENTS IN THE DESIGN OF HEALTHCARE PROJECTS

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ABSTRACT

Healthcare facilities are well known for their complexity. Frequent changes in healthcare processes, as well as the introduction of new technologies, demand changes in the internal layout and in the performance of buildings. Moreover, there are several stakeholders involved, with distinct and sometimes conflicting requirements, including medical staff, patients, visitors, cleaning and maintenance teams, among others. Some of those requirements have been translated into a complex set of norms and regulations. This paper reports the initial results of an ongoing investigation that has explored opportunities for improving value generation in the design and installation of healthcare facilities by using BIM and Lean concepts. The aim of this study is to understand how user requirements can be modelled to support decision making in the design process. Modelling requirements involves several steps: identification, structuring, establishing priorities, translating and representing in a BIM model. It depends not only on the individual user requirements but also on how some critical healthcare processes have been defined. The main contributions of this paper are concerned with the definition of how different types of requirements can be modelled to support the assessment of the healthcare building designs.

KEYWORDS

BIM, requirements modelling, automated rule checking, healthcare design.

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INTRODUCTION

The healthcare built-environment is very well recognised for the complexity related to all phases of its life-cycle, including design, construction and operation. Thus, the impact of the built environment in healthcare services needs to be considered, due to the influence of the spaces over the healing process and healthcare outcomes (Tzortzopoulos et al. 2005). The demand for the fast introduction of emerging technologies on operations and changes in healthcare processes can lead to the need for many changes in the layout and building services. Additionally, the large number and variety of requirements from several different stakeholders, such as medical staff, patients, visitors, cleaning and maintenance teams, among others, must be considered during the design phase, increasing the complexity of the healthcare design process. Often those stakeholders have distinct or conflicting requirements, which makes the processes of capture and assessment difficult to perform. Furthermore, the iterative nature of the design process may result in the evolution of client requirements (Kiviniemi and Fischer 2004). In this context, traditional approaches for design and construction, which are usually manual-based with low use of information technology (IT), tend to become less effective regarding efficiency and value generation (Koskela and Howell 2002).

Value generation is one of the key elements of Lean Construction, being concerned with the fulfilment of client requirements (Koskela 2000). During the product development process, value generation consists of three phases, described by Leinonen and Huovila (2000) as: (i) identifying the clients' desires, needs and expectations; (ii) creating solutions that meet these requirements; and (iii) conducting assessment throughout the design and production process so that customer needs can be deployed in a final product, appropriated to those needs. Hence, this requires an approach towards client requirements management and modelling, which recognizes that requirements change and refinements are needed over time (Jallow et al. 2014). Client requirements management involves the process of managing, controlling and refining requirements throughout the product life cycle (Bruce and Cooper 2000). Requirements modelling should be understood as part of the requirements management process, and is related to requirements representation, which enables information to be better understood, manipulated and managed (Nuseibeh and Easterbrook 2000).

The use of IT has been suggested to support requirements management for a number of years. Kamara and Anumba (2001) indicate that using technology could support the creation, communication, documentation and management of requirements. Additionally, Kiviniemi (2005) suggests that the use of IT for managing requirements is desirable so that some degree of automation in manipulating a large amount of information is involved. Recent advances have discussed the use of Building Information Modelling (BIM) as a key approach to enhance quality and to deal with the complexity associated with healthcare projects. BIM allows requirements modelling through the development of a semantic-rich database, , which are not always explicit for decision making in the design process (Solihin and Eastman 2015). This information can be connected to building models, in order to provide a hierarchical structure to requirements data (Kiviniemi and Fischer 2004) and assess building designs, by using automated rule checking (Eastman et al. 2009). The aim of this paper is to understand how user requirements can be modelled to support decision making in order to facilitate the assessment of healthcare building designs. This paper reports the initial results of an investigation that explored opportunities for improving value generation in the design and installation of healthcare facilities by using BIM and Lean concepts.

REQUIREMENTS MODELLING

Requirements modelling was originally developed in the field of software engineering (Sommerville 2007). Several benefits of requirements modelling have been identified in that context, and it is believed that the construction industry could also benefit from it, such as: (i) simplicity in visualising requirements and making them available to the different stakeholders involved (Grässle et al. 2005); (ii) understanding and verifying requirements in terms of integrity, correctness and consistency (Grässle et al. 2005); and (iii) supporting the traceability of requirements, which reflects in the ease of finding their origin and destination (Sommerville 2007), as well as understanding how requirements evolve during design (Fiksel and Hayes-Roth 1993; Jallow 2011).

BIM can support the achievement of such benefits in construction, and its use for modelling information contributes to the visualisation and organisation of requirements data (Jallow et al. 2014). This can be beneficial both for design teams and also for professionals in charge of assessing building design (e.g. planning approvals). BIM-based requirements modelling has a positive impact on the verification step, as the connection between requirements and the building model enables automated visualisation and verification, and can thus reduce the time spent on the analysis and compliance of project proposals (Eastman et al. 2009). Besides, in the construction context, poor integration of shared information increase misunderstandings and allows information to be lost (Marchant 2016). There are other potential benefits, associated with mapping non-compliance specifications in the early stages of design, as well as allowing for different scenarios and experimenting with diverse design options with a larger input of information from the stakeholders (Zhang and El-Gohary 2015).

Thus, the storage of information on requirements structured in object-oriented tools contributes towards creating a construction industry that is more client-centred (Kiviniemi 2005; Parsanezhad et al. 2016). BIM-based tools such as dRofus® and Solibri® have been developed for this purpose (Parsanezhad et al. 2016). Both allow connecting requirements and different parts of the product model by using the IFC Open Standard, to ensure that the design solution satisfies the requirements (Kim et al. 2015). dRofus® is suitable for modelling requirements in a hierarchical tree structure, which can be used to represent the decomposition of non-functional requirements, such as safety and indoor thermal comfort, into technical-functional requirements, such as requirements related to dimensions of spaces (Eastman et al. 2009). By using Solibri®, requirements can be connected to spaces and translated into logic rules such as some normative requirements of accessibility and space programme (Eastman et al. 2009).

RESEARCH METHOD

Design Science Research (DSR) was the methodological approach adopted in this investigation. The main objective of DSR is to develop solution concepts that are able to solve classes of practical problems and at the same time allow a theoretical contribution to be made (Kasanen et al. 1993). In DSR, the main research outcome is an artefact, which is based on a deep understanding of problems from the real world (Lukka 2003).

The research process was divided according to the following phases: (i) understanding the problem; (ii) development of the artefact; and (iii) analysis and reflection. Several learning cycles are being undertaken during these stages, due to the iterative nature of this research approach, which is very similar to a design process. As this is an ongoing research effort, phases 2 and 3 are currently under development. An empirical study was conducted in close collaboration with a University Hospital in Porto Alegre, Brazil (Hospital A), which is undergoing a major process of redevelopment. An 84.000 m^2 extension in the hospital complex is being built, corresponding to an increase of 70% in the existing built area. This study started in January 2016 and has focused on the Emergency Unit, including both current and future spaces.

Multiple sources of evidence were used in this investigation, such as: (i) 26 unstructured and 6 semi-structured interviews with the hospital staff and architecture and engineering team members; (ii) document analysis (2D and 3D designs, internal operational process descriptions, regulation RDC 50, reports from the hospital staff to the design teams, regarding design modifications); (iii) design assessment reports; (iv) direct observations at the emergency unit, in order to identify new user requirements and assess previous captures; and (v) meetings with engineers, architects and contractors from the undergoing expansion construction project. Five main activities were developed so far, and they are mostly related to the first and second phases of the research process: (i) identification and understanding of the requirements from internal and external clients and the associated healthcare regulations; (ii) structuring and modelling requirements with support of dRofus®; (iii) modelling the building project up to LOD 350 with support of Autodesk Revit; (iv) translation and modelling of rules in order to perform an automated checking process, with support of Solibri Model Checker®; and (v) assessing the design project regarding the attendance of requirements from both clients and regulations.

EMPIRICAL STUDY: HOSPITAL A

REQUIREMENTS IDENTIFIED AT THE EXISTING EMERGENCY UNIT

From the interviews and observations made in the existing emergency unit, as well as information from documents containing requests for changes on the future emergency project, items of users' needs were identified. This information is related to different elements such as: (i) environmental comfort; (ii) accessibility; (iii) visual requirements, as wayfinding' needs; (iv) furniture quality and ergonomics; (v) space programme; (vi) suitability to use and functionality of spaces; (vii) furniture and equipment; (viii) fluid-mechanical installations; (ix) privacy; (x) infrastructure; and (xi) proximity/distances between spaces and functions. The information collected was interpreted and translated into 177 requirements. This is an important activity so that requirements can be understood and interpreted by people and modelled on computer-based tools (Fiksel and Hayes-Roth 1993; Kamara et al. 2002).

REQUIREMENTS IDENTIFIED IN HEALTHCARE REGULATIONS

Codes and regulations for healthcare projects usually contain a large number of requirements, which play a key role in the design for this type of building. The RDC 50 standard, from the Brazilian Health Surveillance Agency, was analysed. This is the most important set of codes and regulations for healthcare projects in the Brazilian context. 864 regulations were identified, 1284 requirements stemmed from these. These requirements are related to: (i) legal aspects of healthcare projects; (ii) existence of certain installation systems (such as medical gases, hot and cold water supply, HVAC, MEP, furniture, fixture and equipment) in specific rooms, according to the activities which shall be executed on each space; (iii) space programme, specifying minimum spaces and areas; and (iv) design and performance criteria for supporting systems, such as fire safety system.

REQUIREMENTS MODELLING

Modelling requirements included (i) requirements structuring and classification; (ii) connecting requirements with the building model; and (iii) encoding requirements into logic rules. These are described as follows.

Requirements structuring and Classification

Users' requirements were organised in a structured way, which contains different levels of detail. Initially, the information was stored in a spreadsheet and grouped according to affinity, such as requirements related to the dimensions of the spaces and, subsequently, it was organised into categories and subcategories of requirements.

These categories and subcategories were based on Kiviniemi's (2005) framework, as well as on the existing structure of dRofus®. As a result, the requirements' structure adapted to healthcare projects includes 13 categories, 32 subcategories (Figure 1). The subcategories are broken down into in 177 requirements.

Categories	Subcategories	Quantity of requirements
1. Conformity space requirements	1.1. Requested location; 1.2. Occupancy; 1.3. Adequacy of Space dimensions; 1.4. Number of space units	60
2. Equipment and furniture requirements	2.1. Equipment and furniture in space; 2.3. Ergonomics; 2.4. Equipment and furniture dimensions; 2.5. Operation and maintenance of furniture and equipment	48
3. Plumbing/piping systems requirements	3.1. Plumbing systems; 3.2. Medical gas pipeline systems	6
4. Flexibility of Building, Spaces and Technical Systems	4.1. Expandability; 4.2. Frame flexibility; 4.3. Alternative use	6
5. Acoustics	5.1. Noise level	1
6. Lighting and Electrical Systems	6.1. Lighting; 6.2. Electrical Systems	7
7. Indoor climate	7.1. Heating and Cooling	1
8. Operation and maintenance	8.1. Cleaning	1
9. Visual requirements	9.1. Internal/ external visual contacts; 9.2. Wayfinding; 9.3. Visual signal; 9.4. Visual control; 9.5. Visual barrier	21
10. Accessibility requirements	10.1. Space Accessibility; 10.2. Building Accessibility; 10.2. Equipments and furniture Accessibility	14
11. Finishing requirements	11.1. Floor; 11.2. Walls and partitions	5
12. Doors and windows requirements	12.1. Doors; 12.2. Windows	4
13. Information technology	13.1. Scope of IT; 13.2. Computerized services	3

Figure 1: Structure of user requirements with categories and sub-categories adapted to healthcare projects. Developed by the authors.

Connecting Requirements to the Building Model

The spaces, equipment, furniture and installations planned in dRofus® can be connected with the building model. On selecting one of the spaces, dRofus® opens a window called Room Data Sheet (RDS), onto which requirements are stored. RDS includes functional categories, such as Conformity Space Requirements, in which requirements were stored in a structured way (Figure 2). The organisation of requirements in dRofus® also allows the insertion of new requirements that may arise throughout the design process.

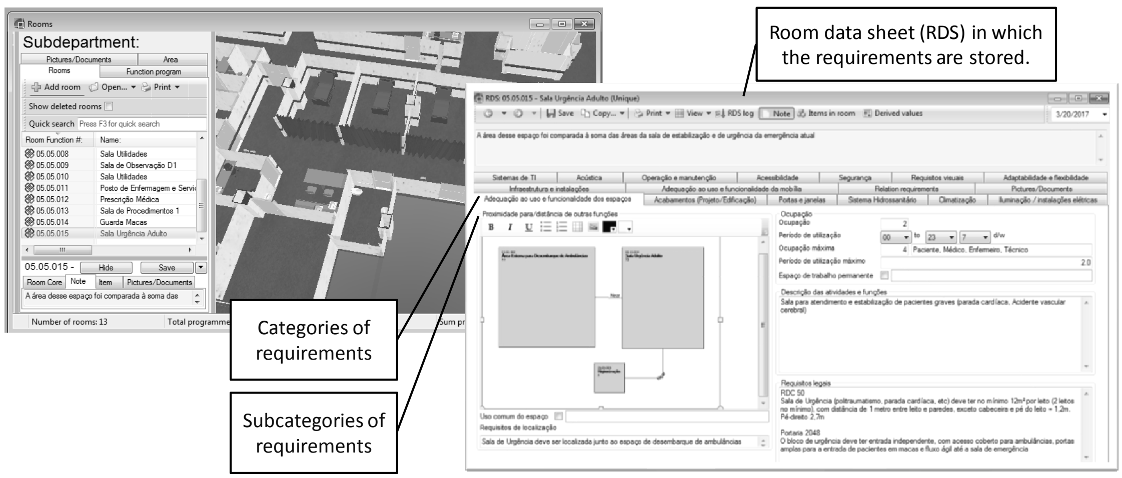

Figure 2: Requirements stored in dRofus® and connected with building model. Developed by the authors.

Encoding Requirements to Logic Rules

The process of encoding requirements into logic clauses was made to allow a rule-structure definition, this was based on the atomic sentence concept. This type of sentence is a declarative clause that can only be true or false and is the "minimum unit" of a logic-based expression, in other words, it cannot be divided into other simpler sentences (Park et al. 2016). An atomic sentence usually is expressed under the structure of S (subject) + V (verb) + O (object) (Lee et al. 2016). More than that, these expressions should consist of the content and the condition to be verified.

The process of defining atomic sentences is based on the meaning of requirements' elements. Thus, it relies on semantic principles, as semantics can be defined as "meanings of terminologies" (Chen and Vernadat 2003). Based on the encoded logic rules, there are different approaches which can be adopted to perform the automated design assessment: (i) re-write logic clauses, which are the output of translating requirements based on semantics, into a computer-executable algorithm; or (ii) using logic clauses in order to support the input of data into a code checking software, such as Solibri Model Checker®.

ASSESSING THE BUILDING DESIGN

Once the requirements were modelled and connected to the building design, structured information became available, which enabled the assessment of the design. The task of verifying semantic-rich data in the 3D model is not an easy step in the assessment process and sometimes might result in inconsistent outputs. Thus, for this empirical study, the assessment process was made by using three different approaches: (a) automated checking; (b) semi-automated checking; and (c) manual checking. Combining different techniques was important, as all approaches have their limitations. These are described as follows.

Automated Checking

The use of automated rule-checking in this study was carried out with the support of Solibri Model Checker®. A wide range of codified requirements was inserted in the software "ruleset manager", in which rules can be modelled according to its internal programming structure. The use of automated systems is promising due to the possibility of providing more coherent results, with little or no ambiguity in the assessment reports.

In this study, Solibri® was successfully used to verify requirements related to accessibility, properties of spaces and installation of systems in specific areas. Figure 3 presents an example of requirement checking: "the invasive treatment room needs to contain: cold water supply system, two oxygen outlets per bed, one outlet for nitrous oxide for every two beds, and two outlets of medical compressed air per bed.".

The main issue regarding the use of automated rule-checking systems, especially hard-coded approaches such as Solibri Model Checker®, is that some of the healthcare requirements are too complex and subjective to adapt to the software demands. Besides, rule creation under the Solibri® interface is an example of what is called a "black-box effect", already described by the literature (Lee et al. 2016; Solihin and Eastman 2016). This happens because "processing rules" becomes an invisible task, the user just receives a report with a pass, fail or inconclusive status, and the actual checking process is hidden within the software programming logic.

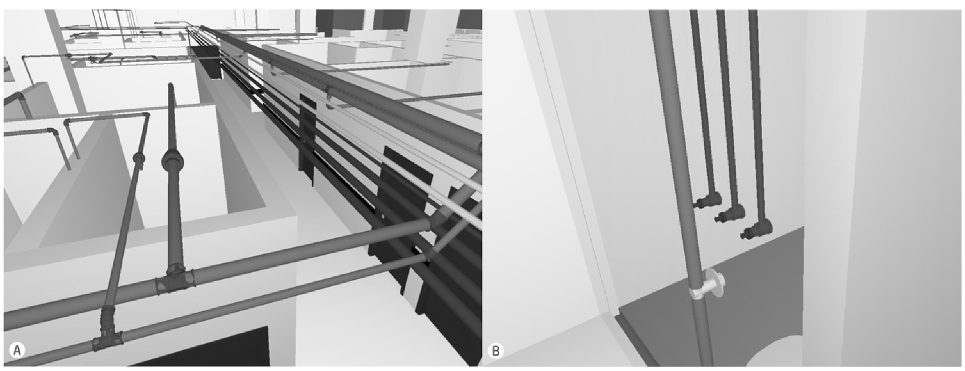

Figure 3: automatic rule-based verification of cold water supply system (A) and medical gases supply (B). Developed by the authors.

Semi-automated Checking

Semi-automated checking can be defined as a human judgment which is made by assessing computer-processed data. The main difference from the automated rule-checking process relies upon who is responsible for the pass or fail status, i.e. the judgment. This approach was used in the study for situations in which it was possible to use structured data from both the 3D model itself, as well as from the modelled requirements, to verify certain criteria with some degree of subjectivity. As an example, it was possible to compare the programmed area with the actual designed area, under computable-processed information from dRofus®. In this approach, the final decision depends on human interpretation and judgment.

Manual Checking

Manual checking can be seen as the opposite of automated rule-checking. The use of manual checking in this study was restricted to some highly-subjective requirements, which could not be verified in either the automated and semi-automated methods. This approach, despite being necessary because of the complexity levels involved in the healthcare context, usually demands more time to perform the design assessment. More than that, manual checking is not replicable, which means each modification or new design must be verified through a completely new set of steps, instead of reusing the rule-structure, which increases even further the efforts put into the assessment process. Additionally, understanding and interpreting the content of requirements sometimes can lead to inconsistency and can be prone to incorrect outputs, because of subjective human interpretation and judgment.

An example of manual checking adopted in this study: there are requirements from the users related to design such as, (i) drawers shall be easy to open; and some are related to operation, (ii) furniture shall function properly in order to avoid noise emission to the patients. These requirements are highly subjective, and their assessment on the design relies upon the particular interpretation of their content and conditions against related design specifications.

Analysis of the Assessment Process

In relation to the 177 user requirements identified in this research, 23% were able to be automatically checked, and a further 23% could be verified by semi-automated checking. It is noted that BIM-based tools were important in the assessment process, as 46% of requirements could be verified by automated and semi-automated methods, while 54% of user's requirements still required manual checking, because of the subjectivity related to the requirements.

Regulatory requirements were analysed based on the possibility of translating requirements into logic rules. This analysis was made based on the levels of subjectivity necessary to assess the requirement in the design, as well as the possibility of re-writing sentences into logic clauses. Based on that, 63% of requirements could be translated into logic rules. Of these requirements, 39% were qualitative, 53% quantitative and 8% were ambiguous.

CONCLUSIONS

The process of modelling requirements allows structuring, classifying and checking semantic-rich information on design projects. While Lean is a fundamental background for developing these activities, its associated use with BIM-based tools appears to be a promising way of mitigating some of the negative effects of complex systems such as those observed in the healthcare context, by means of providing some degree of automation, as suggested by Kiviniemi (2005). Moreover, the relationship between Lean and BIM is even more important, because automated processes for structuring requirements and assessing designs, such as those presented by this paper, may provide opportunities to minimize waste during the design process and to increase the overall quality of healthcare projects, as well as a means of ensuring that design specifications will fulfil diverse clients' needs. In other words, this is an opportunity of increasing value for the customer, which is imperative within the Lean Philosophy.

Even though automation is desirable, the findings of this study indicate that currently not all requirements can be fully translated in terms of automated rule processing and checking. Although this decreases the overall degree of automation in the processes, this fact may provide benefits to the healthcare context. In some complex situations, a fully automated scenario could not allow human-creative solutions to emerge. In other words, the attendance of some of the requirements relies on subjectivity, which depends on human interpretation and creativity, or artificial intelligence techniques, in order to be fully considered in the design.

Thus, assessing the conformity of healthcare designs to clients' requirements involves some degree of subjectivity, while it is possible to introduce some degree of automation. Future research should focus on finding a suitable balance, considering the positive and negative impacts of automation and subjectivity on the requirements modelling tasks to be performed. Therefore, there is a need for further research into the use of BIM for modelling the diversity of connections between functional and non-functional requirements of the model, in order to better identify how this can contribute to the quality of healthcare projects and the associated impacts on the value generation process.

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PRODUCT MODULARITY, TOLERANCE MANAGEMENT, AND VISUAL MANAGEMENT: POTENTIAL SYNERGIES

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ABSTRACT

Product Modularity refers to the hierarchical partitioning of products into their constitutive components. This concept has been explored in manufacturing to ease product design, simplify production, and to efficiently provide variety. Efforts have been made to transfer this knowledge to the construction context (i.e. one-off products, temporary supply chain, production taking place inside the product), especially to support the latter goal: variety. Yet, it is argued that a re-conceptualization of building design and production is required for the successful application of modularization. That is, materials and components used to erect a building should be grouped (at least conceptually) as families of modules and work (production tasks) has to be structured according to such organization. This paper explores the synergies among Product Modularity, Tolerance Management, and Visual Management to improve and ease the understanding of such re-conceptualization in design and production. It also examines patterns from the theoretical background of Design for Behaviour Change, and how these can be adapted to embed information in modules and present tolerance data in design drawings.

KEYWORDS

Work package, poka-yoke, Product Modularity, Tolerance Management, Visual Management, and Design for Behaviour Change.

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INTRODUCTION

Product Modularity is concerned with the partitioning (or hierarchical breakdown) of a product into its constitutive modules (or chunks), namely, a set of one or more physical parts. Modular architectures involve a one-to-one correspondence between functional elements and physical parts comprising each module (Ulrich 1995). The interfaces are loosely coupled (e.g. Sanchez and Mahoney 1996, Hofman et al. 2009), which implies that modules can be mixed and matched to create distinct product variants. Bus, sectional, and slot are some modular architecture types (Pine 1999; Ulrich 1995; Fixson 2005), which vary in terms of interface types among connecting modules. In a bus architecture, each family of modules, a set of modules that provide distinct levels for a given requirement (Salvador et al. 2002), is connected to the main module (bus) via a different interface (Ulrich 1995). Alternatively, in a sectional architecture, all modules are connected via a single interface type (Ulrich 1995).

Modular architectures can be adopted for a number of reasons such as to ease design and simplify production (Sako and Murray 1999; Baldwin and Clark 2003). Product Modularity has also been proposed as a key strategy to provide product variety (or customization) with efficiencies similar to mass production (Pine 1993; Da Silveira et al. 2001; Piller and Kumar 2006) and to minimize disruptions in the construction flow (e.g. da Rocha and Kemmer 2013; 2015). This requires a building and its constitutive components and/or materials to be conceived as modules from design and process viewpoints (Da Rocha and Kemmer 2018). Indeed, a brick can be considered a module, as proposed by Gosling et al. (2016), by directly applying the hierarchical breakdown rationale. Yet, this provides limited benefits despite the fact that bricks are highly modular: they are all connected via the same interface type (mortar) and can create an infinite amount of combinations (Da Rocha and Kemmer 2018). Production benefits are created when small parts such as bricks are grouped into large chunks (or modules).

Such aggregation can be (i) only conceptual or (ii) conceptual and physical. The former refers to traditional construction and requires buildings to be conceived as families of design modules and work to be structured with a one-to-one correspondence with each family (Da Rocha and Kemmer 2018). The latter refers to pre-fabrication, where building parts are added together off-site creating stable sub-assemblies, which are only assembled on site. Japanese houses comprised of volumetric pods produced in factories (Linner and Bock 2012), and pre-fabricated industrial structures and prison building spaces (Falmer 2016; Evans and Johnston 2017) are prime examples. In either case, buildings need to be re-conceptualized from design and process viewpoints (Da Rocha and Kemmer 2018). Buildings should not be designed as an unconceivable large number of small parts (where many parts actually change depending on the customisation requirements) but rather as a manageable set of large chunks that can be mixed and matched to meet all the customisation requirements. In addition, work should be structured so that work packages will deliver the modules (a set of buildings parts) rather than some indistinctive combinations of small parts (Da Rocha and Kemmer 2018).

There are several challenges involved in bringing this re-conceptualization to practice. Two of these can be summarized as follows: (i) *How to communicate this new understanding of buildings (as a set of modules) within and across design and production*? and (ii) *How to ensure an appropriate connection among modules in design and production?*. This paper seeks to address these inter-related research questions by reviewing and examining Tolerance Management and Visual Management and their conceptual underpinnings. Based on this analysis, the synergies among these topics are discussed and suggestions to further advance in the theoretical understanding and practical application of Product Modularity in construction are presented.

LITERATURE REVIEW

VISUAL MANAGEMENT

Visual Management (VM) is a close range communication management strategy that relies on the effectiveness of sensory stimuli; visual (Figure 1), auditory, tactile, olfactory, and gustatory) to facilitate smooth and efficient production (Tezel et al. 2015, 2016). VM systems are often divided into four: (i) visual indicators that only convey information, (ii) visual signals that grab attention, (iii) visual controls that limit human action by imposing some constraints and (iv) visual guarantees (poka-yokes) that guarantee the correct outcome by either warning of or preventing human error (Galsworth 2005).

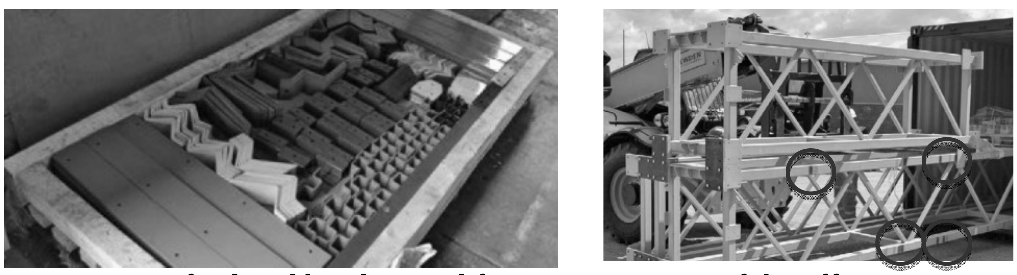

Figure 1: A crate of colored brackets and fixing connections of the off-site components of an industrial plant, which match to the colored stickers positioned on the structural components (circled above) during the construction process (Falmer 2016).

Poka-yokes are often used as complementary systems alongside statistical quality control in manufacturing to achieve quality at source and the zero defect ideal in production (Vinod et al. 2015). They have been classified as symbolic, functional, and physical (Saurin et al. 2012). In the latter case (physical poka-yokes), the contact surfaces of two modules are deliberately designed to allow only the correct assembly of modules (Shimbun 1988).

In a slot architecture, the distinct interfaces design avoids incorrect assemblies. Differently, a sectional architecture does not guaranty a correct assembly as all modules are connected via the same interface type. In the latter case, additional information (besides the geometry of interfaces) can be adopted to enable (albeit not guarantee) only the appropriate combination among modules. This includes coding structures like patterns; distinctive textures on the handles or human contact points of the module elements for tactile coding, colour-coded system (Figure 1), and basic alpha-numeric characters or symbols.

TOLERANCE MANAGEMENT

There is no consensus about what Tolerance Management (TM) exactly is and what it consists of. According to Milberg (2006), TM is about utilising various tools and methods in order to (i) attain the highest conceivable quality and performance to deliver the maximum value and (ii) to avoid any interruption of flow due to tolerance-related problems to minimize the waste. TM includes planning to achieve the required accuracy, incorporate tolerances in design, and control whether tolerance requirements have been obtained. Tolerance problems can be defined as when two or more modules are connected tolerance-wise but either they do not satisfy functional requirements or there is a fit-up problem with them due to exceeded permissible variations.

Conventionally, tolerance risks are often mitigated by specifying stringent tolerances for *in situ* parts (Milberg 2006), manufacturing products with tighter tolerances (Gibb 1999), and gaining better control of tolerances on site (Landin 2010). Yet, two main parameters can lead to problems. First, tolerance can range from less than a millimetre for off-site made parts to several millimetres for *in situ* parts (Ballast 2007). Second, the dynamic loads applied during transport and lifts of modules produced off site (Lawson et al. 2014), and structural movements due to different types of loads (Alexander 2014) can result in tolerance problems in the interface between parts.

Geometric Dimensioning and Tolerancing (GD&T) is a symbolic language that specifies the permitted variation in form, orientation, profile and location of features on a module and represents the relationship between features in an assembly. Feature in this context refers to either the size or the surface of a module (Krulikowski 2012). Milberg and Tommelein (2005) propose a method called tolerance mapping which combines the GD&T principles and graph theory to describe design intent regarding tolerances. Talebi et al. (submitted) took the idea further and propose a system for tolerance specification termed Geometric Dimensioning and Tolerancing in Construction (GD&TIC). GD&TIC groups the geometric variations of a feature into four categories, geometric characteristics and symbols (Table 2). Figure 2a shows the maximum permissible variations in size and geometry of two modules. Figure 2b shows how the tolerance requirements on the modules and between them can be specified using GD&TIC.

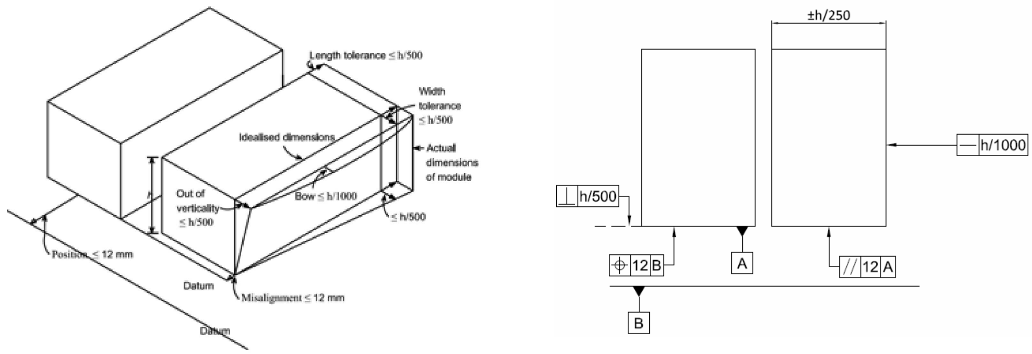

Figure 2: (a) The maximum permissible variations in geometry of a two modules (adapted from Lawson et al. 2014), and (b) application of GD&TIC for the modules

Table 1: Geometric Characteristic Symbols in GD&TIC (Talebi et al. 2018)

Type of Tolerance	Geometric Characteristics	Symbol
Form: establishes the shape of a surface.	Straightness: it represents how straight a surface is on a feature along a line	—
	Flatness: it demonstrates the amount of deviation of flatness that a surface is allowed to have	⏥
Profile: is the outline of a part feature and the True Profile is the exact profile of part feature.	Flatness: it demonstrates the amount of deviation of flatness that a surface is allowed to have	⌓
Orientation: describes the relationship between features and datums at particular angles.	Perpendicularity: It is a condition used to ensure that a surface centreplane, or axis is exactly at a right angle relative to a reference plane or axis.	⊥
	Parallelism: it limits the amount of variation allowed over an entire plane, from being parallel to the reference plane	//
Location: establishes the position of the feature relative to a datum.	Position: It is the location tolerance of a feature relative to its nominal position	⌖

RESEARCH METHOD

The research method adopted here involved three steps. First, the fundamental conceptual underpinnings of each area examined (Product Modularity, Tolerance Management, and Visual Management) were identified and understood. Second, the synergies among these underpinnings were established and graphically illustrated in Figure 3, which is inspired by the time, space, and information diagram for real manufacturing cells proposed by Hyer and Brown (1999). Thirdly, the Design for Behaviour Change literature was reviewed to identify design patterns to embed information either (i) in blueprints, 3D or BIM models or (ii) in module design to bring the identified synergies to a next level, which is detailed in Conclusions.

RESULTS

SYNERGIES ENCOUNTERED

VM provides a number of tools to improve the communication within and across design and production regarding (Figure 3): (i) what are the modules and (ii) what modules are connected/combined to create the product variants to meet various customisation requirements. The double arrows in Figure 1 show the iteration between (i) VM and PM and (ii) VM and TM. Namely, once modules and their combinations become clear by using visual tools, these can be re-defined, similarly to the problem-solution process in design (Dorst and Cross 2001).

Differently, a two-way connection is established between PM and TM. PM provides inputs to TM: it outlines the modules that are combined, which from a tolerance viewpoint defines critical connections to be managed. This is relevant not only for buildings comprised solely of large volumetric pods assembled on site but also buildings erected by fabricating and/or assembling small building parts (pipes, bricks, cladding, rebar, sink, etc) on site.

Complementarily, TM provides an input to PM: it clarifies the technicalities to be considered in the connection between every two modules by using GD&TIC. In PM, such connection is addressed under the interface notion and the terms *loosely coupled* (e.g. Sanchez and Mahoney 1996, Hofman et al. 2009) or *decoupled* (e.g. Ulrich 1995; Doran and Giannakis 2011) are often used. Yet, these are vague, providing limited understanding for its application in construction. Namely, it is not clear how such terms translate into building design and production requirements.

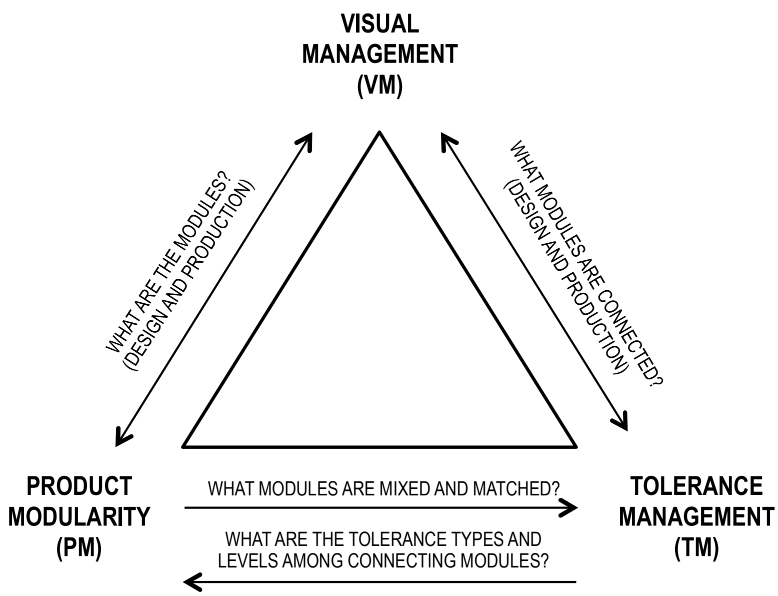

Figure 3: Synergies among Product Modularity, Visual Management, and Tolerance Management

EMBEDDING INFORMATION IN PRODUCT DESIGN

VM aims to create a visual workplace, in which process transparency, the communication ability of process elements, is maintained at a high level (Greif, 1991). In many cases, information is externally presented, particularly, by adding tools such as shadow boards, information boards, A3s, graphs, charts, sketches, mascots, signs, sticky charts, and decisions trees. It can be internally conveyed by embedding information in the product design (e.g. contact type poka-yoke devices such as the elevator not moving unless doors are closed). However, there are in-between instances, where information is not externally provided but is neither completely embedded in the product.

Considering the potential to embed information in product design (more specifically here in modules design), Design for Behaviour Change (e.g. Lockton 2015; Lockton et al. 2010; Daae and Boks 2014; Tromp et al. 2011) including specific application such as Design for Sustainable Behaviour (DfSB) (e.g. Lilley 2009; Wever et al. 2008), can provide important insights. Lockton (2015) devised the Design with Intent (DwI) toolkit: a deck of cards comprised of more than a hundred design patterns (organized in six groups) to support behaviour change via product design. For the synergies considered here, twelve patterns proposed by Lockton (2015) are particularly applicable and can be adapted as follows: (i) colour association (use colour to indicate association among elements); (ii) proximity and grouping (group elements to indicate similarity or joint usage); (iii) similarity (make elements look similar to indicate they share characteristics); (iv) (a)symmetry (use symmetry to make elements look related and asymmetry to show difference); (v) implied sequence (organize elements to indicate the sequence to be followed); (vi) possibility trees (provide a " map" of routes or choice that can be made to achieve different goals); (vii) matched affordances (design modules and interfaces so they fit together only in the right way); (viii) interlocks (design modules and interfaces to be combined only in the right way or sequence); (ix) task lock-in/out (design modules and interfaces to support only the correct assembly); (x) feedback through form (design modules and interfaces to give feedback or suggest cues for assembly); (xi) prominence (exaggerate or make more obvious features of modules and interfaces that require attention); and (xii) perceived affordances (design modules and interfaces to suggest or constraint inappropriate assembly).

CONCLUSIONS

This paper examined the synergies among Tolerance Management, Visual Management, and Product Modularity, particularly for the latter concept to be successfully applied in construction. VM can support the definition of modular architectures during design (i.e. what are the physical chunks comprising each module? what modules are mixed and matched?) by using tools (e.g. A3s, information boards, etc) to ease the visualization and understanding of modules and their combinations. Once the architecture has been defined, VM can ensure only correct combinations (or assembly of modules) are made during production.

TM sheds some light on an ill-defined albeit important conceptual underpinning of Product Modularity: the interfaces among modules that are combined. By understanding tolerance types (form, profile, orientation, and location), the technicalities of combining every two modules (particularly when one is produced on site and the other off site) become clear. Here, VM can ease the communication of tolerance requirements both in design (determining the tolerance types and requirements for the interface between every two modules) and production (ensuring that the modules combined meet the defined requirements).

Lastly, (i) embedding information in product design versus (ii) adding external elements (e.g. signs, notices, charts, etc) to present such information are important notions that emerged. The former is exemplified by poka-yokes, in which information is not presented by a third element (e.g. a sign saying "Buck your seat belt prior driving") but embedded in the product design (e.g. a car which one can only start driving once the seat belt is buckled). Information embedding, as already extensively reported in the poka-yoke and VM literature (Galsworth, 2005; Saurin et al. 2012; Tezel et al. 2015), is a means to ensure that only the desire action or behaviour happens. This can be directly translated and applied to module assembly in production to ensure (i) only the correct/allowed combinations among modules are performed and (ii) that the combination (or interface) of every two modules meets the defined tolerance requirements.

Yet, embedding information (rather than adding third elements) can also be viewed as a means to ease communication and to reduce cognitive effort. For example, embedding tolerance information in the already existing elements (slabs, beams, doors, walls, etc) presented in blueprints, 3D or BIM models rather than adding extra elements such as the symbols for tolerance types (Table 1). Whether and how this can be done remain to be investigated. The design patterns reviewed and adapted to construction (previous section) provide a starting point. For example, the application of the colour association pattern could lead to a colour-coding system to identify tolerance types, potentially leading to less cognitive effort than learning a new symbology (Table 1).

As for the two questions presented in the introduction, the following conclusions can be drawn. VM tools support a visual understanding of what are modules, easing the communication within and across design and production. TM clarifies the technicalities involved in the connection between every two modules (modules interface) in design, and also sets requirements to be considered in production. Such information (involved in design and production stages) can be (i) embedded in blue prints, 3D or BIM models, or in the modules themselves, or (ii) presented by external elements.

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LEAN-DRIVEN PASSENGER EXPERIENCE DESIGN

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ABSTRACT

In the contemporary agenda of airport design, good spatial design is fundamental to properly and efficiently manage boarding and disembarking processes. It contributes to the Passenger Experience and social sustainability of the terminal itself. This correlates with higher satisfaction levels from the passenger experience. By contrast, current practices of airport design do not properly cope with its requirements and the subsequent operation phase, because the project is not associated with the complete set of stake-holder requirements including the passengers to systematic modelling and management of their experience. The airport terminal is considered a temporary production system, its focus being the transformation of travellers, aimed to maximize the value for passengers, exploiting information management to better accommodate processes and project structuring. In a lean perspective, the terminal is a "flight factory", whose layout is crucial not only for process efficiency but also to achieve higher performance and user satisfaction, the main metrics for quality service evaluation. Considering the multidisciplinary and complex features involved in airport terminal space programming, Lean Design could have important outcomes in the search for project design integration, effective solutions, quality and all-encompassing sustainability. In this paper we discuss a theoretical framework to investigate value delivery in airport terminal design through the integration of lean thinking, constituting the basis for future research on Passenger Experience.

KEYWORDS

Project Design, Project Design Process, Project Design Management, Organisational Models for Project Design, Lean Design Management.

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INTRODUCTION

This exploratory paper investigates the current challenges of airport terminal design and Passenger Experience design, and discusses the transfer of Lean process logic to airport terminal project development. It also discusses the potential benefits of strengthening Lean knowledge for airport industry project participants with respect to passenger experience design. We argue that implementing Lean principles in design drivers for Passenger Experience improves travel quality perception and reduces the perceived travel cost for the passengers.

The work is part of a broader research dealing with Lean design methodologies and tools for integrating the service cycle in airport design. The foundational elements of the research are the common practices of airport design (Odoni and de Neufville, 1992; Esposito, 2010; IATA, 2014) and the literature dealing with design process, airport terminal design, Lean Design, and Lean design integration in design process management (Bosi, 2016). The literature review suggests that airport design project participants rely on obsolete matrices for their design process, unable to provide consistent project information and therefore develop a project responding to the requirements. We assume that this is caused by the complexity of design for the aviation industry and the fast pace of requirements changes, both due to regulations and market evolution (De Neufville and Scholtes, 2011). Elements drawn from literature suggest a research gap in the implementation of Lean thinking at the inception of airport terminal projects. This is discussed with a literature review, drawing useful elements to describe a research gap in common design practices for the aviation industry and identifying Lean Passenger Experience design drivers that foster a “Lean Consumption” of the time spent in the terminal.

The field of investigation is limited to scientific and industrial problems connected to project design development, management and design activities for airport infrastructure development. The application of Lean/product development principles in the aviation industry is still at an initial stage of development and the available literature is limited. Therefore, the research group considered it necessary to start investigating methodological and process aspects bound to project design management.

AGENDA AND CHALLENGES OF CONTEMPORARY AIRPORT TERMINAL DESIGN

Capacity and Quality of Service challenges for the aviation industry originate from the evolution of regulations and growth in traffic demand, leading to an increased project importance. The choice of the aviation industry as a reference field comes from the complexity of design and operation requirements, the high degree of standardization of projects, multi-disciplinarity of project participants and the foreseen growth of the industry in the future, due to the constant need for fast connections throughout the world. The performances of the project and of the infrastructure are measured by Levels of Service (LOS) (Bosi and Esposito, 2014), which are also paralleled by the various business processes that run inside the terminal. The current models of Airport Terminal

Design (ATD) are bound to obsolete design matrices that lack flexibility and process-focused features (De Neufville and Scholtes, 2011; Shuchi et al., 2012), with the biggest shortcomings found in project development and delivery processes (QUT, 2012; Shuchi et al., 2012). These are seen as stacks of activities that generate finished products, instead of transforming project information. In the end the industry is capable of delivering quality to airport management companies (its clients), but with scarce coordination within the design process. Also, Project Information (PI) provision and PI management in the life cycle of the airport - critical for Operation & Maintenance - is usually not associated with systematic modelling and standards, resulting in the impossibility to cope with the changes occurring in operations, services and requirements over time (QUT, 2012; Shuchi et al., 2012).

The end-users of most airport services are the airline carriers and passengers/visitors. Project design success is evaluated in airports using several parameters related to different stakeholders' criteria: direct users as passengers through perception, represented by the comprehensive concept of Passenger Experience, and carriers represented by the processing efficiency in term of time and airport fares. To manage such services, efficient and process-oriented space design is needed by the airport owners to carry on the "productive processes" (boarding and disembarking of passengers and cargo, plus ancillary services) within the passenger infrastructure. Accessible services and clear paths for every user category are necessary to properly conduct all activities, therefore the focus of project participants should be on rationalizing the spaces and their use (Odoni and de Neufville, 1992; de Neufville, 2002; Esposito, 2010). These aspects are key in contributing to quality of service, the other aspect featured in the European Union policies as targets for 2030 (EU: European Commission, 2011A and 2011B), that associate terminal design to performance objectives of the infrastructure, because the allocation of flight slots is based on airport efficiency assessments. An inefficient terminal means reduction of the airport capacity: quality and capacity are deeply intertwined in the aviation industry ground infrastructures.

AIRPORT TERMINAL DESIGN AND PASSENGER EXPERIENCE

Passenger terminal design generates the bottlenecks and jams that passengers experience within the infrastructure (Jim and Chang, 1998) and airport owners struggle to satisfy their user requirements. Struggles are often caused by an incomplete understanding of requirements and needs (Asher, 1989; Arif et al. 2013). As consumers are disconnected by service providers (Womack and Jones 2005), there is a gap between airport management companies and the travellers. Despite the airport terminals providing space and services, passengers cope with high levels of stress because of the frustration caused by wait times, signage mis-directions, and anxiety during queues (Snowdon et al., 1998; de Neufville, 2002; Womack & Jones, 2005; De Barros et al., 2007). Striving for improvement is necessary to deal with service quality and passenger experience issues, updating and refreshing at the same time the design paradigms meant to introduce sustainability in the design of terminal infrastructures (Esposito and Macchi, 2012).

Focusing the design of the terminal on perception of time and space, passengers' physical and psychological needs, space and crowd behaviour contributes to incorporating passenger experience sensitivity in design, avoiding possible "tunnel vision" of project participants on an aircraft-centered process and evolving to a passenger-centered methodology (Ariffin and Yahaya, 2013; Caves and Pickard, 2001; Paleari et al., 2010; Popovic et al., 2009; ACRP, 2011; De Barros et al., 2007; Ciolfi et al., 2012). This provides spatial comfort, service volumes and traffic conditions in the terminal premises, expressed in terms of Levels of Service (LOS). LOS link the final user needs with the airport terminal project, serving both as input and output of the design process itself. These represent the optimal compromise between traffic requirements, operational flexibility, owner specifications, community, passenger needs and also development investments (Ashford, 1988; IATA, 2014). LOS can be considered a "lean" concept or an extension of the Lean mind-set under a certain light, since the optimal LOS represents the best balance between investments (resource), space allotment (resource) and enhancement of the Passenger Experience (value).

PASSENGER EXPERIENCE DESIGN DRIVERS AND CRITERIA

In the presented research framework, the passenger is the consumer for the service provided by the terminal and the airport management company. Passenger Experience is the consumed product, combined result of the airport project and the ancillary business processes (Bosi, 2016) ongoing in its premises. Passenger Experience within airport terminals is generally regulated by many parameters. Avoiding level changes, making pathfinding clear, and ensuring terminal layout linearity are key factors in conveying a quality travel experience (Esposito, 2010; IATA, 2014). Terminal projects are oriented on the following drivers (Kronenburg, 2007; Esposito, 2010; de Neufville and Scholtes, 2011; Shuchi et al., 2012; Pitsiava-Latinopoulos and Iordanopoulos, 2012; IATA, 2014):

- **Optimization of passenger flows.** Passengers are introduced to a linear and centralized path with limited forks and level changes. This is a time saving strategy that helps to foster calm and serenity and mitigate travel stress.
- **Levels of Service enhancement.** Operation and services areas of the terminal are evaluated in the design phase to reach the optimal compromise between resource consumption, investments, perceived quality and allocated space for the given function (IATA, 2014).
- **Architectural features.** The passenger route must be characterized by a consistent language and coherent architectural choices, to avoid the sense of loss (Snowdon et al., 1998) usually conveyed by travel terminals.

These drivers lead to a process in which different terminal layout options are generated with the goal of optimizing passenger experience. Another strong input for design options are the passengers themselves and their choices: the general rule is that the passenger will always choose routes and services based on his/her travel cost - in addition to the already funded concept of travel time. The result of his or her decisions and how such decisions affect design determine a scenario where no passenger can further reduce the time spent on a given route or cannot choose a different path. Many variables define this scenario: time, crowding of hallways, route length, services and attraction points along the route, distance of rest areas and stopping spaces. The passengers, trying to minimize travel time and cost (their resources) within the terminal, will make choices according to their own subjective variables. The variables include the current level of stress - which peaks at security controls - and ease of orientation while moving. The direct consequence of an optimal layout tailored for the passengers is the reduction of disorientation and uncertainty, therefore variability, of passenger experience and perception of spaces.

Maximization of value and minimization of waste and resource consumption are at the core of a Lean mind-set (Lander and Liker, 2007): in its application to the aviation industry, Lean Design must aim for mitigation of project non-compliance to requirements with a dynamic and adjustable management of project flexibility and structuring. In the presented research context, Lean Design fosters the idea that the project is intended as a process whose focus is on the management of the embarking/disembarking process. The terminal project organization becomes a temporary production system, whose outcome - the terminal project - is in fact a "prototype", part of the architectural process and precedent to construction. While in serialized production the factory is uniform and the environment is stable (Hicketier et al., 2013), the project organization is a temporary environment with changing structure according to immediate needs. The application of a Lean mind-set, Lean Principles and Lean Design methodologies addresses the need of a production system that maximises project quality, minimizes waste of resources, time, and effort (Aapaoja and Haapasalo, 2014) while aiming to maintain project flexibility (Shuchi et al., 2012) to pursue satisfaction in passenger experience.

IMPLEMENTING LEAN IN TERMINAL DESIGN

Terminal design is not supported properly by traditional design methodologies (de Neufville and Scholtes, 2011; Shuchi et al., 2012; QUT, 2012), mostly because of its complex and evolutionary nature, highly dependent upon market variations. Design methodologies based only on standard requirements, over-rationalistic and structured sequentially, cannot cope with the evolution of airport design requirements over time. In addition, the final users of the terminal are not properly considered during terminal project development, since the intrinsic features of an airport terminal project are not the same as traditional projects and exceed the usual teamwork boundaries (Wu and Mengersen, 2013). Industry stakeholders have differing project objectives, although they should share consensus on a critical factor: passenger processing improvement not only in terms of space availability – as is often done following traditional design matrices - but also of optimization of operations.

Table 1 outlines the differences between common practice and the proposed Lean Terminal Design paradigm. The table clarifies the proposed concept of Lean-driven terminal design with a focus on operation and flow, which is the primary research contribution. Remodelling consumption of passenger experience at its roots - the terminal project - should follow the guidelines of Lean consumption, identified by Womack and Jones (2005) and adapted for the presented scenario:

- Lower the travellers' anxiety curve by providing efficient and stress-free passenger processing;
- Do not waste passengers' time - incoherent signage and wayfinding, path loops, excessive level changes;
- Tailor the services on the passengers' needs and requirements, placing them in appropriate locations along the processing chain (passenger route);
- Provide aggregated services in passenger areas to reduce the passengers' hassle.

Implementing Lean principles in Passenger Experience design also implies re-evaluating the design drivers under the People, Process and Technology pillars of the Lean mind-set. Noticeable Lean design drivers are identified for this scope are (Bosi, 2016):

- Maximizing the contribution of technology for the process, fostering advanced facility management and operation models;
- Optimization of Levels of Service, maximizing processing capacity in the allocated space and with determined resources;
- Linearity and suitable length of paths according to provided facilities and services;
- Coordinated design of dwelling and queuing areas to avoid interferences;
- Dedicated paths for different categories of users, without being discriminatory;
- Guarantee of a minimum LOS in case of airport service disruption, to improve the terminal's social sustainability in any circumstance.

These design drivers establish a connection between the project and Passenger Experience Delivery, implying a shared consensus on the terminal space layout. They subtend a stochastic equilibrium within the terminal facility because, given the passenger and business processes ongoing in the terminal environment, it is not possible to have the same degree of information for every driver. For example, passengers will choose the route that minimizes his perceived travel resource consumption (travel time, energies, etc.); aligning this perception influenced by many random variables to one deterministic and controllable quantity is the aim of Lean-driven Passenger Experience Design. The goal is managing information and reducing the perceived travel cost through the project. This can be achieved through different measures aimed at reaching an "Involuntary System Optimum", e.g. improving pathfinding, Levels of Service, utilizing new technologies such as location-based apps, virtual assistants, customized messaging, information beacons that communicate with passengers' devices while collecting passenger and visitor metrics, fundamental for adjusting the ongoing processes.

Table 1. Comparison of common airport operation design practices and Lean terminal operation design

Design Aspect	Common Airport Design Practices	Lean Terminal Design
Design priority	Satisfying traffic/capacity demand	Design flexibility and perception of service quality
Scope	Space program optimization	Passenger Experience optimization
Main evaluation metric	Processing capacity of the terminal	Perception of infrastructure by users, passenger experience
Design goal	Passenger processing activities	Passenger processing flow
Project management focus	Project delivery	Management of project information during the service life
Technology integration	Technology integration in operation is functional to improve operations efficiency	Technology integration in operation is functional to improve Passenger Experience
Functional priority	Controlling environment: pyramidal hierarchy of operation over business processes	Integrated environment: parallel ongoing operations and business processes
Design driver	Operation design is driven by the terminal project	Operations and passenger processing is a driver for terminal design
Terminal function over time	Operations change in time according to the evolution of the terminal space program	The space program and terminal operations' evolution is intertwined
Process planning	Process planning does not allow variability and adaptability	Process planning has a margin of variability and adaptability

CONCLUSIONS

Integrating Lean principles in passenger experience design results in an innovative design philosophy not only of spaces but also of services for project design teams, whose priorities and targets have a deep connection to passengers' behaviour and their perception of the infrastructure. Implementing Lean consumption principles can enhance Passenger Experience, avoiding misplaced activities and amenities in passenger processing. It allows airport owners to use the information generated in the design phase to optimize the Operation & Maintenance phase of the building, aiming to improve passenger services. Information obtained from targeted analysis is used for quick-response problem solving, defining technical, formal and spatial solutions that meet evolving project requirements and passenger expectations. Methodologies originating from this theory could be tested in airport project case studies that have to deal with the development of a new terminal project, creating a passenger experience from scratch, or extension of existing airport terminals, confronting the challenge of design to avoid disruption of the Passenger Experience during the construction phases.

The target audience for Lean integration in terminal design practices are stakeholders and project participants from the civil aviation industry, in addition to managers and project teams interested in in airport design methodologies and design verification. Airport owners are the direct beneficiaries of Lean implementation aimed at design and operation flexibility, with airlines and passengers (intended as final users) being indirect beneficiaries. In general, the entire terminal design chain draws benefits from Lean. Scholars and academia in general can further research on the grey fields suggested by this paper, fostering the diffusion of Lean knowledge in the industry along with the integration of Lean in the entire building life cycle.

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ASSESSMENT OF LEAN PRACTICES, PERFORMANCE AND SOCIAL NETWORKS IN CHILEAN AIRPORT PROJECTS

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ABSTRACT

Airport projects are complex in nature because they include several specialists from the public and private sector who must temporarily interact for the fulfillment of previously defined objectives. The design of these types of public projects in Chile does not apply the Lean philosophy in a formal way or Lean management tools; therefore, it is necessary to assess the management practices, performance and organizational logic that are currently generated in these types of projects. This is fundamental to understanding how professionals who are involved in the development of airport project design interact with each other. The objective of this paper is to understand the functioning and performance of the temporary organizations that are generated in the development of airport project design. To achieve this goal, it is necessary to assess Lean management practices, performance and interaction among the professionals of this temporary organization. This was carried out in 9 Chilean airport projects that showed an exhaustive management of requirements; however, this does not include all of the stakeholders, which generates low levels of interaction in the organization, directly affecting the performance of the project due to high levels of rework.

KEYWORDS

Lean practices, performance, social networks analysis, airport project.

INTRODUCTION

The industry of architecture, engineering and construction (AEC) is fragmented into several specialties, which appear at different stages during a product's life cycle (Love et al. 2002). Although fragmentation generates a high level of specialization in each of the

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disciplines, its integration becomes more complex as the number of actors involved leads to increases in work breakdowns (Thomas & Tang 2010).

Poor integration in work teams of the AEC industry can generate deficient performance, both in the realization of each of its stages (design, construction, maintenance, operation and deconstruction) and globally in the product's life cycle (Baiden et al. 2006). Low performance is generated due to the realization of activities that do not add value and that are considered as project wastes, such as rework and waiting times, among others (Aziz & Hafez 2013). In particular, the design stage is fundamental in the life cycle of a project because the decisions taken in this instance can significantly affect the following stages. In addition, the costs of changes in the design stage are negligible compared to the costs of changes in future stages (AIA 2007), which represents a great potential to make improvements to the project.

Airport projects are complex in nature because they include several specialists from the public and private sector who must interact temporarily for the fulfillment of previously defined objectives. These objectives come from the transportation demands coming from the community, the requirements and needs of the airport organizations and the standards and regulations required for the airport's proper functioning. In addition, most airport projects require that the airport, or aerodrome, continue to operate normally during the construction phase of the new project.

For these reasons, it is fundamental to assess the relation among lean management practices, performance and organizational logics (interaction patterns) in the design team of these types of projects. Thus, the objective of this paper is to understand the functioning and performance of the temporary organizations that design airport projects, making a comparison between projects in preliminary and final design.

BACKGROUND

LEAN PRACTICES IN DESIGN

The literature shows several applications of Lean practices in design. Fosse & Ballard (2016) presented a case study that shows the change between traditional planning and planning using Last Planner System (LPS) at the design stage. Although they did not present evidence of changes in project performance, they concluded that the degree of satisfaction of the project's stakeholders increases when LPS is used. Knotten et al. (2016) emphasized that the use of LPS and collaborative planning in the design reinforces trust and commitment among the members of the team, both being considered as fundamental elements for having an effective team (Svalestuen et al. 2015).

Lean Design introduces several elements with the aim of reducing rework and unnecessary tasks (Gambatese et al. 2017), for example, the early involvement of the client, maximization of value, identification of the needs and objectives of all interested parties, simultaneous design of the product and the process, and delaying the decision-making until the last responsible moment. These Lean Design elements are embedded in several Lean tools and methods such as Target Value Design, Set-Based Design, Building Information Models, Choosing by Advantages, and LPS.

KEY PERFORMANCE INDICATORS

There are several performance indicators associated with the results of the construction process (Chan & Chan 2004); however, when the indicators of the design process are revised, the checklist is smaller. Some metrics used to measure design productivity include hours per drawing and hours per number of elements designed (Ebrahimy & Rokni 2010); other metrics are associated with the quality of the design and are calculated from the number of occurrence of design errors (Al Hattab & Hamzeh 2015). Freire & Alarcón (2002) included, as an indicator of productivity, the percentage of activities that do not add value. Later, Coates et al. (2010) presented a set of indicators to measure the efficiency of the design process, such as hours spent per project, cost efficiency, development speed, income per capita, and cash flow.

INTERACTION OF THE ORGANIZATION

The interaction between the professionals involved in a temporary organization of an engineering project is fundamental to the performance of the project (Svalestuen et al. 2015). To analyze the interaction of work teams, different tools can be used, such as frequency analysis, n × n matrix, and social network analysis (SNA), among others (Yang & Tang, 2004). Recently, the SNA has gained attention in the AEC industry because it can be used to understand the role of non-formal structures coexisting with formal ones.

Social networks are a set of relationships between actors who occupy different roles. The SNA uses the theory of graphs to explain these relationships with mathematical indicators, such as the density, length and diameter of the network (Marin & Wellman 2011). SNA can be used as a diagnostic tool for the flow of information in the AEC industry (Alarcón et al. 2013). Flores et al. (2014) proposed the use of SNA, together with inferential statistical analysis and discussion roundtables, to improve the integration and connectivity of information flows in a project team.

METHODOLOGY

The research methodology is a case study of nine airport projects developed by the Ministry of Public Works of Chile. Five of these projects were in the initial study phase and preliminary projects, and the other four were in the final design and detail stage. In each project, the level of implementation of Lean practices, key performance indicators and social network metrics were assessed to understand the interaction of organizations.

Lean practices in the design stages were defined based on an extensive literature review of the last 10 years, which was then analyzed in interviews with ten professionals and academics experts. Performance indicators in the design were created based on the results of the team of researchers and professionals of the Ministry of Public Works. These indicators (Table 1) are adjusted to the major sources of waste generated in the design stages (Freire & Alarcón 2002). These KPIs were measured during 5 weeks of each of the projects. The measurement was carried out through the report of each of the members of the design team on the following variables: total hours dedicated to the project, hours of rework, latency by request for information, number of errors detected, complete and committed activities.

Table 1: KPIs for the design stage

Name	Description
Rework	Percentage of hours that the design team is working on a task that had already been done (rework) in proportion to the total time spent working on the project in that week
Waiting times	Average waiting time that exists between the request and delivery of information between two or more project members.
Quality defects	Number of failures, errors or nonconformities detected in the design process per week
Commitment achievement	Percentage of plan completed within the week (PPC)

The analysis of social networks (SNA) was carried out according to the methodology proposed by Alarcón et al. (2013), and included the following dimensions: knowledge of roles, complete interaction, work information, planning and problem solving, learning, and trust. The following indicators were obtained from each of the dimensions: number of people, number of connections, density, diameter and average length. To collect the data for these networks, an online survey was used, and the data were processed with the Gephi Software. It is a tool to generate interaction graphs between different nodes, in this case people, and that through graph theory obtains different mathematical metrics that explain the relationships between the members of a design team.

RESULTS AND DISCUSSION

CONTEXT OF CHILEAN AIRPORT PROJECTS

The airport projects in Chile are supervised in the design and construction stage by the Airports Department (AD) of the Ministry of Public Works, while the person in charge of the operation is the Directorate General of Civil Aeronautics (DGCA). The AD hires a consulting company to carry out the design of the project in its stages of preliminary design and final design. The preliminary design goes through three reviews of the AD and the DGCA, and 6 to 10 people participate (designers and reviewers) in this stage. Meanwhile, the final design is divided into basic engineering and detailed engineering, each of them having three instances of revision by the AD and the DGCA and 9 to 22 people participate (designers and reviewers) in this stage.

The AD, as an organization, has a group of professionals, mostly engineers and architects, who have two main functions within the team. The first is to review the designs and reports delivered by the consultant in each of the projects, and the second function is that of fiscal inspector (FI), a professional that is in charge of leading the reviewers team of a preliminary or a final design and that has a team of professionals with different specialties, among which some are from the AD, and some are part of the Ministry of Public Works. Therefore, the same AD professional in the same moment of time can be the FI of a project and part of the team of professionals that reviews other projects. For airport projects, the AD plays a customer role.

The DGCA is the institution in Chile responsible for operating the airport facilities, and therefore, within the development of the design of the projects, fulfills a user role. This organization has a group of professionals in charge of reviewing the projects and creating observations in its three instances.

The consultant is usually a highly complex engineering company that has several specialists who apply for a public tender to develop the design of an airport project, either the runway, the terminal building or other operational facilities. The consultant must appoint a project manager who oversees his team of designers and specialists and who is also the counterpart of the FI throughout the development of the project.

LEAN PRACTICES: IDENTIFICATION AND ASSESSMENT

From literature review and expert interviews about Lean management practices in the design stage, 19 practices were defined, which were categorized into dimensions of stakeholder management, planning and monitoring, problem solving and decision making. To measure management practices, the researchers applied a semi-structured interview to the IF of each project with open questions about each of the management practices. Based on these interviews, the researchers evaluated the actual practice at the level of implementation on a Likert scale from 1 to 5, with 1 being that the practice did not exist and 5 that the practice was fully implemented.

- P1: Specialist designers get involved in the early stages of the project.
- P2: The builders are involved in the early stages of the project.
- P3: The requirements of the stakeholders are exhaustive, where they are defined as requirements, restrictions, technical specifications and special requirements.
- P4: The participation of the client in the design stage involves systematic participation and support in the decision-making meetings and resolution of problems.
- P5: The design of the product and the construction process are carried out simultaneously.
- P6: Project planning considers delivery date, phases, milestones, task subdivision and control instance. All of the above are immersed in a scheme in which gaps, buffers and points, are clarified so they can perform pull/push actions within the program.
- P7: Planning considers information about internal and/or external projects of the organization generated through a benchmarking exercise.
- P8: The planning is done collaboratively among several actors.
- P9: Planning is done at different levels (global, phase, intermediate and weekly).
- P10: The restrictions in the design process are identified, registered collaboratively and released by a responsible person. Then, they are followed up.

- P11: The coordination of project information with the different stakeholders is done through a single platform, which allows systematic updating and continuous communication between the stakeholders.
- P12: There is a protocol to solve problems collaboratively.
- P13: The last planner identifies the problem and carries out a causal analysis (for example, 5 whys?).
- P 14: The solution to the problem is implemented, monitored and documented to verify that the problem was solved.
- P 15: In the decision-making process, options are evaluated, planned, and tested, and results are validated and applied.
- P 16: The time to make decisions is the last responsible moment and with all the information that can be gathered for that moment.
- P 17: To make decisions, information on internal and/or external projects of the organization is used, which is generated through a benchmarking exercise.
- P18: The decision-making mechanism is a meeting with those involved, where a formal technique is used, for example, WRC, AHP, CBA or other.
- P19: After the decision and actions are taken, it is verified if satisfactory results were obtained. In addition, the lessons learned are identified and documented.

Figure 1 shows the results of the measurement of the 19 management practices on a scale from 1 to 5, representing the level of implementation of each practice with the median of the nine projects. In addition, the graph shows the median of the 5 projects in the preliminary project stage (PD) and the median of the 4 projects in the final design stage (FD).

The practices with the highest level of implementation have to do with the surveying of stakeholders' requirements in a comprehensive manner and with the participation of the client in a systematic and empowered manner. Both practices have an outstanding level of implementation due mainly to the fact that the AD functions as a technical entity for the revision of designs rather than only for administrative purposes. This technical profile helps them to be more empowered in the decisions that are made during the design.

In contrast, the practices with the lowest level of implementation are those that must have early involvement of the builders, and therefore the design of the construction process is not carried out simultaneously with the design of the product. In addition, the use of information from previous projects for planning, problem solving and decision making of current projects have a low level of implementation. This is generated due to a poor culture of knowledge management, in addition to not having the appropriate computer systems to take advantage of so much prior information. Finally, a last low-implementation practice has to do with the collaborative work at the time of planning and with the standardization of the process of monitoring the projects.

When comparing projects in PD and FD, projects in a preliminary stage (PD) stand out when including specialist designers from the beginning (P1), while projects in a final design stage (FD) stand out in the planning practices, both in their level of detail and in the tools used for monitoring (P6 and P9) and in decision making (P13 and P16).

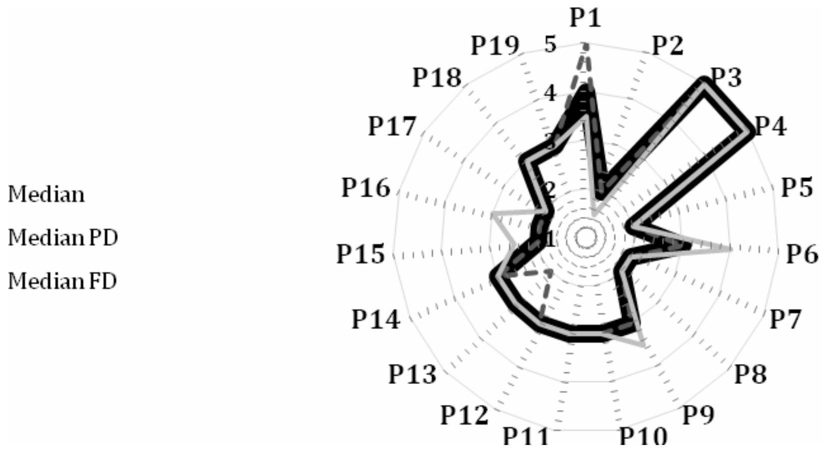

Figure 1: Lean practices assessment

KPIS: IDENTIFICATION AND ASSESSMENT

Table 2 shows the mean and the standard deviation (STD) of the 9 projects in general, of the projects in the preliminary design (PD) stage and the final design (FD) stage.

The average weekly rework of the nine projects oscillates within 20% of the hours dedicated; that is, one in five days is dedicated only to rework. It is important to mention that the airport projects of Chile define instances of revision and correction; therefore, there are weeks in which the projects have a high level of rework. This explains the high variability of the percentage of rework among the nine projects. In the PD stages, the average rework percentage is approximately 26%, while in the FD stages, it reaches 14%. This is mainly because during the PD stages, there is a high level of uncertainty in the design, which does not occur in the FD stage.

The average waiting time for information is 9.78 hours; that is slightly more than a day of work. Again, there is a significant difference between the projects in the PD stage and in the FD stage, with the longest duration in the first stage (12.55 average hours), while in the FD stage, the average time is 6.44 hours. This is mainly because FD times are shorter, which forces the consultant and the client to have a faster information flow. Even so, these latencies appear to be reasonably short compared to the typical latencies in the construction phase of international projects.

The average number of quality errors detected per week fluctuates between 0 and 6. This is mainly due to the revision and correction times that exist in the planning of the project. In this case, the projects in the FD stage have a higher number of quality errors than the PD projects because in the FD stage, the number of designers and other interested parties increases significantly, causing an increase in the probability of finding errors and incompatibilities between the different specialties.

Finally, the fulfillment of the weekly commitments in each project, which averages approximately 75%, without significant differences in the different stages of the projects. It is important to highlight that the percentage of activities that are not achieved is directly related to the percentage of unplanned rework that must be carried out week by week, which is approximately 20%.

Table 2: KPIs assessment

KPI	Mean	PD Mean	FD Mean	STD	PD STD	FD STD
Rework (%)	20.94	26.08	14.51	17.40	17.12	15.50
Waiting time (hours)	9.78	12.45	6.44	6.69	7.00	4.42
Quality defects (#)	2.87	2.04	3.90	2.33	2.03	2.27
Commitment achievement	74.85	75.85	73.60	13.71	8.26	0.00

SNA: IDENTIFICATION AND ASSESSMENT

Figure 2 shows the average density metric (0 to 1) of the networks that were measured as well as a partial average calculated for the projects in the PD stage and in the FD stage. Segarra et al. (2017) present a direct relationship between the number of teams and the density of the work information flow, where a project with two teams (in this case designers and reviewers) should have a density close to 50%, however, airport projects have an average density of close to 40%, i. e. their density of work information is lower than other projects. One of the fundamental characteristics is that the network of knowledge of roles is practically the same as the network of complete interaction, both in the form of the network and in its metrics. This means that if people do not know what another person does in a project, they do not interact. After a workshop with the study participants, an emphasis was given to the kick-off meetings of each project.

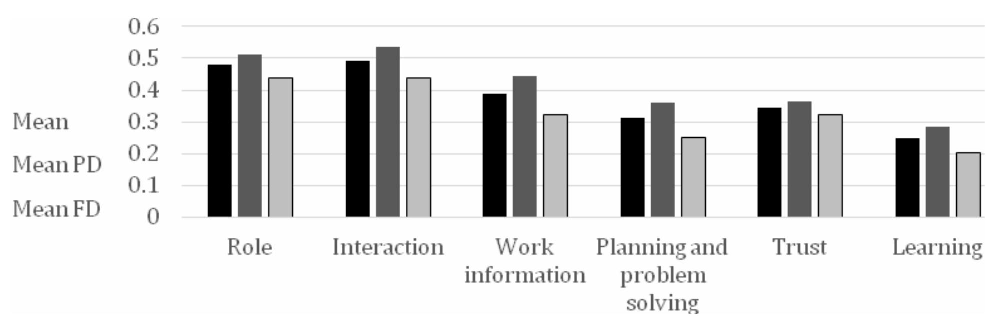

Figure 2. Social Network Density

Another important element to emphasize is that the learning network is born from the trust network; this means that there is no learning among people as long as there is no trust relationship that supports it. On the other hand, the network for planning and solving problems always focuses on positions with responsibility in the project team, which is directly related to a poor practice of collaborative planning. Finally, Figure 2 shows that PD projects have a higher density than in the FD stage, mainly due to the growth of the number of people in the team, as presented in the research by Segarra et al. (2017).

CONCLUSIONS

From the results, it is possible to draw the following conclusions: At the level of literature review and interviews with experts, Lean practices in design focus on stakeholder management, planning and monitoring, and problem solving and decision making. In the public projects that were evaluated, it was possible to identify that the practices with the greatest development are the management of requirements and the systematic participation of the clients, while the ones with the worst performance are the early involvement of builders and collaborative work. The projects in the preliminary stage stand out in the involvement of designers from the beginning and the projects in the final design stage in the planning and monitoring tools. These practices have a direct impact on the interaction between the different professionals in the organization, which is represented by a low level of work information flow and in the planning and resolution of problems. Considering that the members of the temporary organization do not necessarily know the role that other members of the team have, the kick-off meetings are essential to initiate the expected interaction between the different professionals. The low level of interaction directly affects the performance of the project, especially about rework (average 20%) and design quality errors (average 3 per week), since this generates unplanned work that permeates the PPC of each project.

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DESIGNING AS A COURT OF LAW

Lauri Koskela[1], Paz Arroyo[2], and Glenn Ballard [3]

ABSTRACT

It is contended that legal proceedings, as they have evolved from Antiquity onwards, embrace important and effective principles for collaborative competition in pursuit of a common goal, in the considered context, justice. Seven principles contributing to this goal can be recognised: "hear both parties", reasoned judgment, right to appeal, use of both logical and rhetorical arguments and reasoning, standardized proceedings and documents, public nature of proceedings, as well as dedicated and structured space.

It is contended that the court of law can be used as a metaphor of what is happening in design. There are wishes, concepts and solutions competing against each other. For reaching the best outcome, each wish, concept or solution needs to be promoted and defended in the best possible way, and a reasoned judgment among them has to be done. Then, the question arises whether the seven principles found in legal proceedings have relevance for this collaborative, yet competitive pursuit of a common goal in design, namely the best solution in view of customer requirements.

For initial exploration of the relevance and validity of the seven principles in design, a case study was undertaken. It turns out that all the seven principles are being implemented. The outcomes of the project are clearly better than in projects managed in the traditional way; although it is not possible to trace back the benefits only to the collaborative principles and related practices, their emergence, and continued use, provide solid circumstantial evidence on their efficacy.

KEYWORDS

Collaborative design, competition, design management, communication, legal proceedings, lean construction.

INTRODUCTION

The rich connections between rhetoric and design have been analysed in prior research from several angles (Buchanan 1985, Buchanan 2001, Ballard & Koskela 2013, Koskela

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& Ballard 2013). It is well-known that the classical rhetoric originated from the need of citizens in ancient Greece to make speeches in a court of law. Understandably, the discipline of rhetoric was then built up around the unit of a speech. Unfortunately, this notion of rhetoric has largely side-tracked the related innovations in how legal proceedings, as a whole, should be organized. It is contended that legal proceedings, as they have evolved from Antiquity onwards, embrace important and effective principles for collaborative – but simultaneously competitive - pursuit of a common goal, in the considered context, justice. Seven principles contributing to this goal can be recognised: “hear both parties”, reasoned judgment, right to appeal, use of both logical and rhetorical arguments and reasoning, standardized proceedings and documents, public nature of proceedings, as well as dedicated and structured space.

Arguably, the law court can be used as a metaphor of what is happening in design. In all stages of design, there are wishes, concepts and solutions competing against each other. For reaching the best outcome, each wish, concept or solution needs to promoted and defended in the best possible way, and a reasoned judgment among them has to be done. We posit that the principles of legal proceedings can effectively be used in this endeavour. To support this claim, we show that in the advanced practice of lean construction project management, methods and tools resonating with the principles related to legal proceedings are already being used, with very good overall results.

Following this introduction, the paper is organized in the following sections: Learning from legal proceedings; Competition of ideas in prior design theorizing; Case Study; Discussion; Conclusions.

LEARNING FROM LEGAL PROCEEDINGS

We posit that legal proceedings, as they have evolved, embrace important and effective principles for collaborative yet competitive pursuit of a common goal, in the considered context, justice. In the following, we briefly discuss such principles and their significance.

In the legal science, this area is called procedural law. From early on, interest to procedural law has been unsystematic and scanty in comparison to other areas of law. It has been said that the Romans treated old procedural rules as if they were old newspapers (Metzger 2013). It is for this reason that it has been necessary to determine fundamental principles of legal proceedings in the underlying work for this paper. In most cases, we refer to ancient Greek and Roman legal proceedings, but also newer developments are taken into account. The three first principles are associated to the characteristics of the rule of law (Bergholtz 1987). Most of the remaining principles are features connected to legal proceedings from ancient times and still today.

HEAR BOTH SIDES

The principle of “hearing both sides” of the case, *audiatur et altera pars*, is of course fundamental to the idea of fairness. Another term for this principle is “the level playing field”. It implies accommodating the proceedings so that both sides have an equal opportunity for presenting their case and responding to evidence against them. For example, this means that a session has to be postponed if one side cannot be present or needs more time to acquire materials for preparing their case.

REASONED JUDGMENT AND FACT FINDING

The reasons for the judgment, *ratio decidendi*, is another idea stemming from ancient Rome. Although not systematically provided, a considerable part of judgments contained such reasons already in Roman times (Honore 1973). The requirement for giving reasons has later evolved into a key principle of a due process (Bergholtz 1987). These reasons cover both rules of law and facts of the case.

RIGHT TO APPEAL

The right to appeal regarding a judgment has its origin in Roman legal proceedings. It is still today seen as one of the elements of the rule of law (Bergholtz 1987). From Roman times, the opportunity to appeal about a judgment to a higher court has had an important implication: the judgment had to be delivered in writing (Honore 1973). Further, there is a relation to the previous principle: the subsequent appeal process is considerably facilitated if the reasons for the judgment (*ratio decidendi*) are also provided.

The right to appeal, besides giving the possibility of correcting obvious mistakes and poorly prepared judgements, has a proactive impact: for the judge, it provides an incentive to carry out the process and to formulate the judgement in such a way that there is no need for an appeal, potentially leading to the embarrassing situation that the judgement of the lower court is overruled.

NOT ONLY LOGICAL BUT ALSO RHETORICAL REASONING

From the 19th century onwards, the mainstream assumption has been that legal rules and decisions are deduced directly from legislation, previous cases, and secondary authorities (Sinclair 1971). Thus, legal reasoning has been seen to primarily fall into the realm of logic. However, since the 1950's, the rhetorical approach to reasoning has been forwarded, pioneered by Perelman (Perelman & Olbrechts-Tyteca 1969), Toulmin (1958) and Viehweg (1993) (largely based on ideas originated in ancient rhetoric). This approach emphasizes the content of arguments and the context-dependent aspects of acceptability. Especially, the acceptability of argumentation is dependent on its effectiveness for the audience to which it is addressed (Feteris 1997). Finding the starting points (*topoi*) of reasoning, and creating persuasive arguments about the particular and probable thus accentuate.

PUBLIC NATURE OF PROCEEDINGS

The court sessions were public in ancient Greece and Rome (Samons II 2013, Metzger 2013). This ensured that no party could make claims that would have been generally known to be incorrect. Also, this created a situation where the judges, the witnesses and the jury are publicly accountable. An eloquent, and more current, justification for publicity of courts of law is provided by Bentham (1843, pp. 316-317):

Publicity is the very soul of justice. It is the keenest spur to exertion, and the surest of all guards against improbity. It keeps the judge himself, while trying, under trial. …Nor is publicity less auspicious to the veracity of the witness, than to the probity of the judge. Environed as he sees himself by a thousand eyes, contradiction, should he hazard a false tale, will seem ready to rise up in opposition to it from a thousand mouths. …. Without publicity, all other checks are fruitless; in comparison to publicity, all other checks are of small account.

STANDARDIZED PROCEDURES

From early on, it has been found useful to standardize both court procedures and the contents of documents and presentations. Already Corax (5th century BC) suggested a way to arrange the presentation of a legal case as follows (1) Introduction, (2) Statement of the Case, (3) Argument Summary, (4) Proof of the Case, (5) Conclusion. Still today, the U.S. Supreme Court requires essentially the same structure to be used (Frost 2005).

An example of an early standard procedure is provided by the preliminary hearing (*anakrisis*) of Socrates (Linder 2002):

The preliminary hearing before the magistrate at the Royal Stoa began with the reading of the written charge by Socrates' accuser, Meletus. Socrates then formally answered the charge. Both the written charge and denial were then attested to by each, under oath, as being true. The next phase of the preliminary hearing was one of interrogation: the magistrate questioned both Meletus and Socrates, and then both the accuser and defendant were allowed to question each other. In the final phase of the hearing the magistrate, having found merit in the accusation against Socrates, drew up formal charges and set a date for a public trial.

The standardized order of presentation helped to communicate the case in a logical and persuasive way. In turn, the standard procedure let both sides to be fully heard and brought order and certainty to the process: no disagreement how the matter was to approached needed to be solved. Perelman and Olbrechts-Tyteca (1969) pinpoint a further benefit: order ensures that particular premises are given sufficient presence for them to serve as starting points for reflection. Thus, fruitful paths will not be prematurely abandoned.

DEDICATED AND STRUCTURED SPACE

From early on, a dedicated place for court hearings was found helpful. The mentioned Socrates' trial was held in a courthouse obviously built for this specific purpose. The Scandinavian thing rings (Wildte 1928) provide a well-known example.

The dedicated venue for court proceedings emphasized, for its part, the authority of the court and focused attention to the matters being handled. Even in the archaic Scandinavian conditions, justice was not delivered by any assembly of men, but by those gathered to the thing ring for the specific purpose of proceedings.

It has been held that due process has a readily identifiable spatial structure with deep historical and cultural resonance: it is the trial courtroom (Spaulding 2012, p. 330):

On a symbolic level, elevation, ornamentation, and partitions (specialized boxes, benches, bars, and tables) serve to fix and hierarchically segment lay and expert role players. At the visual and aural level, however, the division of space accentuates accessibility. The standard organization of partitions ensures proximity, audibility, and clear sight lines to stage adversarial confrontation-sequences of viva voce testimony and argument directed by the judge and elicited by attorneys.

COMPETITION OF IDEAS IN PRIOR DESIGN THEORIZING

The bulk of domain-independent design theorizing addresses the design process. The starting point has been the analysis-synthesis-evaluation model, which has been refined into many different variants, including Pahl & Beitz (2013) model and Gero's and Kannengiesser's (2004) model. The common feature in all these descriptive process models is that there is the assumption of selections and decisions between different ideas, sub-solutions being made in satisfactory manner; however, the models are silent on how the decisions are or should be made. This applies also to the C-K theory (Hatchuel & Weil 2009), which abstracts away what is occurring between the concepts providing the starting point, and the knowledge used for realizing those concepts.

Besides process models, design theorizing covers several narrower topics (partly based on Kroes 2002), such as (creativity in) design thinking, design education, design effort, conceptual design as a process, design progress, communication of design knowledge, managing design information, the role of computers in design, design as a cognitive activity, decision making in design, design intent/rationale, collaborative design, team cognition. From these, most relevant for the angle of competition of ideas are perhaps decision making in design, collaborative design and design intent/rationale.

The topic of decision making in design triggered first the idea of optimal design, inspired by economic thinking. However, the approach of optimal design was at the outset constrained by the unrealistic requirement of formulating decision situations in clear-cut mathematical formalisms. As Belton and Stewart (2002) argue, design is a different kind of decision-making problem, which comprises research to identify or create new decision alternatives to meet the goals and aspirations revealed through the design process. Many other decision-making methods have been proposed, also for allowing a bigger role for subjective assessments, for example Analytical Hierarchy Process (AHP). The use of such methods has not grown in the design arena, presumably either because of their lacking transparency or because their assumption that the decision can be entirely objective (Singh and Tiong, 2005; Arroyo et al., 2015).

Regarding collaborative design (or co-design), the majority of research has focused on describing the determinants of collaboration. While initial understanding has been provided, this research has suffered from fragmentation, due to historical discontinuities and many different disciplinary backgrounds. For example, the ancient idea of common ground as a precondition for collaboration, only recently reinvented, can be found under confusingly many terms (Koskela et al. 2016).

Research focusing on design intent/rationale (Fischer et al. 1991, Lee & Lai 1991) has pursued conceptual frameworks and computer tools, which would document the design history and especially support changes to design. However, their uptake has been modest.

Up to now, in design theorizing the angle of competition of ideas has either mostly been abstracted away or some specific topic in relation to that competition has been examined; however, theoretical and practical gains have been modest. By and large, the question on how this competition should be arranged has been left disregarded.

CASE STUDY

The case study was done in retrospective for a design of a large complex campus (circa 600,000 sf) located in Silicon Valley, California. Researchers collected evidence of the application of legal proceeding principles in a portion of the project where advanced lean design principles and methods were implemented. Documenting where the seven legal proceeding principles were used was done after the fact, using three sources of evidence: 1) direct observation, the second author acted as one of the lean coaches for the project; 2) project documents-A3s, meetings agendas, drawings, project schedule and budget; and 3) interviews with the project manager and mechanical engineer. In addition the benefits of using lean in design were calculated and reported by the project manager, and validated by the owner.

HOW WERE THE SEVEN LEGAL PROCEEDING PRINCIPLES REALIZED?

Hear both sides

All relevant stakeholders were invited to each of the 52 meetings held to select from design alternatives. Even where there was not a physical meeting, everyone had the chance to participate in the decision remotely through a videoconference. If any of the relevant stakeholders could not attend, the meeting was rescheduled. For example, when one of the mechanical engineers could not attend a meeting to decide about the HVAC system zoning, the meeting was rescheduled. If more information was needed, follow up meetings were scheduled before a decision was made.

Another, generalized realization of this principle occurred through the application of set based design (SBD). In this practice, several alternatives are explored collaboratively and decision-making is deferred to the last responsible moment, instead of selecting one alternative early for allowing certain inputs to subsequent tasks. The rationale of SBD is to “hear the alternatives” until there is as much information available as possible.

Reasoned judgment and fact-finding

The method of Choosing by Advantages (CBA) was used to evaluate design alternatives by considering their attributes (characteristics relevant to determining if and how well they meet agreed criteria). These facts were also documented in A3 reports. This is different from legal practice, since in law evidence is about the past and in design evidence is about understanding future physical performance of the building. For example: For a decision, where to locate the outdoor fitness area for future building users, the baseline design was compared to four other alternatives. In order to look for facts, several factors and criteria were agreed, to be able to compare alternatives fairly. Each alternative is evaluated using facts (attributes in CBA language) according to criteria shown in Table 1.

Table 1: The criteria evaluated for each alternative

Must Criteria:	Want Criteria:
a. Pathway between CE and fitness location must comply with ADA code requirements	f. The less travel time between locker room and outdoor fitness location the better
b. Location must be shaded a minimum of 25% utilizing architectural elements	g. The more privacy from pedestrian walkways and vehicular traffic the better
c. Must have a minimum of 2,400sf of flat space to comply with program requirements	h. The less acoustical and visual impact to desks the better
d. Must be secure and provide ample storage	i. The less impact to City entitlement approval process the better
e. Must have access to drinking water, convenience outlets and light fixtures for night workouts	j. The less impact to current site design (ecology, elimination of tranquil space, etc.) the better
	k. The less pedestrian pinch point on route to main entry the better.

Right to appeal

As in courts of law, the right to appeal a decision was always available. Further, anyone could offer new information, a new alternative, a new factor to consider, and new facts that help differentiate the alternatives, perhaps correcting a mistake in previous assessment of attributes. There were several meetings before the final decision was presented to the client; therefore there were several opportunities for appeal.

Use of logical and rhetorical arguments

Rhetorical arguments were used several times at each decision. CBA is well aligned with the use of rhetorical arguments, which have been divided into three types: *logos, ethos and pathos* (Arroyo et al. 2014).

Logos: In CBA, the use of logos is encouraged by requiring the design team to describe the advantages of the alternatives based on their attributes. The design team needs to think of all available arguments, which favor a particular alternative, for example: gather data or facts to support an advantage, considering a shared point of comparison (anchoring); agree on criteria to be considered in the decision; understand the current conditions on the baseline design; and understand the regulatory requirements.

In the previous section on reasoned judgment and fact-finding, examples were provided how logos is used in lean design.

Ethos: In several occasions lean design methods support considering the arguments from people who have authority or relevant knowledge. During the decision-making process, several specialists were giving their assessments for evaluating possible outcomes of alternatives, and assessing accuracy of data. For example, in a particular decision geotechnical engineer was concerned about other members understanding the level of uncertainty in the practice. During the lean design process, all relevant specialists are given the option to speak and provide pertinent advice.

Pathos: CBA involves arguments that appeal to the people who will be affected by the decision (e.g., users, environment, etc.). Designers appeal to emotion in many ways; e.g., by considering how an alternative will impact the user experience. Consider this statement of objective from an A3: “Find an outdoor fitness location that evaluates aesthetics, privacy and disruption (nearby pedestrian pathways, vehicular traffic, loading dock deliveries, etc.)". The whole point of changing the baseline or current design is to produce a better user experience in the future.

All meetings are public

All records are public to the design team. Everyone in the project has access to the A3 files, and can see the status and history of each decision.

Decision meetings were mostly held through videoconferences. Participants would retrieve general access documents such as drawings, specific architectural models (BIM Models), structural models, or mechanical models, depending on their pertinence to the discussion. Also design guidelines and contractual documents were retrieved from shared files, for the purpose of discussion or for finding relevant information to inform the design. Every one in the team was able to share a screen to show relevant information. The models and access to specific information was hyperlinked to A3 documentation for facilitating the access to information.

Standardized procedures

This is a one of the main points of the lean design implementation, where everyone has a standard to process an issue in the design, documented in an A3 report, exploring alternatives (using SBD when needed), and CBA when decision was complex and required multiple criteria. In the case of issues that required a collaborative decision-making process, the standard was the following:

- Problem definition: Problem to be discussed, background and current state (baseline design). What is the objective of the meeting? What are the factors and criteria (must and want to have) for judging alternatives?
- Proposals / Solution Analysis: What alternatives can be considered? What facts can we use to describe the characteristics and consequences of the alternatives? What are the advantages of each alternative? What are the costs of the alternatives? How important are the advantages compared to each other? Propose a recommendation (if all information is available).
- Actions: Obtain more information if required, and meet again if needed. The recommendation is presented to the client when all the relevant information is obtained, and the team has achieved consensus to make an informed recommendation, or the time to make a decision has finished (last responsible moment). Approvals (including virtual signatures).

Dedicated and structured space

The project had critical team members working remotely in several different locations (i.e. San Francisco, New York, and London), therefore physical co-location was not always possible (in contrast to many other current projects organized in similar lines). However, one week per month the team had a big room dedicated space, the remaining weeks virtual co-location was implemented. The team had regular meeting scheduled through videoconference, and discussed design decisions collaboratively across disciplines (e.g., mechanical, structural, architectural, and construction perspectives were often discussed in the same meeting) using real time collaborative documents and spreadsheets hosted on the cloud. In addition, BIM models, plans and specifications were accessible for the team.

EVALUATION

Before the team implemented lean practices, embodying the principles of legal proceedings, designing was a frustrating and confusing process, where relevant information was not shared when needed, and where the team did not had a clear procedure to discuss design problems or new possibilities. After implementing lean, the design team was able to increase the design value for the client, while saving time and money. Quantified saving of lean design practices were 9.7 million USD (11% less than the original design budget). Increased efficiency in design process was measured through meeting records (time reduced by 37% per decision in a 4 month period). In addition, according to members of the design team, less negative design iteration existed since decisions "stuck" with the client, and the design team developed mutual trust and respect. These results were validated and approved by the owner, then presented in the 2017 Lean Construction Institute Congress.

The performance outcomes of implementing lean practices embodying the principles of legal proceedings are thus clearly better in comparison to the situation before. Although it is not possible to trace back the benefits only to the principles of legal proceedings and related practices, their emergence, and continued use, provide solid circumstantial evidence on their efficacy.

CONCLUSIONS

This paper continues the authors' study of the relationship between rhetoric and design (Ballard & Koskela, 2013; Koskela & Ballard, 2013; Koskela, 2015; Arroyo, et al., 2014; Arroyo, et al., 2015), in this case by examining and elaborating courts of law as a metaphor for design. An advanced lean construction project has been presented as an example how design is organized and managed when the competition of ideas is held to be central. In contrast to this perspective, current design theories barely consider the competition of ideas if at all.

The findings of this paper suggest several lines of research going forward. One such is to revisit design theories to incorporate competition of ideas. Another is to understand more completely how competition is actually structured and managed in different design practices, and also what can be learned across these different practices.

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IMPLEMENTATION OF MASS CUSTOMIZATION FOR MEP LAYOUT DESIGN TO REDUCE MANUFACTURING COST IN ONE-OFF PROJECTS

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ABSTRACT

MEP systems are complex system representing a considerable portion of commercial and industrial projects, comprising 25%-40% of the total project cost and covering more than 50% of the total duration of the project. The layout design of MEP system is generally based on client and system requirements, space limitations, interference within the system as well as with other trades. Not much consideration is given to the design optimization as per fabrication and constructability perspective thereby often adding significant cost and time to a project in term of its component manufacturing.

This paper introduces Design for Manufacture approach into MEP system design to reduce the manufacturing cost of varieties of MEP components by using mass customized components. Mass customization is the ability to design and produce customized products to meet customer needs at reduced cost and duration.

We propose a framework to automatically develop the layout of the piping system using mass customized components as a reference, which can be used for other MEP aspects such as Mechanical & Electrical with relevant changes. We hypothesize that using mass customized MEP components will increase the efficiency and reduce the cost of manufacturing the MEP components. The paper presents a theoretical framework that is the basis for further research.

KEYWORDS

Mass customization, standardization, cost.

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1. INTRODUCTION

Mechanical, Electrical and Plumbing (MEP) systems are complex system representing a considerable portion of commercial and industrial projects, comprising 25%-40% of the total project cost and covering more than 50% of the total duration of the project (Riley et al. 2005). In fact, the cost associated with the MEP engineering and design can be up to 50% of the total investment in some large-sized public projects.

Specialized consultants and contractors are responsible for MEP systems design including responsibility for checking clearance, identifying routes and fabrication details and installation locations (Korman et al. 2001).

MEP systems directly influence the total cost of the project as well as its operating efficiency, safety, energy utilization, and flexibility of the architectural and structural design. Considering the value of the MEP portion of a facility, this research investigates how to efficiently layout the MEP systems to reduce manufacturing cost of the MEP components.

The layout design of MEP system is generally based on client and system requirements, space limitations, interference within the system as well as with other trades. Not much importance is given to the design optimization as per fabrication and constructability perspective thereby often adding significant cost and time to a project in term of its component manufacturing. This paper introduces Design for Manufacture (DFM) approach into MEP system design to reduce manufacturing cost of varieties of MEP components by using mass customized components.

Mass customization is the ability to design and produce customized products to meet customer needs at lesser cost and duration. Manufacturing and production have been a big contributor to improved quality and sustainability of human life. Current market trends, such as customer demand for variety, high product quality, short product life cycles, and low cost, have ensured the need for efficient, robust, responsive, and sustainable manufacturing. (Kwok et al. 2016).

Innovative practitioners begin to throw away the old paradigm of mass production and find their way to a new paradigm, mass customization, by creating variety and customization through flexibility and responsibility to meet customers' diverse and ever changing needs at near mass production prices (Pine 1993; Tseng and Jiao 1996; Jensen et al. 2013). The basic idea of this theory is to reuse standard modules and parts across different product variants in order to enable mass customization (Meyer and Lehnerd 1997; HööK and Stehn 2008; Gerth 2013)

However, customized product is very challenging to be produced in masses using traditional manners, and the business has to wait for today's advanced technologies to enable profitable customization (Bourell et al. 2009).

One of the reasons behind the low level of intelligent MEP system design is that MEP consultant does not fully utilize new techniques emerged like mass customization along with the development of information technology, such as the Building Information Modeling/Model (BIM) technology.

There is a need to automate the process of MEP design layout with the use of mass customized components to reduce the manufacturing cost of the components. Using Building information modelling as a tool to assist DFM appears to be an effective approach to overcome various challenges.

2. LITERATURE REVIEW

Designing MEP systems involves defining the location and routing for different components of building systems to comply with diverse design and operation criteria. (Barton 1993). Preferably, the best coordinated design location is considered as most economical and effective arrangement that meets critical design criteria and performance specifications (Korman et al. 2003)

2.1. PROBLEMS WITH CURRENT MEP DESIGN

MEP system is composed of the numerous components with different size and shapes having complex logic structure among them. Whether MEP systems are installed onsite or in a factory as part of modular construction project, the coordination of the different components and their fabrication has historically been a challenge (Lu 2008).

Table 1: Problem with current MEP design

Current practice	Reference
• Effective MEP coordination requires recalling and integrating knowledge regarding design, construction, operations, and maintenance of each MEP system. • This multi-discipline process is time consuming and expensive. • Most visible parts of MEP design only focus on geometry and functionality of the building systems.	Korman et al. 2003
• Current focus of MEP system design is only to satisfy performance requirements for the specific project and comply with codes and standards. • The coordination process is slow and expensive. • Constructability issues are not considered as a part of the MEP design consultants scope of work. • Coordination is often not budgeted in the construction cost. It is a hidden cost in the design category.	Korman et al. 2006
• Low level of standardization in the piping fabrication	Li et al. 2017

2.2. RESEARCH RELATED TO MEP SYSTEM DESIGN

Before conducting our research to reduce manufacturing cost of different MEP components, we investigated various researches related to MEP system design criteria and intent and its components fabrication and construability issues. We found that most researches focus on coordination issue of MEP systems in design as well as construction phase, as described in following researches table 2:

Table 2: Research related to MEP system design

Author	Research work
Korman et al. 2003	Developed a knowledge framework for MEP coordination that reflected the complexity and variety of all the components
Korman et al. 2006	Developed a computer-based tool to assist in MEP systems coordination to assist in planning the construction of MEP systems
Korman and Lu (2011)	Explored how BIM can be utilized to increase the opportunities for prefabrication of MEP systems for modular construction projects
Wang et al. 2016	A practical BIM framework was developed for coordinating MEP layout from the preliminary design to construction stage

Although a significant amount of research efforts has been carried out in improving the MEP system design for better performance, operation and its construction. No attention was given to a vast variety of components in MEP system and their manufacturing cost. The fabrication of these components constitutes huge cost and time. Thus, there is need to focus on how the manufacturing cost of various MEP components can be curtailed while not comprising with system performance and operation.

The theory of mass customization aims to offer increased product flexibility by standardizing components without increasing manufacturing costs, thus appears to be an effective approach to overcome manufacturing cost of a vast variety of MEP system components. Studies advocate the application of mass customization (MC) in building as it can provide value-added products at reasonable cost. There is still lack of studies of the use of mass customization in MEP system.

2.3. SUMMARY

The primary objectives of various researches are to design MEP systems layout such that it follows universal design, occupancy requirements, environmental regulations, fire safety, space constraints, maintenances and daily operations requirements,

No regard is given to massive diversity of components in MEP system and their manufacturing cost. The fabrication of each and every component constitutes huge cost and time, thereby often adding significant cost and duration to a project in terms of its components fabrication. Thus, there is increased need to focus on how the manufacturing cost of various MEP components can be curtailed keeping its performance and operation at its best.

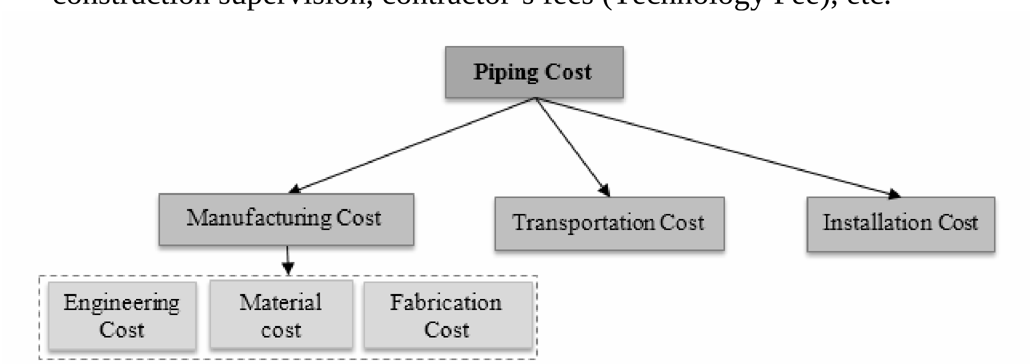
This research focuses on design optimization by opting Design for Manufacture approach into MEP system design to reduce manufacturing cost of varieties of MEP components by using mass customized components. Therefore, we propose a framework to automatically develop the layout of the piping system using mass customized components as a reference which can be used for other MEP aspects such as Mechanical & Electrical with relevant changes.

3. DETERMINATION OF PIPING COST

In order to develop a piping layout which is economical and also satisfy all the operation and design criteria's. The first step is to know what are the drivers for piping cost.

The piping process can be divided into four phases: designing, pipe fabrication, transportation to site, and site installation. Piping cost estimation depends on many variable factors such as:

- Direct Costs related to piping: The direct cost of piping is related to the procurement and installation of piping along with other piping accessories. This cost generally deals with raw materials, labor, energy, space, etc.
- Indirect Costs related to piping: This cost deals with design and engineering cost, which basically comprise of cost of design and engineering of the piping system, construction supervision, contractor's fees (Technology Fee), etc.



The above mentioned various factors can be summarised into three wider categories: Manufacturing cost, Transportation cost and Installation cost, as shown in figure 1.

Figure 1: Overview of piping cost

There exist various solutions which can aid to decrease the above mentioned costs. Some of the are listed below:

- Engineering cost: opting for various technological advancement and automation.
- Material cost: choosing proper layout i.e. opting shorter route for costly pipes.
- Fabrication cost: using DFM, use of mass customized components.
- Transportation cost: supply chain management practices.
- Installation costs: use of simulation, opting for simple connection, modularization, Design for assembly (DFA).

4. FRAMEWORK ON PIPING SYSTEM LAYOUT DESIGN USING MASS CUSTOMIZED COMPONENTS

A piping works engineer should have wide engineering knowledge, understanding of engineering economics, methods of pipe fabrication, costs of metallurgical, erection and installation requirements and knowledge of other disciplines such as mechanical, civil, electrical and instrumentation engineering to discuss coordination requirements.

In order to design piping system so that its component can be mass customized, there is need to find appropriate sizing option as per the design criteria's and proper layout (without any clashes)

SIZING OF A PIPE SYSTEM

Pipe sizing and routing is one of the most important and critical activities for any piping project. The selection of the optimal pipe route (length), diameter, wall thickness, material and equipment location are typically the result of economic scrutiny and investment evaluation of the most reasonable structure developed through the design phase.

Pipe size is determined with proper dimension calculations considering various parameters and design calculations. Pipe sizing decisions affect project economics substantially which include cost of pipe and accessory as well as cost of support etc. Pipe route should preferably be shortest with minimum bends, closer to wall or other devices to support them, with no obstruction around etc

The term sizing of a piping system refers to the completion of two independent design functions: the fluid flow design and the pressure-integrity design.

Before the start of the above mentioned designing process there is need to fix the position of source and demand points (its position is prefixed as per some guidelines and experience). Next a preliminary pipe route clash free route having appropriate length, least bends etc. to know the approximate route length of the pipe. After the preliminary layout of the piping system is achieved, the design process will proceed.

System Flow Design

- The objective is to determine the minimum acceptable inside diameter of each segment of the piping system that will accommodate the design flow rate.
- The detailed system flow design of a piping system depends on various inputs such as shown in table 3:

Table 3: Input type for system flow design

Input Type	Parameters
Space (geometry)	Size and configuration (length of the pipe, Location of source, demand points)
Fluid characteristics	Design temperature, viscosity, density
System requirements	Required pressure, flow rate, type of connections and bends etc.
Material attributes of pipes	pipe wall frictional drag

Pressure Wall Pressure (Integrity) Design

- After the fluid design is complete and the minimum inside diameters of the various segments of the piping system are determined, the piping wall pressure design may proceed. It determines the minimum or nominal pipe wall thickness and the pressure rating of the in-line components, such as fittings and valves.
- The Pressure wall pressure (Integrity) design of a piping system depends on various inputs such as shown in table 4:

Table 4: Input type for Pressure wall pressure (Integrity) design

Input Type	Parameters
Design pressure	Maximum pressure at expected conditions. Generally, the maximum flange pressure at design pressure is used.
Diameter of pipe as calculated by system flow design	-
System requirements	Type of joints, design temperature
Material attributes of pipes	Allowable stress, toughness, corrosion resistance, thermal insulation

With the two above mentioned design process the necessary minimum dimensional requirement of various piping components is determined. For example, for pipe, its minimum required diameter, thickness for the adopted route lengths are known. The final piping layout on the basis the above design process is still to be achieved.

LAYOUT AND SIZE OPTIMIZATION

After calculation of minimum size requirement of the components, adoption of appropriate size of the components is done. Normally, a size just bigger (next integer value) than the minimum one is chosen and is assigned to the particular section of layout.

Treading to the path of this research, there is a need to determine what can be the best layout and optimum dimension for a particular piping component which can be used repetitively in order to mass customize whole piping layout on the basis of the above two designs. The selection of proper size of the components is influenced by various economical aspects for example, if the size is too large than what is required can be highly uneconomical, etc. Therefore, a fast and reliable optimization technique is required to be introduced to get the best fitted standard dimensions of a component to mass customize the piping layout.

An optimization operation will be carried out to choose best layout and standardize each pipe segments and layout in terms of length, diameter and thickness, height. The potential optimization technique which can solve the objective of the proposed research are Genetic Algorithm or Simulated Annealing, as they work on search technique and provide the best alternatives to the objective function based on the fitness of the parameters among the given possible populations. Weights should be assigned to different parameters of the objective function. The objective function should also comprise of penalty function (having infinite weights) if the constraints are violated as well as bonus function (negative weight components) if the standard pipe sizes are used, this can be understand by a simple equation (3) below:

$$\text{Minimize: } f_{singleP} = w_1 f_{length} + w_2 f_{bends} + \cdots + w_{n-1} f_{penalty} + w_n f_{bonus} \quad (3)$$

Where, $f_{singleP}$ = pipe route; f_{length} = length of the route; f_{bends} = No of bends; $f_{penalty}$ = penalty function (eg. Technical constraints); f_{bonus} = bonus function (eg. use of standardized components) and w_1, w_2, w_{n-1}, w_n are respective weights assigned for the different parameters mentioned.

Using the above two independent design processes and optimization technique, a pipe system design layout is obtained with standardize pipe segments and accessories. A design checks and loading and service condition check is done to confirm the obtained layout. To show the proposed pipe design process, a theoretical framework is developed to obtain pipe system layout having standardized components as shown in figure 2.

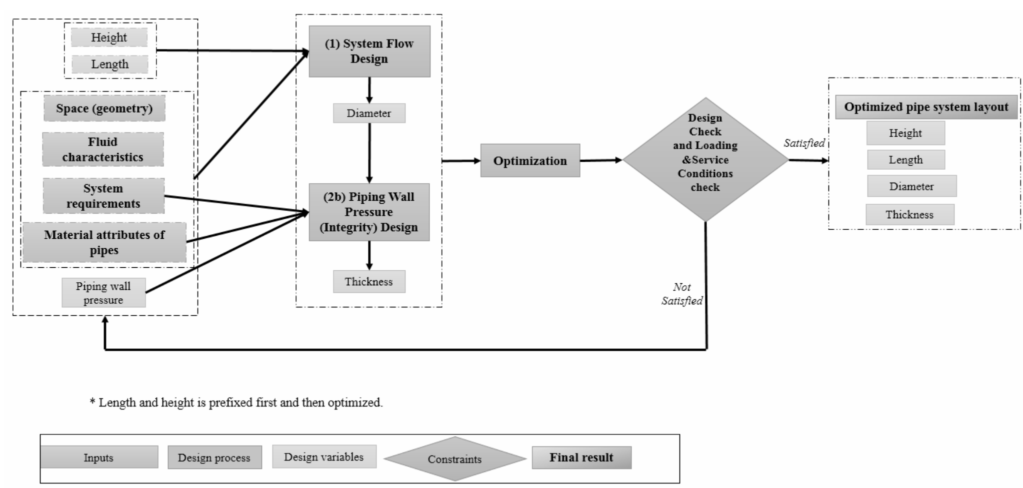


Figure 2: Framework to standardize piping components

5. CONCLUSION AND DISCUSSION

The traditional approaches for MEP design layout requires the calculation of minimum sizing requirements and thereby choosing of appropriate size as per the availability convenience. Several research efforts were made to MEP design layout and the most visible parts of MEP system design focus only on the geometry and functionality requirement of the building systems. However, none of them considered the importance of manufacturing cost associated with variety of MEP components and ease of the fabrication of these components, during design stage. The fabrication of diverse components in MEP system constitutes huge cost and time, thereby often adding significant cost and duration to a project in terms of its components fabrication. Thus, there is requisite on how the manufacturing cost of various MEP components can be curtailed keeping its performance and operation at its best.

Mass customization combines the individualization and flexibility to custom-made a products and matching its level to that of mass production, thereby offering a lower unit cost. The benefits mass customization can provide concerning to the different types of variety of components in a particular product is comprehended in this research and represented by optimization technique to provide advice for MEP design for manufacturing.

This paper presents a theoretical framework that focus on design optimization by opting Design for Manufacture approach into MEP system design to reduce manufacturing cost of varieties of MEP components by using mass customized components. The developed framework also focus on manufacturing aspects of MEP component in addition to operation al requirement which will solve many of the current MEP design problem such as not accounting constructability issue, low level of standardization etc. As this research aims to use BIM as a means to develop the framework, the whole MEP design process can be speeded up thereby potentially reducing the designing time of MEP systems.

This approach has potential for various EPC projects (oil and gas plants, power plants, metallurgy plants etc.) as they engage huge amount of investment and also consist of massive diverse components and sub components and thus reducing the manufacturing cost of various components and sub components can contribute significantly to the whole project cost.

As the developed piping framework is theoretical in nature. More development and mathematical validation are required to prove the proposal. Therefore, extending the framework for the validations will be considered in the future work. The developed framework can be extended for other trades such as Mechanical etc. Further research on quantitative aspect of cost and time will be beneficial to influence customer value.

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CHOOSING BY ADVANTAGES; BENEFITS ANALYSIS AND IMPLEMENTATION IN A CASE STUDY, COLOMBIA

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ABSTRACT

There are many methods of multicriteria decision analysis (MCDA), each one with properties and benefits. In the Architecture, Engineering, and Construction (AEC) sector most of the time, the decision–making involve different interest of the stakeholders of the projects, must of the times applying methods with the focus on the result. This paper presents a case study of a new University's facility construction that compares the traditional decision–making approach used in the design-bid-build procurement method of AEC industry in Colombia with an MCDA approach. Choosing By Advantages (CBA) has been used to analyse the reasons that could help explain why the subcontractor of a project construction was not meeting the client's expectations during project execution. Results include a discussion of main differences between these decision methods, the main difference is that in traditional decision–making approach the main criterion was cost while in the CBA was value. Consequently, the method's results were different for the alternatives.

KEYWORDS

Choosing By Advantages (CBA), multicriteria decision analysis, contractor selection.

INTRODUCTION

Decision-making may be one of the most common processes that faces professionals in the day-to-day work, but this practice could be very complex, especially when several objectives, factors, criteria and alternatives must be considered. Nowadays there are

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many decision-making methods aimed to obtain the best results for the decision-making process, but its application used to be complex with questionable or mixed results at best.

In the Architecture, Engineering, and Construction (AEC) sector, the decisions taken are of great importance in order to increase the value in the different stages of the projects. One of the most critical decisions is the selection of the contractors, which implies not only the cost of the different alternatives but also technical and quality factors among others. Due to the importance of this process, this research analyses and compare the traditional methods used actually in the Colombian Industry with the Choosing By Advantages (CBA) method in the selection process of the structural contractor in a new University's facility construction.

In order to expose this proposal properly, this research is organized as follows. First, a literature review of the state-of-knowledge of the decision-making in the AEC is shown and consequently the next section details the traditional method selection used in the design-bid-build procurement method in Colombia. Next, a real academic construction project is used as an example of application, exposing and comparing the results obtained by the traditional and CBA method. Finally, on the basis of the results obtained, the conclusions, limitations and further research are drawn.

STATE OF THE ART

The multidisciplinary nature of decision-making in the AEC sector and the involvement of multiple stakeholders, such as designers and users, often result in decision tasks with multiple objectives (Kpamma, Adinyira, Ayarkwa, & Adjei-Kumi, 2016). An example of this is the construction project outcome that may be measured in terms of time, cost and quality achieved (Holt, Olomolaiye, & Harris, 1995). Commonly, the time-cost trade-off problem is a known as bi-objective problem in the field of project management where quality has been considered as an objective which is improved by increasing the cost of the project (Fallah-Mehdipour, Bozorg Haddad, Rezapour Tabari, & Mariño, 2012).

In the example above, there is a conflict management situation where the decision involves multiple objectives. How is shown in the Figure 1, the nature of these decision tasks calls for approaches known as multicriteria decision-analysis (MCDA) (Abraham, Lepech, & Haymaker, 2013). The MCDA may be considered as a complex and dynamic process (Kumar et al., 2017) including two levels: one managerial and one engineering level. The managerial level defines the objectives and chooses the best alternative and in the other hand, the engineering level defines the different alternatives and points out the consequences of choosing any one of them from the standpoint of various criteria, in this order of ideas; this level also performs the multicriteria ranking of alternatives (Opricovic & Tzeng, 2004).

Furthermore, there are many methods of MCDA, its use depends on the functions defined in the problem (Kumar et al., 2017). The CBA decision system developed by Jim Suhr (1999) is one of the methods that takes into account the comparisons of the advantages of alternatives (Kpamma et al., 2016) in order to construct the preferences of the decision-makers (Arroyo, Tommelein, & Ballard, 2012). Consequently, CBA promotes the correct use of information (Karakhan, Gambatese, & Rajendran, 2016) basing decisions in objective questions, relevant facts, more consistent and less subjective processes (Suhr, 1999).

In the literature review, CBA is not well known (Schöttle & Arroyo, 2017) but increasingly it has become a valuable method because consider different factors, which affect the alternatives as social and environmental factors that are not traditionally considered (Arroyo, Tommelein, & Ballard, 2016). In contrast with other methods, CBA considers cost separately from other factors and does not treat it as a criterion (Parrish & Tommelein, 2009), in other words, in CBA, the cost in considered as a restriction and not as a factor.

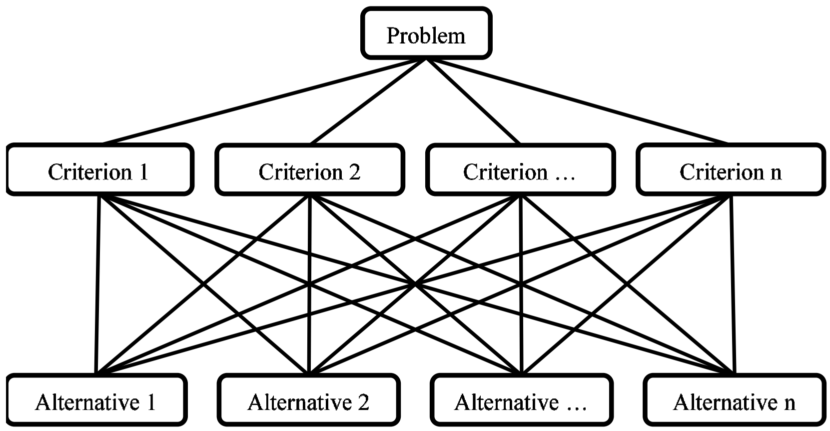

Figure 1: Multicriteria decision analysis diagram (Vallejo-Borda, Gutierrez-Bucheli, Pellicer, & Ponz-Tienda, 2015)

The general phases of CBA implementation have evolved thanks to innovation phases. Paz Arroyo et al. (2013) describe that CBA Tabular method, for moderately complex decision, consist of seven steps: (1) identify alternatives, (2) define factor, (3) define must/want have criteria for each factor, (4) summarize the attributes of each alternative, (5) decide the advantages, (6) decide the importance of each advantage and (7) evaluate money data. In addition, the terminology used by CBA for the decision-making process must be understood before making any application (Martinez, Tommelein, & Alvear, 2016):

- **Alternative:** Person, thing or plan which is a subject of choice.
- **Factor:** An element, part, or component of a decision.
- **Criterion:** A decision rule, or a guidance – usually, either a must or want.
- **Attribute:** A characteristic, quality, or consequence of one alternative.
- **Advantage:** A benefit, gain, improvement, or betterment.

The use of CBA in the AEC industry has been framed, in its majority, in the design and construction decision making (Parrish & Tommelein, 2009) for example to select the formwork system (Martinez et al., 2016), the ceiling tile (Arroyo et al., 2013), the fall protection measures (Karakhan et al., 2016), the sustainable materials (Arroyo et al., 2016), among others. In the case of contractor selection, the MCDA is suggested to be a viable method (Cheng & Li, 2004) and especially for contractor selection, it has been used methods like weighting-rating-calculating (WRC), best value selection (BVS), and CBA (Schöttle & Arroyo, 2017). Despite that, in Colombia Lean Construction has being explain in three main pillars: culture, philosophy and technology with various methodologies (Pellicer & Ponz-Tienda, 2014), even so, the use of new tools is difficult and face similar barriers related to contractors' engagement, reluctance to change and lack of training (Mejía-Plata et al., 2016). However, the research is limited about the differences based on a comparison of CBA and traditional industry methods of contractor selection, which have a similar nature to the value-based decision-making methods (usually confused with cost) that is based on the factors to be evaluated.

TRADITIONAL METHOD OF CONTRACTOR SELECTION

The contractor selection processes in the construction industry could be the most complex procedures in terms of the data analysis, due to the amount and nature of the data required for the decision problem. In order to provide transparency to these processes, guidelines and general rules were established to carry out the selection and hiring processes in Colombia through the law 80 of 1993. This document, updated with the law 1150 of 2007, institute the principles to ensure the objectivity in the selection. In this sense, the choice is made to the offer more favorable and following the purposes of the contractor, without taking into consideration the factors of any kind of subjective motivation like affection or interest.

It also establishes that the selection and qualification factors, which are established in the contract specifications, have to include criteria such as legal capacity, experience conditions, financial and organizational capacity of the proponents. In the same way, the requirement of such factors must be adequate and proportional to the nature of the contract to be subscribed and its value. Finally, it is established that the most favourable offer will be the most advantageous for the contractor, taking into account the technical and economic factors contained in the specifications.

In the case of entities of a private nature, the law 80 does not act as a binding regulation, but as a guide or principles with the aim of generating transparency in the decision processes. This is reflected in the fact that, despite not being obliged to do so, most private organizations structure their search and selection processes for contractors as established in Law 80. In these processes, the documentation that allows to evaluate the factors that are requested and described in the legislation, in addition to the methods of weighting or scoring of the proposals, both in technical and economic aspects, which, by assigning a percentage to the factors, are adapted to take into account value the compliance for each proponent.

RESEARCH METHOD

The focus of this study is the comparison of the CBA with the traditional method in the Colombian AEC Industry. With the goal of establishing if the CBA method provides significant advantages and add value over the other method, first, a background literature study of MCDA was made in order to deepen about the CBA application and its relation with similar methods used for contractor selection. In addition, from the case study, it was possible to compare the results of CBA using the process proposed by Paz Arroyo et al. (2013) with the results obtained based on the selection and hiring processes through the law 80 of 1993 of Colombia. Finally, the paper analyses the impacts of the decision taken on the project develop.

CASE STUDY

The selected project is an University's facility construction conformed by 8,555m2 constructed in irregular five stories and three basement building located in the middle of the campus of the Universidad de Los Andes (see Figure 2), located along the slope of the eastern range of the Andes Mountains.

The main procurement method adopted at Universidad de Los Andes is Design-Bid-Build (DBB). Moreover, this building was not the exception. When the project is in the construction-building process, most construction systems are already assigned to a contractor and a few ones are now in the final phase of the bidding process. In order to support these decisions, the project manager provided all the project information needed for the process: a) the contract specifications where specify the factors and the criterions, b) the four alternatives proposals and c) the tendering evaluation used to take the decision.

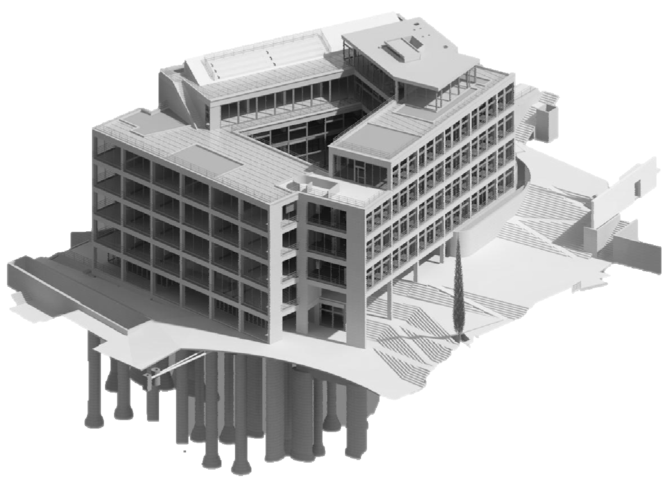

Figure 2: Revit model of Case Study

TRADITIONAL METHOD RESULTS

The structural contractor on a project was selected by a traditional method, according to the law 80 of 1993, as is shown in Figure 3 taking into account the technical and economic criteria contained in the specifications.

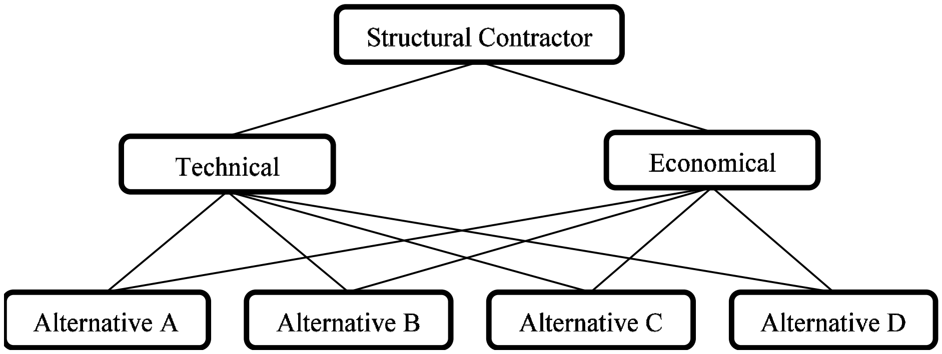

Figure 3: Multicriteria decision-analysis diagram

The economic evaluation has 700 points and the technical only 300 points. The cost as a factor has 550 of 1000 possible points (view Table 1), which tilt the balance in the cheapest alternative.

As can be seen in Table 1, the tendering D was the most favourable bid, and consequently, it was selected to build the structure phase of the project. Note that in the technical evaluation, it was "the worst" but due to the economic ponderation evaluation it was selected as the "the best", with a final difference of only one point.

Table 1: Results obtained by the traditional method

			Tendering			
Evaluation criteria		**Points**	**A**	**B**	**C**	**D**
Technical evaluation	Business organization	150	140	123	121	88
	Management system	50	0	50	50	0
	Planning and logistic	50	50	48	50	38
	Makespan	50	38	42	50	42
	Sub Total	**Max 300**	**240**	**272**	**255**	**209**
Economic evaluation	Equity	26	23	18	23	16
	Liquidity	13	13	13	13	13
	Level of debt	11	6	6	9	6
	Payment method	25	25	25	25	25
	Total Cost	550	393	448	486	550
	Risk management	50	50	45	45	40
	Evaluation of AIU	25	12	25	25	25
	Sub Total	**Max 700**	**526**	**574**	**633**	**680**
	Total	**Max 1000**	**767**	**846**	**888**	**889**

CBA RESULTS

In order to validate the decision taken, it was applied the CBA method with the same criteria and using the information provided by the project manager by applying the seven steps proposed by Paz Arroyo et al. (2013). The first six steps organized in the tabular method (Table 2) and Figure 4 shows the seven-step, in which the Importance of

Advantage (IofA) vs. cost of the alternatives is analysed. An application developed in VBA for Excel® can be downloaded from http://bit.ly/CBA_Excel.

The D alternative is the less favourable instead the result obtained by applying the traditional method. In Figure 4 can be seen that alternative D have a difference of almost 700 million of COP compared to the alternative C with, considered "the best" by CBA with more IofA.

Table 2: CBA results for steps one to six and the four alternatives (A to D).

	A		B		C		D	
Years in construction	40 years		20 years		8 years		6 years	
More is better	34 more years	**12**	14 more years	6	2 more years	3		
Similar experience	155,69 m2		202,65 m2		202,02 m2		21,77 m2	
More is better	133,92 m2 more	25	180,88 m2 more	**30**	180,25 m2 more	**30**		
Bussines organization	30 Professionals		40 Professionals		57 Professionals		15 Professionals	
More is better	15 Prof. more	20	25 Prof. more	25	42 Prof. more	**30**		
Own equipment	$ 15,866,544.08		$ 4,021,164.85		$ 4,917,604.93		$ 1,029,660.96	
More is better	$ 14,836,883.12	**30**	$ 2,991,503.89	10	$ 3,887,943.97	10		
ISO Certifications	SIG		9001-18001-14001		9001		SIG	
At least one (1)			Have 3 certification	**50**	Have at least one	**50**		
Makespan	14,5 months		13 month		11 month		13 month	
Less is better			1,5 month less	40	3,5 month less	**50**	1,5 month less	40
Equity	22,55 smmlv		8,21 smmlv		33,33 smmlv		2,54 smmlv	
More is better	20,01 smmlv (2)	18	5,67 smmlv	10	30,79 smmlv	**26**		
Liquidity	2,18		3,2		4,47		2,5	
More is better			1,02 more	7	2,29 more	**13**	0,32 more	4
Level of debt	63,3		28,75		30,76		31,48	
Less is better			34,6 less	**11**	32,54 less	**11**	31,82 less	**11**
Payment method	0,3		0,3		0,3		0,3	
Less is better								
Risk management	$ 26,943,619.57		$ 8,554,684.62		$ 20,564,512.99		$ 2,040,078.90	
More is better	$ 24,903,540.67	**50**	$ 6,514,605.72	15	$ 18,524,434.09	30		
Evaluation of AIU	0,41		0,48		0,33		0,23	
Less is better	0,07	10			0,15	15	0,25	**25**
TOTAL IofA	**165**		**204**		**268**		**80**	

Notes: (1) At least one of of ISO 9001-18001-14001

(2) smmlv is the spanish acronym of current legal minimum monthly salary

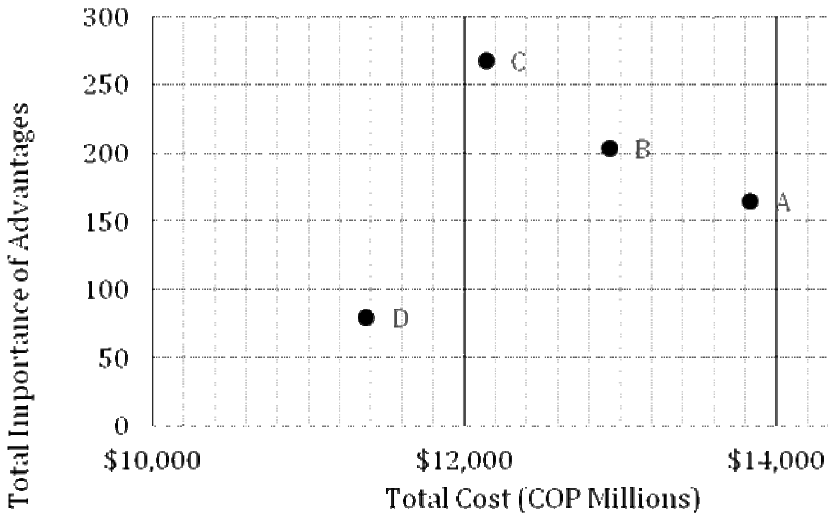

Figure 4: CBA results IofA vs. Total cost

DISCUSSION OF THE RESULTS

This comparison allows analysing the decision in two different perspectives of the construction management: the management in the world of the cost and the management in the world of the value. These differences are reflected in the results shown in Figure 5.

The obtained results were in line with the expected: the best option applying the traditional method is the worst by applying CBA. In the CBA method, the differences among alternatives A and B decreases, while the alternatives C and D change in the order of preference. Additionally, the difference between C and D, increase from 1 point to 188 points or IofA showing that CBA considers that the best alternative is the one that provides more value to the project.

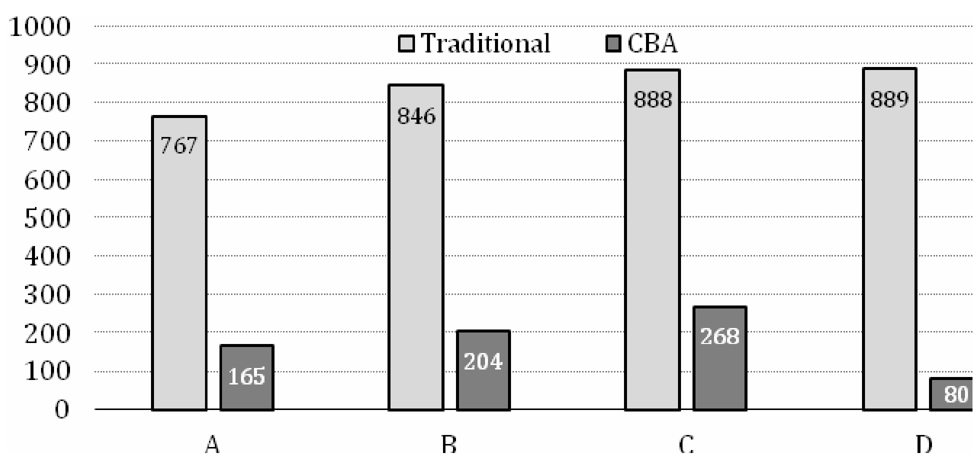

Figure 5: Comparison of results Traditional vs. CBA

Nevertheless, it is important to highlight that the alternative D, selected by the traditional method, only obtain advantage in a few factors by applying the CBA method, being the worst ranked in: a) construction experience (in years), b) experience in similar buildings, c) business organization, d) own equipment, e) ISO certifications, f) equity, g) payment method, and h) risk management. This could be the reason why the problems arose and the project manager wondered if it was the right decision. The analysis of the results shows the benefits of CBA as an effective decision making tool compared to the traditional methods.

CONCLUSIONS AND LIMITATIONS

The present research has analysed and compared the traditional method applied in Colombia for the selection and hiring of services provider with the CBA method in the process of select the structural contractor for an academic building in order to validate the decision made by the traditional method.

Therefore, the difference of the results among alternatives varies among methods; partly, as a consequence of not considering the cost as the main criterion. In addition, in CBA, the results of alternatives are easy to analyse, identifying the advantages, the factors in which is the difference and offer clearness to the criteria. Also, the traditional way in which decisions are taken is targeted on the result, disparaging the methodology to obtain it. Nevertheless, the making decision method is also important as the alternative selected.

Finally, it is considered that this case study does not evaluate if the factors were the correct and if the criteria was the right one; as a result, this is material for another research because it is not enough to use a different method of selection, it is also required to know how to use it. In this case, it implies to define correctly the factors, criteria and importance of each advantage.

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THE DUAL NATURE OF DESIGN MANAGEMENT

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ABSTRACT

Design management profession has probably got the least attention in the construction industry. One reason could be the lack of explicit conceptualizations about its nature, subject matter and principles. In this article, a conceptual design management framework is proposed on the premise that design management is the management of a structured system of object and subject-oriented, technical and social design activities. Additionally, an example of a mediating visual model is proposed to facilitate the discussions about design activities and design management in academia and practice. The two major premises of this research are 1) as design management is the management of design activity, it is dependent on the way design is conceptualized; and 2) design is a human activity, but not a thing (e.g., representation) or an event (e.g., decision-making).

KEYWORDS

Design management, activity theory, design activity, design system, shared mental models.

INTRODUCTION

Although the first practices of managing design were already documented in Germany as early as in 1907 (Schwartz 1996), it is only in the recent decades that design management gained widespread scholarly interest. Despite numerous efforts, the design of buildings is still suffering from many failures (Pikas et al. 2015). Literature review reveals that one primary cause of these problems could be the poor conceptualizations of design management (Koskela et al. 2002; Pikas et al. 2015). The rest of this article builds on this insight and proposes a design management framework together with a visual model as a mediating artefact to facilitate the conversations about design management within the design management academia, and hopefully, also in practice.

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The importance of using frameworks has been illustrated by Woods (2009): "In science we need frameworks that hit an intellectual sweet spot for their research communities - the frameworks must provide conceptual leverage without being fatuously simple (overly "lumped") or distractingly complex (needlessly "split"). The form of such frameworks is as much about the order that our own minds require to move forward effectively as it is about the accuracy with which some aspect of the world has been captured."

This study is conceptual in nature. Based on a literature review, the emphasis is placed on the conceptualizations of design activity and its relation to design management. The paper is divided into three parts: the first section addresses the conceptualization of design from the activity approach and theory perspectives; the second section addresses the lean and social conceptualizations of design management. In the third section, a framework and a visual model are constructed and proposed.

DESIGN ACTIVITY

Design activity is a complex phenomenon, defined in many different ways and on different levels. There is hardly any consensus on what design is (Love 2000). At the macro level, the design is the whole process and practice of design concerning the design project organization, including considerations about the specific stages, phases, and elements in the design process (Cash and Kreye 2017). At the meso and micro levels, a design activity can be defined concerning the individual designer or collective of designers and their mental and practical actions and operations (Cash and Kreye 2017).

DESIGN PARADIGMS

No design conceptualization takes place in a vacuum, and the same applies to any scientific discipline (Kuhn 1962). Particular views on design conceptualization determine the focus of analysis, its content (attended and disregarded features) and expected outcomes. This is known as the design paradigm, which describes the different perspectives, assumptions and prescriptions underlying the design research (Stumpf 2001).

In this study, the underlying assumption is that design is an activity of a human agent, and thus, any theorization about designing can be understood only in a human context. This is supported by several design researchers (Bedny and Meister 2014; Cash and Kreye 2017; Love 2000).

Bedny and Meister, referring to the leading Soviet philosopher G. Shchedrovitsky, argued that the 20th century epistemologies can be divided into two contrasting, non-exclusive, approaches (Bedny and Meister 2014):

- **Naturalistic approach –** concerned with the descriptive studies of transforming the unmediated experiences directly into knowledge about the existence of objects and phenomena in nature;

- **Activity approach –** the meaning of human life (things and events, features and relationships of those things and events) and its context can only be revealed through a process of human activity (making it useful for practical interventions).

The majority of design paradigms tend to fall under the naturalistic approach, for example, the science of the artificial proposed by Simon (1981), while fewer consider design from the activity approach perspective (Love 2000). In the following, the four well-known design paradigms are briefly reviewed.

Dorst (1997) studied two paradigms of designing, ‘rational problem-solving’ and ‘reflective practices’. Stumpf (2001) added to this list of design paradigms ‘design as a social process’ and design as ‘hypothesis testing’. Dorst (1997) differentiated the design paradigms based on three dimensions of the design conceptualization: models of the designer (features of the designers, how designers reason and behave), the design task (the intricacies of how designers understand design tasks) and the dynamics of the design process (activities of designers divided into macro, meso and micro-level processes). The study of these aspects of designing is collectively referred to as the design methodology (Cross 1984): “the study of principles, practices and procedures of design”.

The positivist information-processing conceptualization of design activity uses analytical and symbolic approaches and methods to problem-solving (Simon 1981). The ‘second-generation’ design paradigm was proposed by Rittel (1984), who defined design as a social process, subject to the ‘wicked’ and 'tamed' problems.

The third design paradigm, developed on the idea of ‘analysis-by-synthesis’ (Lawson 2006), emerged as a response to the limitations of the rational and social design paradigms and was named hypothesis testing (Broadbent 1984). The fourth design paradigm is referred to as the reflective practice (Schön 1984), describing designing as a dynamic, continuous, cyclic and unfolding process of individual learning.

The first two (the rational and social views) lean towards the naturalistic approaches of design conceptualization; while hypothesis testing and experiential learning lean towards the activity based conceptualizations of designing. However, these design paradigms are not necessarily exclusive and could form complementary frames of reference (Bedny and Meister 2014).

ACTIVITY THEORY

Activity theory (AT) originated as an alternative approach to the Western behaviorist approach to the study of human psychology. AT was initially formalized by the Russian philosophers and scientists S. L. Rubinshtein (1889–1960) and A. N. Leont’ev (1904–1979) (Bedny and Meister 2014). There are several Western interpretations, of which one well known is by Engeström et al. (1999). In the present article, the structural activity theory approach by Bedny and Meister (2014) is followed.

AT describes design activity as a hierarchically organized system of conscious and unconscious, goal-directed actions and operations. Design activities are either object or subject-oriented, technical or social (Cash and Kreye 2017).

In the technical activities, designers use different architectural and engineering instruments (e.g., BIM) to transform design object between different design states. In the social activities, interactions between two or more design team members are constituted in the information exchanges, personal interactions and mutual understanding. The social activities are mediated by different internal (e.g., language) or external (e.g., video conferencing) instruments (Bedny and Meister 2014). It is important to note that social relationships also matter in the object-related activities as an inner dialogue about the given situation, surrounded by norms and standards (Engeström et al. 1999).

Bedny and Meister (2014) differentiated between object, goal, result and motives. The object (either concrete or abstract; e.g., steel structure or building information model) of design activity is either what goes through a change process or is being explored by a designer according to the goal of the design activity. The goal is "a conscious cognitive representation of the desired future result of activity accepted or not, transformed or not, before or during activity" (Bedny and Meister 2014). The result is the actual outcome of the design activity. Motives (the gap between the need and actual) are what energize the goal, connecting needs and objects (Bedny and Meister 2014). Figure 1 adopts the high-level structural description of the human activity from Bedny and Harris (2005).

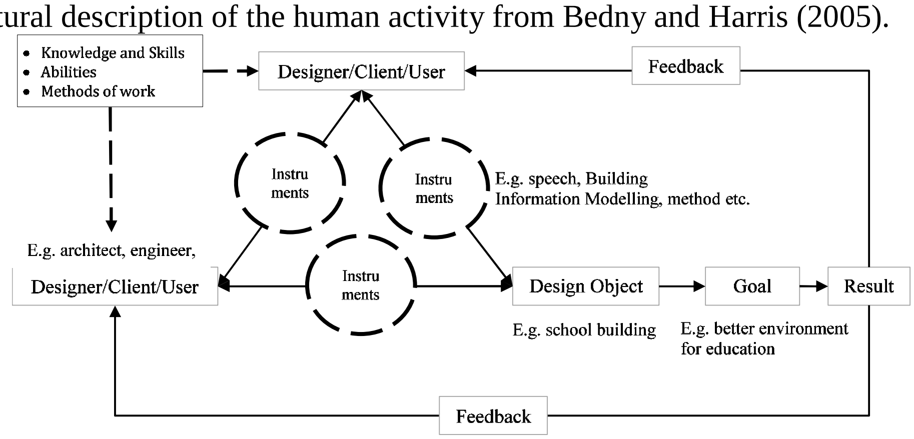

Figure 1. A description of an activity system (adapted from Bedny and Harris (2005)).

Based on this description of AT, a building design activity can be defined concerning the purposes of a building project and designers' behaviors (Bedny and Harris 2005):

> *The building design is a purpose directed system where motivation, cognition, and behaviors are integrated with respect to the 'bringing-into-being' of a new building.*

In the following, the different levels of human activity based on the AT formalism are summarized, consisting of conscious activities, tasks and actions, and unconscious operations:

- **Activity:** subjectively distinct periods of human activity associated with fulfilling a motivation. As designers can have more than one motivation at any time, then more than one activity can be progressed at one time (Bedny and Meister 2014). An example of building design could be an activity focused on developing a design embodiment.

- **Task:** a temporally and subjectively distinct part of an activity, required for the achievement of a goal under specific conditions (Bedny and Meister 2014). Within the context of building design, an example of a task could be the dimensioning of a primary part of a building structure.
- **Action:** mental and practical actions are the last conscious level of design activity (fragment of task), always associated with the duration, place and a designer. Actions have a recursive loop structure, with multiple forward and backward interconnections (Bedny and Meister 2014). Bedny and Harris (2005) proposed a one-loop model for action, consisting of four actions (see Figure 2): Identify (acceptance and/or transformation of action's goal(s)); generate (development of ideas, alternatives, conditions and plans for the design action); develop (preparation/creation of designs, (e.g. calculations, drawings, specs and/or models, and their testing/demonstration (e.g. BIM simulations, prototypes)); and evaluate/decide (communication and decisions for further actions). An example of action could be the calculation of loads as a part of the task of dimensioning the primary building structures.
- **Operations:** actions are further divided into unconscious mental and practical operations; i.e., a continuous process and structured system of processing units as well as the system of internal mental processes underpinning behavior (Cash and Kreye 2017). For example, the movement of a hand for drawing a line or memorizing an idea.

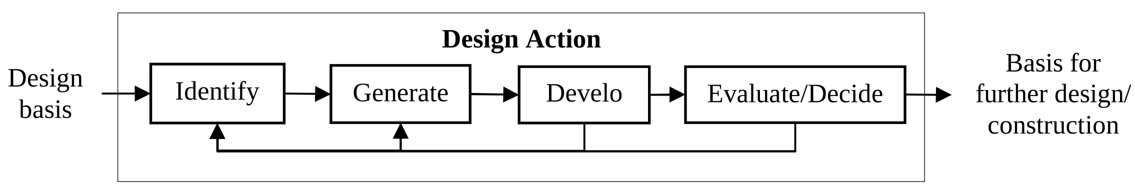

Figure 2. Design action as a one-loop system (adapted from Bedny and Harris (2005)).

To summarize, AT is a holistic psychological approach to the study of human activity. The two first levels of the activity structure (activities and tasks) are the objects of study, the two last (actions and operations) are the units of analysis. This means that actions and operations are more basic, from which the objects of study emerge.

LEAN DESIGN MANAGEMENT

In this section, the focus shifts from describing the design activity to describing the managerial activities. Although the different methods of lean design management embed the management of the social aspects (such as the Language-Action Perspective (LAP) in the Last Planner System (LPS) (Ballard 2000)), it is essential to clarify the function of design management concerning the social dimensions more explicitly.

CONCEPTS IN LEAN DESIGN MANAGEMENT

According to the Transformation, Flow and Value (TFV) theory, lean design project (system) management has three functions, each with its specific managerial principles (Koskela et al. 2002): design system design, design system operation and design system improvement. The idea of 'design system design' concerning three goals (value, transformation, and flow) is well established in the lean community (Ballard et al. 2001).

The operations management of a design system through the different phases of the project is divided into three management functions: planning, execution, and control of design operations (Koskela et al. 1997).

According to Koskela et al. (1997), the partial models for conceptualizing the different dimensions of planning include management-as-planning and management-as-organizing. The former is responsible for the structuring and sequencing of the design tasks, and latter is responsible for the structuring of the environment to contribute to purposeful acting - to avoid making-do (Koskela 2004). In the design process, inflows include (Bølviken et al. 2010): expectations and demands, decisions, manning, methods and tools, and dialogue. LPS divides planning into four levels, each with their specific focus and planning horizon: master (entire project), phase, lookahead, and weekly/daily planning (Ballard 2000), incorporating the technical and social considerations.

Execution can be conceptualized by using the two partial models, the classical communication theory and the language-action perspective (Koskela et al. 1997). The former is focused on the efficient transmission of information, and later on the promise-based management of the design process.

Managerial control also consists of two partial models (Koskela et al. 1997): the (mindless) thermostat model based on control theory and the scientific experimentation model (plan-do-check-act) by Shewhart and Deming.

The design system improvement is focused on the feedback of lessons learned through the different phases of the design process and the project in general (Koskela et al. 2002). First run studies have been proposed to prototype and test the capability of operations to meet targets and make corrections when necessary. Metrics on different levels of resolution, such as key performance indicators (KPIs) or Percent Plan Complete (PPC), have been proposed to facilitate the process of learning (Ballard 2000).

SOCIAL ASPECTS OF DESIGN MANAGEMENT

In addition to the technical level of design management, Rekola et al. (2012) identified three other essential levels of design management: the substance level, the communicational/interaction level, and the personal level. These levels correspond to the social dimensions of design management, especially crucial in the early stages of design when the design activity is language rich framing and re-framing of views (Stumpf 2001).

Development and Maintenance of Shared Understanding

The development of a shared understanding between the design team members has been studied through the development of shared mental models (sMM). As most of the designing happens within the heads of individual designers, especially in the early stages of design, the concept of mental models (MM) is valuable for understanding the cognitive processes of designers (Casakin and Badke-Schaub 2017).

MMs are simplified internal representations of the world constructed by individuals for gaining and processing information, depending on the context and social setting in which these MMs are constructed. MMs influence the team´s communication and performance, and aid the coordination and adaptation of the design activity (Casakin and Badke-Schaub 2015).

The studies on sMM in teams have been divided into three major types, the MM of the design task, of the design process and the individual´s or the team´s MMs (Edmondson and Nembhard 2009). A few concepts either from the perspective of an individual or collective have been proposed to describe the interpretative dimensions of design tasks and processes.

Stumpf (2001) proposed a concept for describing how learning and the development of shared understanding emerge from the individual level to the level of the design team. The concept combines design rhetoric and Schön’s reflective practices, and consists of collective framing, naming, moving and reflecting processes. Within the context of organizations, Nonaka and Takeuchi (1995) proposed the processes of internalization, socialization, externalization, and combination.

The difference in the two approaches is that Stumpf (2001) focused on the development of the sharedness of mental models (design-as-argumentation), while Nonaka and Takeuchi (1995) were interested in tacit knowledge (design-as-knowledge-explication). Therefore, although this is not their interpretation, Stumpf (2001) is concerned with the development and maintenance of common ground, while Nonaka and Takeuchi (1995) are concerned with the development and maintenance of boundary objects (e.g., BIM) and standardized methods (e.g., LPS) (Koskela et al. 2016; Pikas et al. 2016).

Thus, in the social dimension, design management is responsible for the facilitation of communication to develop sMM throughout all phases of the design process by using different means to explicate the tacit knowledge. This requires a shift from focusing on the problem solving to facilitating the co-evolution of shared understanding of needs, requirements, ideas and solution principles.

DEVELOPMENT OF A FRAMEWORK AND CONSTRUCTION OF MEDIATING ARTEFACTS

In this section, different concepts on design and design management activities are synthesized to propose a new design management framework.

Before this can be done, the relationships between the hierarchical dimensions of design activity and the different levels of management need to be clarified. Ballard and Tommelein (2016) propose a convention for breaking tasks into different levels of detail based on the Gilbreth’s motion analysis. However, there is an essential difference between the AT theory and the Western approach. The Western approach to human psychology was behaviorist in nature, focusing on the practical actions and operations of humans, neglecting the mental ones. In the Russian AT, the behavior necessarily included the mental actions and operations in addition to the practical ones (Bedny and Meister

2014)[6]. Consequently, as illustrated in Table 1, it is not a coincidence that LPS has four levels of management considerations.

Table 1. Relationships between design activity and design management functions.

Focus of Study	**Objects of Study**			**Units of Analysis**	
Activity Theory	Activity		Task	Action	Operation
Building Design Example	Project	Phases	Tasks	Actions	Operations
Lean Design Management	Design, Operate, Improve		Plan, Execute, Control		
Last Planner System	Master plan (Should)		Phase (Pull) Planning (Should)	Lookahead (Can), Weekly (Will), First Run Studies, Metrics	

Within Table 2, the dual nature of design management is illustrated, including the technical and social aspects. In the technical view of the design system design, the TFV theory is instructive. In the social view, the design-as-argumentation and design-as-knowledge-explication are useful. Thus, as part of the design system design, it is crucial to establish the necessary conditions for the design collaboration (Koskela et al. 2016): how common ground is created; goal alignment and situational awareness maintained; continuous improvement during the project encouraged; and integration with production achieved.

The design system operation is divided into three management functions: planning, execution, and control. Under planning we find the management-as-planning and management-as-organizing; under execution the communication theory and language-action perspective; and under control, the thermostat model and scientific experimentation have been proposed to correspond to the technical and social views respectively.

The improvement of the design system can be informed by the use of metrics to illustrate the trends and systematic experimentation through the design process.

Table 2. Mapping lean design management concepts to technical and social views.

	Production Management Functions				
	1. Design System Design	**2. Design System Operation**			**3. Design System Improvement**
		2.1 Planning	2.2 Execution	2.3 Control	
Technical view of design	TFV	Management-as-planning	Communication theory	Thermostat model	Metrics
Social view of design	Design-as-argumentation Design-as-knowledge-explication	Management-as-organizing	Language-action perspective	Scientific experimentation	First Run Study

In the following, a visual model for the execution of design activity is proposed. The model is based on the technical and social views of design. Similar models can also be constructed for all the other pairs in Table 2. The proposed model is adapted from Bølviken et al. (2010) and further clarified based on the design activity theory. At the

[6] A detailed discussion of the differences is beyond the scope of this work, and need to be addressed within a future study.

center of the model is the last level of conscious, goal-oriented design activity, namely the design actions. The dialogue in the language-action terms (including communication and argumentation, coordination and decision-making) is needed between the design team members to secure a sound design process. This conversation takes place in the context of a design task, to which a designer (or a team of designers) has committed himself in the phase planning.

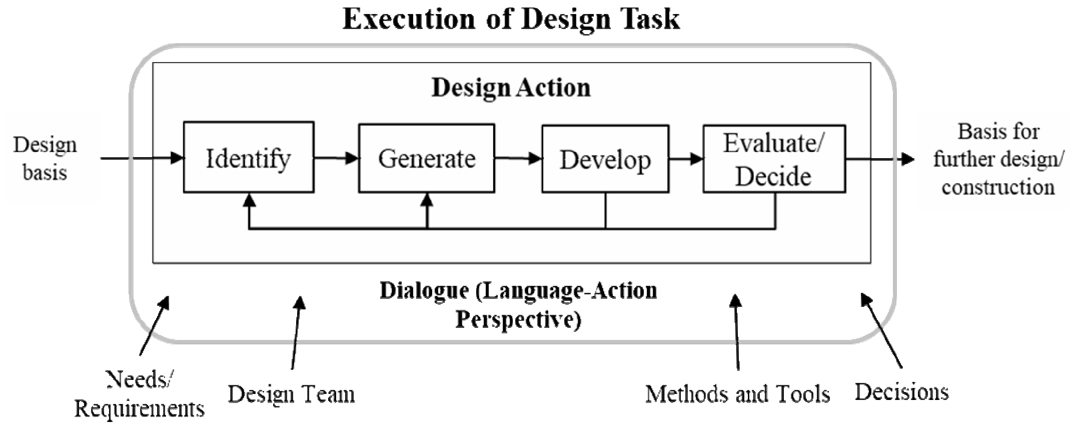

Figure 3. Design management model for the design management execution function (adapted from Bølviken et al. (2010)).

CONCLUSIONS

The design is a complex phenomenon, and so is the design management. Design management is influenced by how a design activity as such is conceptualized. In turn, this is dependent on the particular design paradigm that has been chosen by the researcher for studying and developing the descriptive as well as prescriptive concepts and practices. In this article, designing was conceptualized as a human activity, not as a thing or event. Based on these premises, a comprehensive framework supported by a visual model for conveying conceptual ideas was proposed. Holistic design management has a dual nature as design management is the management of a structured system of object and subject-oriented, technical and social mental and practical actions of design.

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IS INTEGRATION OF UNCERTAINTY MANAGEMENT AND THE LAST PLANNER SYSTEM A GOOD IDEA?

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ABSTRACT

The Last Planner System (LPS) is a tool for project planning and control, and is an important contribution from Lean Construction. LPS focuses on scheduling, task coordination and time management. Uncertainty Management (UM) is a key element in Project Management, where uncertainty is the totality of opportunities (potential upsides) and risks (potential downsides). UM addresses all types of uncertainty (related to cost, time, quality, scope, safety, customer satisfaction, company reputation, etc.). The aim of UM is to exploit the opportunities and reduce the risks.

Two construction companies involved in this research are working with both LPS and UM. One has extensive experience with LPS, but less experience with UM. The other has extensive experience with UM, but less experience with LPS. Two questions are raised and discussed in the paper: 1. Could project planning and control be improved by an integration of LPS and UM? 2. If yes, how could LPS and UM be integrated to improve project planning and control?

The paper proposes a conceptual model where UM tools are integrated in the plan and meeting structure of LPS. The model is to be tested in forthcoming case studies.

KEYWORDS

Uncertainty Management, Risk, Last Planner System

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INTRODUCTION

The Last Planner System (LPS) is a method to execute planning and control of construction projects. LPS is mainly a scheduling system, focusing on activities, their sequence and their dependencies in time (Ballard 2000, Ballard and Tommelein 2016). Handling uncertainty is one of the key factors for successful project management (PMI 2013, Hillson 2004, Chapman and Ward 2003). In traditional Project Management literature, Risk or Uncertainty Management (UM) has developed as an important activity and Risk Management is one of the core competence areas in Project Management (PMI 2013).

Klakegg et al. (2017) argue that an increased and explicit focus on uncertainty has something to add to LPS. This is in line with Wehbe & Hamzeh (2013) and Aslesen et al. (2013). The latter propose to extend LPS to include safety risk management by including safety risk considerations on each of the plan levels of LPS. The argument is that accidents and injuries on the construction site are deeply intertwined with the workflow that LPS seeks to control. We suggest that it is worthwhile to build further on this reasoning. We do however propose that the concept of safety risk discussed by Aslesen et al. (2013) could be extended to the broader notion of uncertainty. The main reason is that whereas safety is only about preventing negative outcomes (risks) in the form of accidents, uncertainty, whether related to costs, progress, quality, corporate reputation or health, also includes the possibility of positive outcomes. Example of an opportunity for a construction project could be that during the ground works, one reveals that the ground conditions is better than expected. This leads to less costs and less time used on ground works. To deal with uncertainty requires a more balanced approach where analyses and management of risk can be counterbalanced by investigations of opportunities to avoid a one-sided focus on all the things that might go wrong.

This study aims to explore the opportunity of using UM to broaden the scope of LPS. The following research questions are addressed:

- Could project planning and control be improved by an integration of LPS and UM?
- If yes, how could LPS and UM be integrated to improve project planning and control?

RESEARCH METHODOLOGY

The aim of this paper is to develop a framework for how UM and LPS could be integrated. Given this aim, a qualitative approach was chosen. A literature review was done, searching for the research gaps for LPS and for UM, and literature discussing a possible integration of the two. A series of workshops were held to discuss how it could be possible to integrate UM and LPS, including representatives from academia and the two construction companies involved in the research. The workshops were used to discuss the advantages and disadvantages of integrating LPS and UM, and to discuss possible ways of integrating the two. Since this is a theoretical study where our aim is to propose a framework for integration of LPS and UM, no case studies are included this far.

THEORETICAL BACKGROUND

UNCERTAINTY MANAGEMENT

There are several definitions of the terms uncertainty (Galbraith 1977, Andersen 2005, Hillson 2004, Johansen 2015). In this paper, the following definition of uncertainty is used: Uncertainty is an event that if it occurs, has a positive (potential upsides or opportunities) or negative (potential downsides or risks) effect on a project's objectives (PMI 2013). Uncertainty Management processes aim to reduce the risks and exploit the opportunities (Hillson 2004).

Uncertainty can be either statistically describable variation or single event uncertainty (Ballard and Vaagen 2017). Statistically describable variation is variability in time, cost, etc. of events that will happen, while event uncertainty is described by probability and consequence of possible events that might and might not happen. An example of statistically describable variation for the main contractor is the price he will get from the sub-contractors. Whether a sub-contractor would go bankrupt during the project is a single event uncertainty.

Uncertainty Management (UM) includes both proactive, interactive and reactive ways of thinking. Proactive UM is about analysing the uncertainty upfront to make actions before things happens. Interactive UM is about being able to handle things as they happen. Reactive UM is about understanding things that have happened, it is about repairing, exploiting opportunities and gathering experiences for future learning.

A number of Uncertainty Management processes are described in the literature (Raz & Hillson 2005, Chapman and Ward 2003, PMI 2013). Torp et al. (2007) propose an Uncertainty Management Process with the following five steps; Uncertainty Management Planning, Perform Uncertainty Analyses, Handling/Treat Uncertainty, Uncertainty Monitoring and Evaluating the Uncertainty Management Process. Typical tools for Uncertainty Management are stochastic cost or time estimation, scenario analysis, SWOT-analysis, single event uncertainty analysis, uncertainty matrices, uncertainty registers and different treatment strategies and action plans (Hillson 2004, Chapman and Ward 2003, Lichtenberg 2000). These tools are used with an aim either to quantify the size of the uncertainty or to prioritize between different uncertainties (Lichtenberg 2000). One result from the uncertainty analyses is a list of the identified uncertainties and their impact on the project objectives. This list is called the uncertainty register and includes all relevant information about the uncertainties, their size and possible impacts. From the uncertainty register a shortlist of the most important uncertainties is formed. This shortlist is also referred to as the focus list, the priority list, the top-10 list or the uncertainty profile.

An uncertainty analysis meeting, a gathering of a group of experienced people, is described by Lichtenberg (2000), establishing the basis for the uncertainty register. Uncertainty management includes a series of uncertainty analyses, and a series of uncertainty management meetings, where the uncertainty register and the focus list are updated. The length of the periods can vary, but for a large project uncertainty management meetings are typically held two to four times a year.

Much literature focuses on overall uncertainty management processes (Hillson 2004, Chapman and Ward 2003), typically on a project-owner level. How to operationalize uncertainty management in weekly and daily project planning and control activities is not well described. How is for instance the focus list for a project operationalized for each phase of a project, to each contract and then to operational plans for the supervisors and workers?

THE LAST PLANNER SYSTEM

The Last Planner System (LPS) is a system developed for the planning and control of project-based production (Ballard 2000). The system is based on the following principles (Ballard et al. 2009):

- Plan in greater detail as you get closer to doing the work
- Produce plans collaboratively with those who will do the work
- Reveal and remove constraints on planned tasks as a team
- Make and secure reliable promises
- Learn from breakdowns.

The Last Planner refers to the planners last in a chain of planners, in a construction project typically the supervisor, squad leader or even the trade workers. The system is based on their involvement in the planning and control of the project's progress. A fundamental recognition is that due to the high degree of variability characterizing construction production, decision-making is best done by letting those closest to the operations have substantial influence on scheduling. Even more so, the last planners are the key to produce good assignments (Ballard 1993). For them to fulfil their role, the system advocates a shielding process distinguishing what "should" be done, from what "can" be done, and what "will" be done (Ballard 2000). This is done by introducing several levels of planning, to make people "look ahead" and make sure all necessary preconditions are in place before a task is assigned to the workers on site. The shielding process, thereby, shields the last planners from an erratic flow of resources.

As originally presented by Ballard (2000) LPS consists of four levels of plans: The master schedule (made once, covering the whole project), the phase schedule (made once, covering one phase), the look-ahead schedule (continually updated, covering the next 6-9 weeks) and the weekly work plan(continually updated, covering the next 1-2 weeks)[8]. In practice, this also constitutes a meeting structure and a structured division of labour in the planning and control process. Different people in different meetings handle different plans.

LPS constitutes a proactive make-ready process where tasks can be seen as traveling top down through the plan and meeting structure. Along this travel,variability (uncertainty) is gradually reduced and constraints are removed, allowing only sound tasks

[8] Versions with five and six levels have later been developed.

to be released for execution[9]. This way LPS has a fundamental top-down functionality. However, it also facilitates local handling on each plan level and bottom-up processes.

INTEGRATION OF LPS AND UM INTO ONE SYSTEM

IS INTEGRATION OF LPS AND UM A GOOD IDEA OR NOT?

Klakegg et al. (2017) find that some of the basic ideas UM and LPS are based on are the same and that an increased and explicit focus on uncertainty can add value to LPS. By bringing people together to integrate all efforts toward a common objective, a plan should point more directly to difficult and significant activities, to uncertainties, and not least to the problems of achieving the objective. For a start, construction management must apply plans, which tell with as much accuracy as possible how the efforts of the people representing various functions should be directed toward the project's completion. To succeed, however, management must not only be able to collect all pertinent information to form a basis for prediction and planning. Likewise, it is important to evaluate alternative plans for accomplishing objectives. Construction management is not so much about defining the perfect plan as it is about developing a plan that will work under varying circumstances.

LPS deals with reduction of variability in the work flowby proactive project planning and control. This enables activities to be sound and made ready to be done. Ballard and Vaagen (2017) introduce a framework to manage variation in a project, where both statistically described variation and single events are handled. The main ways of handling statistically described variation are to reduce variation in stable processes, buffering of variations not reducible and redesign unstable processes, while single event uncertainties are handled by including flexibility in teams or flexibility in plans. Therefore, LPS offers a proactive approach to reducing variability, an interactive approach, handling what happens, but also includes reactive tools, e. g. to learn from what happened by calculating PPC and asking 5 whys.

Klakegg et al. (2017) see look-ahead planning as the mechanism in LPS that in the most concrete and systematic way seeks to eliminate causes of uncertainty by checking for preconditions and thereby securing sound activities. This is in line with Wehbe&Hamzeh (2013), who propose a framework for integrating Failure Mode and Effects Analysis (FMEA) as an addition to constraints removal in the look-ahead planning. In look-ahead planning, specific measures for reducing the impact of events that could create problems should be identified and implemented. This logic should also be applied in the weekly work plan.

The following similarities and differences between LPS and UM are observed:

- Both LPS and UM aim to reduce variability in time;

[9] A sound task is a task where all preconditions for doing the task in an efficient way are present. Koskela (1999) presents seven preconditions for a task to be sound, often referred to as "the seven preconditions" (materials, labor, equipment/tools, pre-requisite work, space, information, and external conditions).

- While LPS focuses on schedule uncertainties (uncertainty in the work flow and the flows of resources feeding the work flow), UM focuses on all types of uncertainty (uncertainty in income, procurement costs, quality, safety, corporate reputation, etc.).
- LPS focuses on the preconditions for sound activities (typically the seven preconditions described by Koskela (1999)), while UM focus on the most important uncertainties, prioritized through uncertainty analyses.
- LPS focuses on reducing waste, and hereby reducing variability, while UM in addition aims to exploit opportunities that occur in the project; and
- UM also covers, in addition to variability, analysis and management of single event uncertainty. (Originally, the focus on waste reduction came from industrial production and was often shielded from event uncertainty, while single events were more relevant to project-based production.)

An important question is how uncertainties are prioritized when focusing on the preconditions for sound activities in LPS. UM might help prioritizing the most important uncertainties in LPS, not only importance for schedule, but also for other factors such as cost and quality. Other important questions are; what are the relationships between the different plan levels, and how can we secure that the weekly work schedule and look-ahead schedule are in compliance with the milestones in the phase schedule and again in the master schedule? And how can we integrate the focus on schedule with the focus on cost and quality so that UM helps focusing on the right uncertainties/variability on all levels?

An important issue in UM is how to transfer the focus list down to the operational level. Another is how to achieve a balanced focus on opportunities and risks instead of ending up with a one-sided focus on risk alone. We think that integration of UM into the plan and meeting structure of LPS would help operationalize UM and to some degree solve some of the described challanges. Based on this, we conclude that integrating UM and LPS could be a good idea. In the next chapter, a framework for how this could be done is presented.

HOW COULD LPS AND UM BE INTEGRATED INTO PROJECT PLANNING AND CONTROL?

Klakegg et al. (2017) proposes the following regarding how elements of UM could be integrated into different levels of plans in LPS: In the master schedule a probability-based approach could be used. As a follow-up to this, the phase schedule meeting can be used as an arena for identifying uncertainties for all disciplines and for raising awareness about measures for limiting the probability of something going wrong. Physical measures and control points for following up high-risk events can be shown explicitly in the phase schedule. The uncertainty matrix and uncertainty register should be updated in the phase schedule meeting. The phase schedule perspective on a good work sequence for all the disciplines represents an opportunity perspective.

Together with the meeting structure and corresponding organizational levels, the different plan levels of LPS form an effective structure for production planning and control. From UM, the uncertainty analysis meeting is an arena for discussing, quantifying and prioritizing uncertainties. Typically this kind of uncertainty analysis is done for the project owner prior to the final decision to start the project; for the contractor it is done prior to delivering the tender and as a part of establishing the master schedule. The master schedule will offer input to LPS, and uncertainty analysis done prior to delivering the tender will function as input to the first version of the uncertainty register and the focus list.

We suggest using the LPS meeting structure as a framework to link UM and LPS. An important issue is what kind of uncertainty that can be managed by LPS. From the uncertainty focus list, different kinds of uncertainties can be identified and prioritized. It might be relevant to handle some of them in the meeting structure of LPS, others might best be handled in other arenas, e.g. by the owners decision plan. In the rest of the paper only uncertainties that could be handled through the LPS meeting structure are considered.

A potential improvement of UM, as discussed earlier, is the operationalization of UM down through the different levels of planning. A focus list should be established at the level of the master schedule. The list should not only consider schedule uncertainties, but give an overall picture of the top uncertainties for the project. The uncertainties on the list, both positive and negative, should if possible be estimated in monetary values.

The relevant uncertainties in the focus list on the level of the master schedule should be transferred down, concretized and translated to the phase schedule. In addition new uncertainties could be identified at this planning level and added to the uncertainty register (and if they are important enough, to the focus list). Next would be to translate and operationalize the focus list to the look-ahead level. Again, the focus list should be translated, specified and presented in a way that makes it possible for larger parts of the organization to take part in the mitigation and elimination of risks and the realization of opportunities. Moving to the level of the weekly workplans, the translation process should be carried out once more. This way, a separate focus list is established at all plan level. The list should build on the corresponding list on the higher level, but re-formulating (translating) the uncertainties if needed in order to make them relevant, understandable and manageable at the level in question. Through this top down process, the entire organization could be mobilized in a better way to manage uncertainty, see Figure 1.

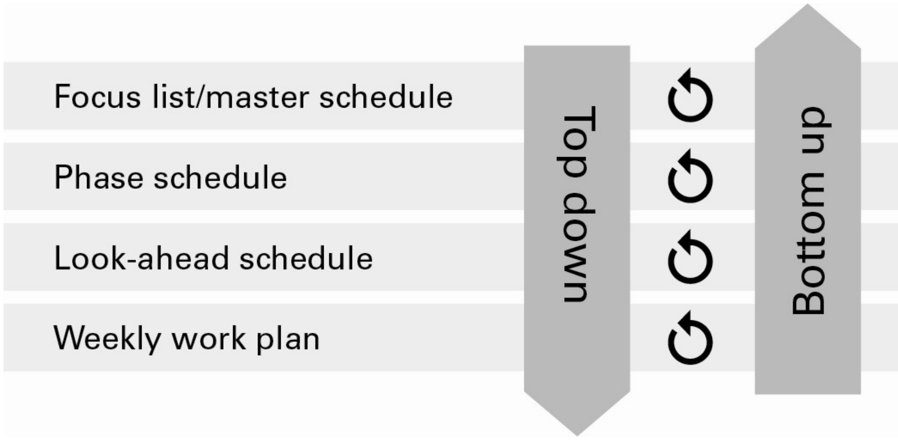

Figure 1: Top down, bottom up and local management of uncertainty integrated into LPS.

In the above-described process, there would be different ways of handling and transforming uncertainties. This also has to be seen in relation to the organizational level that owns the different plans. Some uncertainties could be handled on the level on which they are identified, and not transferred down to the underlying levels. Some uncertainties could or should be handled outside LPS. Some uncertainties are translated and transferred down to the next plan level. Other uncertainties might not be a part of the focus list, but could occur on the operational level. Some of these might be handled on the operational level, others might be necessary to handle at a higher organizational level.

As you move to the more detailed levels, uncertainty management is more about handling risks, and not so much about exploiting opportunities. The discussion is about constraints and preconditions for sound activities, and not so much about improvements. In Lean terms, the opportunity perspective could be expressed as waste reduction or increase of value. At the level of the look-ahead schedule or weekly work schedule, the focus is mainly on waste reduction. Prior to the phase schedule meeting, look-ahead meeting and the weekly work schedule meeting, the coordinator of the meeting, in preparation for the meeting, needs to translate the focus list from the level above. The owner of the meeting also needs to set the agenda for the meeting at his level. This process is illustrated in Figure 2.

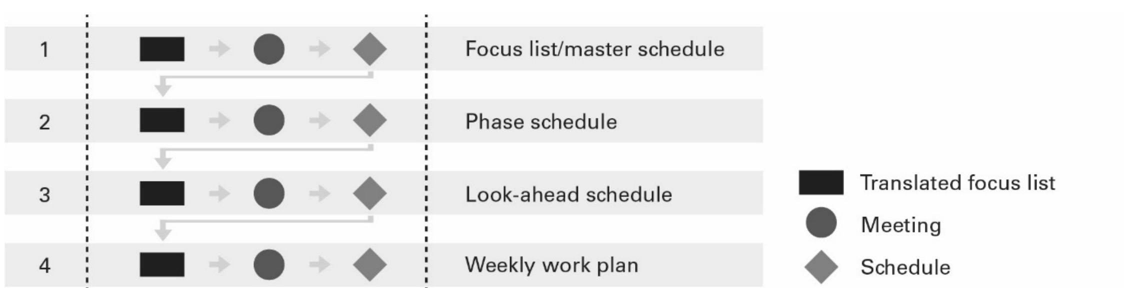

Figure 2: Top down translation of uncertainties.

One example of risk for a main contractor is procurement of sub-contractors. During the bidding process, the sub-contractor market is uncertain(price, quality, solidity, cooperation etc.). This will be reflected in the master schedule, and in the focus list from uncertainty analysis. Some risk-reducing measures could be identified at the master schedule level, such as the market survey. During phase planning, this risk could be concretized as different risks related to the sub-contractor being considered, where one risk could be the possibility of the plumber going bankrupt. There are some signs seen by the main contractor that this specific sub-contractor struggles with the economy. In the phase-plan analysis, the best case is when the sub-contractor does his work without any problems. The most likely case is that the sub-contractor survives, but there will be some problems with the schedule and low quality deliveries. The worst case scenario is bankruptcy and the need for a new sub-contractor to replace the plumber. In the look-ahead schedule meeting, this risk could be translated and reformulated to compliance and commitment to the plan, with the best case scenario that everyone do as planned, the most likely scenario that some parties do not follow the plan, and the worst case scenario that one party is far behind the plan. Risk reducing activities at this level could be that the main contractor asks for a manpower plan and a procurement plan for the main materials and deliveries from the large sub-contractors. In the look-ahead process, the main contractor can observe the sub-contractor and his manpower and logistic flow. An observation could be that the plumber starts working with the wrong activities - typically activities where he get paid by the hour - without buying materials. The risk is concretized and translated into the uncertainty register at weekly work schedule level, as lack of deliveries by sub-contractors. These might not be described by scenarios, but this is a risk to be followed up by the site manager and his internal foremen. Risk reducing measures could be that the main contractor supports the sub-contractor by providing materials directly to the supplier, and identifying buffer areas where the general contractor's own people and other sub-contractors can work while waiting for the plumber to do his work. Another measure is that the main contractor asks the plumber to be represented by his project manager in addition to the foreman in the look-ahead meeting. At the weekly work schedule meeting, real work done by the plumber is observed. Problems will be visible in PPC-measurement and actions can be taken before serious problems arrive. Depending on the level of the problem, actions can be taken in weekly work schedule meetings or raised to the look-ahead meeting. If the plumber is very close to or even goes bankrupt, risk mitigation needs to be done on the strategic organizational level, where the project manager or site manager needs to handle uncertainty, giving a reactive perspective.

DISCUSSION AND CONCLUSION

In this paper we have discussed similarities and differences between LPS and UM and proposed a way in which LPS and UM could be integrated into one system. Our proposal is to do this by translating the relevant uncertainties on the focus list of the project to the different levels of planning in LPS. Today, UM is mainly seen as an activity in the top project management group. By extending UM to all the levels of planning in LPS, we seek to engage the entire project organization in the UM process of reducing risk and exploiting opportunities.

There are however, some important issues that must be assessed and tested before concluding whether or not our proposal will work or not in practice (Klakegg et. al 2017):

- Is there a risk that loading even more tasks onto LPS may result in dilution?
- Which specific questions concerning uncertainty should be asked at the different planning levels and how should the answers be documented, communicated and followed up?
- Will the translation of the focus list to the different plan levels in LPS function in practice?
- Is LPS equally suitable for managing all types of uncertainty or are there specific types of uncertainty that demand other approaches?

We plan to test the concept in case studies in both construction companies involved in the present paper. Our ambition is to present the results from the case studies at the forthcoming IGLC conference in 2019.

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LITERATURE REVIEW ON VISUAL CONSTRUCTION PROGRESS MONITORING USING UNMANNED AERIAL VEHICLES

Juliana S. Álvares[1], and Dayana B. Costa[2]

ABSTRACT

Due to the complexity and dynamism that characterize construction activities, the execution of work packages as planned requires a systematic monitoring and control of their operations and progress. However, the most common practices for construction progress monitoring are still based on individual observations and often still rely on text-based documentation. In order to improve the collaboration and transparency of this process, studies highlight applications of visual data, such as photographs, videos, 3D and 4D models. Due to the large number of publications that address the use of visual data for construction progress monitoring, and the growing use of Unmanned Aerial Vehicles (UAVs), the objective of this work is to present a systematic literature review concerning the use of UAVs as a tool for aiding construction progress monitoring. For that purpose, a literature review was carried out for papers dated from 2008 to 2018 using Scopus database. The findings indicated that the development of progress monitoring automated systems, the use of 3D as-built point cloud models and Building Information Modeling are the most frequently discussed subjects within the papers surveyed. Also, a gap was identified regarding the lack of studies that effectively integrate the visual monitoring with the construction management systems.

KEYWORDS

Construction progress monitoring, Visual data, Unmanned Aerial Vehicles/Systems (UAVs/UASs).

INTRODUCTION

The activity of work progress monitoring and controlling is one of the fundamental tasks for an efficient management of the construction process (Del Pico, 2013).Del Pico (2013)

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defines the process of progress monitoring and controlling as a series of established steps and metrics that aim to evaluate and compare current performance against planned performance, identifying variances/deviations (differences between as-planned and as-built). Ballard (2000) states that for effective monitoring and control, negative variances should be mitigated by implementing corrective actions (necessary to keep production aligned with planning).

However, according to Teizer (2015), the most common practices for monitoring construction progress are still based on frequent individual observations and often still rely on textual documentation that require intensive and time-consuming data collection, analysis, updating, review and reporting. In order to improve this process, studies highlight the use of visual data (photographs, videos, 3D and 4D models) as solutions that simplify and optimize the progress monitoring, reducing the number of steps and parties involved and the time spent interpreting work status. Thus, this facilitates analysis of potential delays in production and improves the implementation of corrective actions (Golparvar-Fard *et al.*, 2009; Han and Golparvar-Fard, 2015; Teizer, 2015).

The use of visual technologies in construction can reduce the non-value adding, costly and time-consuming activities associated with the progress monitoring process, mainly in regards to the as-built model creation that can be visualized and automated to a certain degree (Tezel and Aziz, 2017). This visualisation and automation can decrease the number of mistakes made in those routine tasks. Thus, the outcomes related to higher visualization and process transparency reducing the amount of non-value adding activities and minimizing defects are very much associated with Lean Construction principles (Sacks *et al*., 2010).

Lin and Golparvar-Fard (2017) comment that the use of site realistic visual data and the superimposition and comparison of those data with visual representations of planning (using Building Information Modelling- BIM, for instance) corroborates for an integrated visual management of planning and control tasks and production performance in a more transparent and collaborative way. Such visual technologies have the potential to improve the information flow of communication, comprehension, evaluation and application of corrective actions of construction progress (Han *et al*., 2018; Lin and Golparvar-Fard, 2017; Tezel and Aziz, 2017).

Therefore, the most common tools used for recording visual data on construction sites include digital cameras and devices with integrated cameras, such as smart phones, tablets, terrestrial and aerial unmanned vehicles, as well as laser scanning devices (Han and Golparvar-Fard, 2017; Han *et al*., 2018). Among these, Unmanned Aerial Vehicles (UAVs) have distinguished themselves for their advantages.

The advancement of Unmanned Aerial Vehicle technology, especially related to the small UAVs and those operated by rotary propeller systems associated with attached sensors, such as high resolution digital cameras and GPS, makes it a reliable tool and easy-to-operate on construction sites for visual data recording (Han *et al*., 2018; Han and Golparvar-Fard, 2015; McCabe *et al*., 2017).By enabling fast and complete construction site images capture from different positioning, the potential of UAVs to monitor and document construction progress has been explored in recent studies(Lin *et al*., 2015; McCabe *et al*., 2017).

In view of the large number of publications that address the use of visual data for construction progress monitoring and the growinguse of UAVs for recording the work status, the main goal of this study is to present a systematic literature reviewaiming to discuss the use of UAVs to aid construction progress monitoring. This study attempts to bring to light the current state of this subject, taking into account the main recurrent or relevant specific issues discussed and how the studies address the use of UAVs specifically.

RESEARCH METHOD

This study consists of a literature review of relevant publications related to the topics addressed. The scientific database chosen was the Scopus of Elsevier, because it represents one of the most wide-ranging abstracts and citations database from publications in journals and conference proceedings. According to Elsevier (2016), Scopus covers over 5000 international journals, and papers from more than 83,000 events.

Two systematic literature reviews were carried out. The first was related to use of visual data for construction progress monitoring, and the second addressed the use of UAVs to aid construction progress monitoring. In both searches, the filter options of *Article title, Abstract, and Keywords* were used.

LITERATURE REVIEW 1: USE OF VISUAL DATA FOR CONSTRUCTION PROGRESS MONITORING

For the first literature search, the following combination of terms was used: *Construction "progress monitoring" and Visual*. In addition, only papers from 2008 onwards and the ones published in consolidated journals were considered. Figure 1 shows the step-by-step structure adopted for literaturesearch1 on Scopus database.

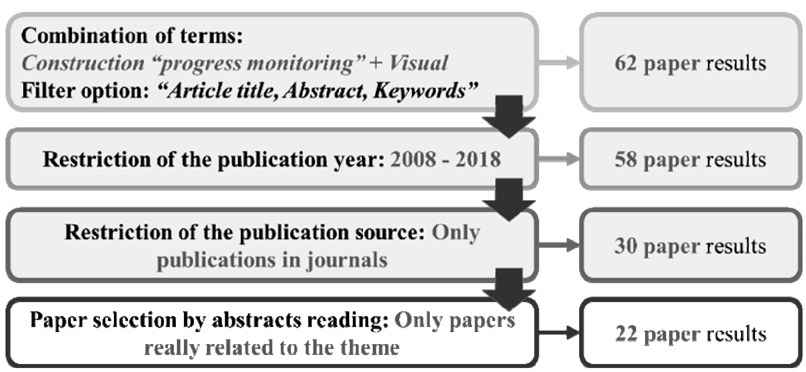


Figure 1:Step-by-step of the literature search 1

From the 22 papers selected, the following analyses were carried out:

- Quantitative distributions: number of papers published per journal and number of papers per year;
- Identification of specific frequent or relevant issues classified according to: (a) visual data recording technologies, (b) other associated technologies, and (c) other topics, including construction typology, integration of visual technologies with

construction management systems, the analysis of the costs involved in adopting the technologies and the literature review articles.

LITERATURE REVIEW 2: USE OF UAVS TO AID PROGRESS MONITORING

For this search, the following combination of terms was used: *Construction "progress monitoring" and UAV or UAS*. Due to the relatively small number of papers initially found (13), the restrictions considered in the previous search (year and journal) were not performed. Only a paper selection was done by general reading, trying to remove works in which the UAV was only cited, but its use or application were not presented and discussed. The structure, with the steps adopted for this literature search, is presented in Figure 2.

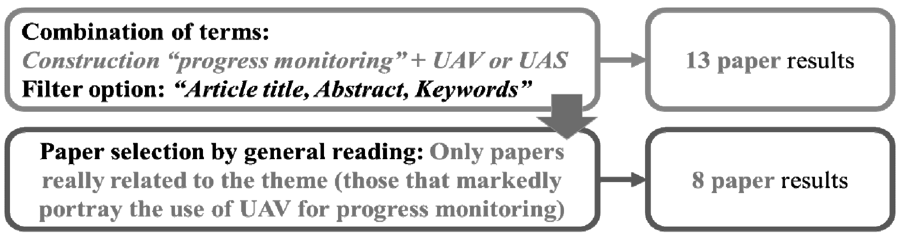


Figure 2:Step-by-step of the literature search 2

The same analyses previously described were performed for the eight selected papers. However, in addition to the identification, the discussions on how the studies deal with the main frequent or relevant issues and how the papers address the specific use of UAVs were also developed.

RESULTS AND DISCUSSION

This section presents the main results obtained with both the literature reviews performed.

USE OF VISUAL DATA FOR CONSTRUCTION PROGRESS MONITORING

As shown in Table1, among the 22 papers selected, the journal with the largest amount was *Automation in Construction*, with a total of nine papers (40.9% of the sample), followed by the *Journal of Computing in Civil Engineering* with five papers (22.7%), *Journal of Information Technology in Construction* with two papers (9.1%), and six other journals, all with one paper each (4.5%each).

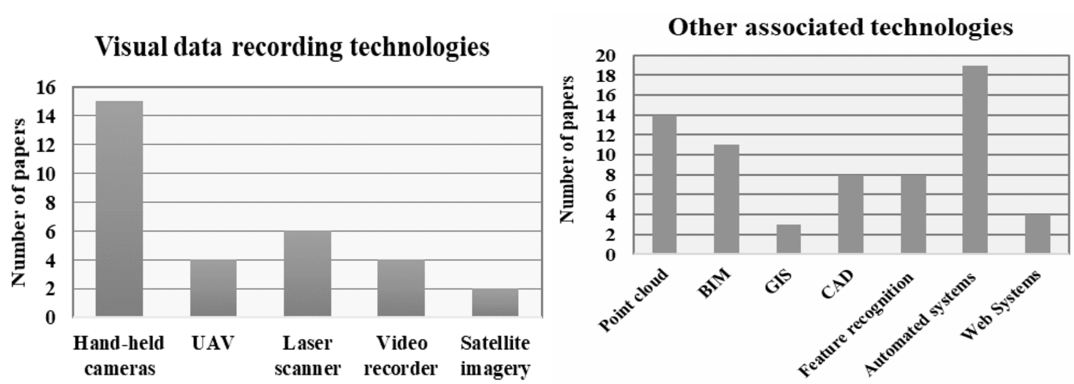
The great majority of these journals is focused on subjects related to the use of technologies in construction. The journal with the largest number of papers has the second largest Impact Factor of the sample (2.919), which is a very significant when compared to the values of the journals in this knowledge area. Thus, the use of visual data to progress monitoring seems to have a considerable impact regarding the technologies applied to construction.

Table 1: Distribution of the number of papers per year and sources of publication (Literature review 1)

Paper Source	**Impact Factor**	**Distribution of papers per year (20__)**											**Total**
		08	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	
Automation in Construction	2.919			1	2	1	1		1	1	1	1	**9**
Journal of Computing in Civil Engineering	2.310		1				2		1	1			**5**
Journal of Information Technology in Construction	-		1						1				**2**
ACM Transactions on Graphics	4.088							1					**1**
Advanced Engineering Informatics	2.680								1				**1**
Journal of Management in Engineering	2.011									1			**1**
Journal of Construction Engineering and Management	1.735											1	**1**
Photo grammetrie Fernerkundung Geo information	0.852										1		**1**
Canadian Journal of Civil Engineering	0.591	1											**1**
Total		**1**	**2**	**1**	**2**	**1**	**3**	**1**	**4**	**3**	**2**	**2**	**22**

Regarding the distribution over the last years of publications (Table 1), there is a certain variation related to the quantity of papers from year to year. The higher concentration occurred between 2013 and 2016 (despite the decrease in 2014), with the peak of four papers in 2015. Another highlight is the presence of two papers already in 2018, in which such data was measured at the beginning of March 2018.

The most frequent or relevant subjects among the papers identified in this literature review were divided into three main categories: (a) visual data recording technologies, (b) other associated technologies, and (c) other topics addressed. The frequencies for the items considered in each of these categories are presented in the graphs of Figure 3.



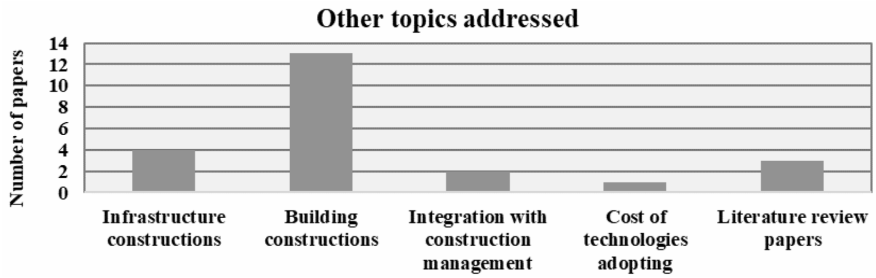


Figure 3: Frequencies of the most frequent or relevant subjects in the 22 papers, according to three main categories

For the category of technologies for visual data recording in sites (Figure 3), a major highlight is the acquisition of images by hand-held digital cameras, presented in 15 of the 22 papers, since the maximum obtained for another technology type was six papers (Laser scanner). This represents a predominance of digital photographs as the main type of visual data to record work status used for progress monitoring.

Regarding other types of associated technologies (Figure 3), the use of automated systems is noteworthy, appearing in 19 of the 22 papers. Examples of these types of systems include automated image processing techniques, and computer systems for progress monitoring by automating the superimposition of visual as-built and as-planed representations (using 4D BIM, for example). In addition, there is a relative frequency of 3D as-built by point cloud technologies (present in 14 of the 22 papers) and as-planned BIM (in 11 of the 22 papers), often presented in a comparative approach, as a way of identifying deviations between what was planned and constructed.

Among the papers selected, the predominance of the use of visual technologies for building construction monitoring (in 13 papers), compared to infrastructure construction (in only four papers) (Figure 3) was noted. The topic concerned with the integration of visual progress monitoring to the construction management system presented very low frequency among the papers and was addressed directly by only two of the 22 (Figure 3). However, it can be considered as an important and relevant topic when analysing this subject from a managerial point of view, since progress monitoring is an important activity in production control, which must be part of the site management routine as well as being systematic. Moreover, these two papers were written practically by the same authors, who present an identical approach (the same idea of managerial workflow) in both papers.

USE OF UAVS TO AIDPROGRESS MONITORING

Due to the reduced number of publications in journals that specifically addressed the use of UAVs for visual data collection for construction progress monitoring (only four papers),this second literature search also considered the publications in conferences proceedings, representing a still relatively small amount of studies. Table 2 shows the distribution of the eight papers selected according to the source and year of publication.

Table 2: Distribution of the number of papers per year and source of publication (Literature review 2)

Paper Source	**Impact Factor**	**Distribution of papers per year**				**Total**
		2015	**2016**	**2017**	**2018**	
Automation in Construction	2.919	-	-	1	-	1
Journal of Management in Engineering	2.011	-	1	-	-	1
Journal of Construction Engineering and Management	1.735	-	-	-	1	1
Photogrammetrie Fernerkundung Geoinformation	0.852	-	-	1	-	1
Conference proceedings	-	1	1	2	-	4
Total		1	2	4	1	8

According to the Table 2data, the publications have been found since 2015, with an apparent increase over time (one paper from 2015, two from 2016, four from 2017 and another one already from 2018).These results might show a relatively recent, but growing, state of research that addresses UAV as a visual data capture tool for progress monitoring. Thus, consequently, this topic probably still has fields to be explored by future works.

Table 3presents the main recurrent or relevant specific subjects addressed by the eight papers, as well as how these studies approach such issues, following the classification of the three major categories and organization of items similar to those presented previously.

Other Technologies for Recording Visual Data

Other visual data recording technologies include digital cameras for image recording, video recording and laser scanning for point clouds generation (Table 3). Han *et al.* (2018), Tuttas *et al.* (2017) and Han and Golparvar-Fard (2017) present the hand-held camera as a source for images used in image-based point cloud model generation, as a representation of the as-built status. Tuttas *et al.* (2017) make a comparison between UAVs and hand-held cameras, showing that UAVs were more successful in providing images from different angles and heights, allowing for complete coverage of the site and guaranteeing great overlap between images (fundamental criterion for good quality photogrammetric processing).

Regarding video recording, Han and Golparvar-Fard (2017) commented that this is also a good alternative for construction monitoring purposes, since it allows for the visualization of work in progress. However, the use of the laser scanners, although more expensive, with more limited mobility and positioning compared to image registration, allows for the generation of point clouds with less noise and generally denser (Han *et al*., 2018; Tuttas *et al*., 2017; Han and Golparvar-Fard, 2017).

Table 3: Most frequent or relevant subjects covered by the papers

Most frequent or relevant subjects in the 8 selected papers			Subjects of each paper								Total
			A1	A2	A3	A4	A5	A6	A7	A8	
Other technologies for recording visual data		Images by hand-held digital cameras	x	x			x				3
		Laser scanner	x	x			x				3
		Video recorder					x	x			2
		Satellite imagery									0
Other associated technologies		Point cloud (digital photogrammetry)	x	x	x		x		x	x	6
		Building Information Modeling (BIM)	x	x	x	x	x			x	6
		Geographic Information System (GIS)									0
		Computer-Aided Design (CAD)									0
		Feature/pattern recognition techniques	x				x		x	x	4
		Automated systems technologies	x	x	x	x	x		x	x	7
		Web Systems				x	x				2
Other themes	Typology	Building constructions	x	x	x		x	x		x	6
		Infrastructure constructions									0
	Integration with construction management		x				x				2
	Cost of technologies adopting							x			1
	Literature review papers					x	x				2

Most discussed subjects; Less discussed subjects; Subjects not covered

A1: Han *et al.* (2018); **A2:** Tuttas *et al.*(2017); **A3:** Qu *et al.* (2017); **A4:** McCabe *et al.* (2017); **A5:** Han and Golparvar-Fard (2017); **A6:** Irizarry e Costa (2016); **A7:** Fang *et al.*(2016); **A8:** Lin *et al.* (2015).

Other Associated Technologies

For this category, as in the first search, automated systems technologies were more prominent addressed(in seven of the eight papers – Table 3), which include: systems for UAV automatic control (McCabe *et al*., 2017; Han and Golparvar-Fard, 2017; Lin *et al*., 2015);automated photogrammetric processing for point cloud generation(Structure-from-Motion - SfM) (Han *et al*., 2018; Tuttas *et al*., 2017; Qu *et al*., 2017; Han and Golparvar-Fard, 2017; Fang *et al*., 2016; Lin *et al*., 2015);automatic object detection by identifying the BIM elements' geometry present in the point cloud model(Han and Golparvar-Fard, 2017),and the use of this for point cloud automatic filtering (Han *et al*., 2018); automated appearance-based material classification technique (Han *et al*., 2018; Lin *et al*., 2015); and semiautomatic moving object detection (Fang *et al*., 2016).

Technologies such as point cloud by digital photogrammetry and Building Information Modelling (BIM) are also addressed in most papers (both in six of eight papers). In the works that address BIM, this is treated as the main visual representation of as-planned (4D BIM), used as a comparative basis for visual evaluation and communication of deviations from planed construction progress.

Other Themes

The most important construction typology among the studies (presented in case studies or field tests) are building construction (in six of the eight papers – Table 3), and no study that dealt with infrastructure works was observed.

One of the most relevant subjects among those addressed by the papers was the systematic integration of the UAV-supported visual monitoring systems with construction management. However, only two papers dealt directly with this approach, and were the same studies mentioned in the previous literature review.

In their study, Han and Golparvar-Fard (2017) point out that the construction sites recording by images and videos, along with as-planned4D BIM, provide good opportunities for detection, analysis and communication of construction performance among project teams, and can thus serve as support to daily execution activities and short-term planning. Therefore, the authors present a continuous workflow cycle between short-term planning and daily work control based on visual data, as shown in Figure 4.

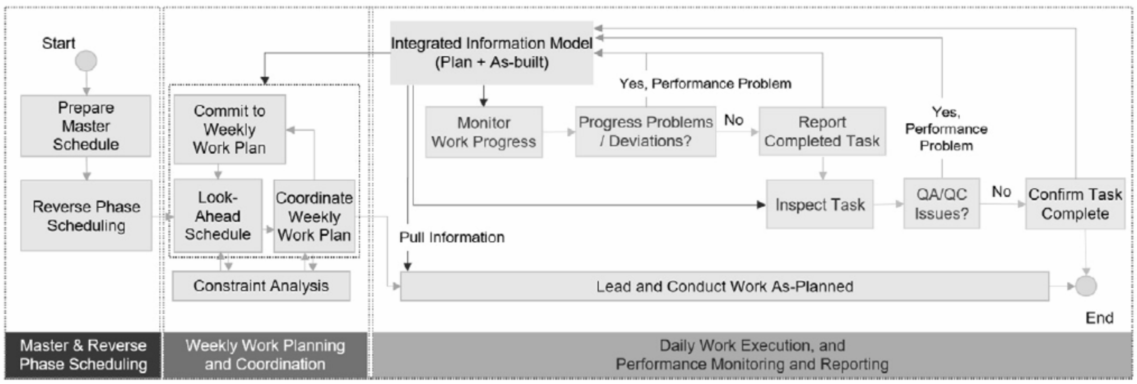


Figure4: Example workflow of the integration of visual data into the construction management system (Figure 1 in Han and Golparvar-Fard, 2017 and in Han *et al*., 2018)

The other study which also deals with this topic (Han *et al*., 2018), presents the same workflow as Han and Golparvar-Fard (2017) (Figure 4), with direct citation of this work. Han *et al*. (2018) emphasize that these visual systems for progress monitoring, according to the workflow presented, allow for more effective production control by almost real-time automated evaluations of the work on site, aiding project teams in maintaining a continuous flow of information and production.

Another relevant aspect was the issue of the costs involved in adopting the technology. Irizarry and Costa (2016) comment that these costs include the necessary authorizations for UAV operation (depending on the country's regulations), the equipment itself, operators' training or outsourced service contracting to operate the UAV, as well as insurance.

The UAV as a tool for Construction Progress Monitoring

The specific approach of the UAV technology for progress monitoring varied slightly among the eight selected papers. Five studies (Han *et al*., 2018; Tuttas *et al*., 2017; Qu*et al*., 2017; Han and Golparvar-Fard, 2017; Lin*et al*., 2015) approach the UAV as a tool for continuous acquisition of site images, used for point cloud model generation, that visually represent the construction evolution (different phases and changes). In all of these five papers, the point cloud models (as-built representation) are used in comparison with 4D

BIM (as-planed work evolution representation), aiming to analyse the construction performance, identifying progress deviations.

For the other three papers, Fang *et al.* (2016) present UAVs as an alternative for recording images used in the continuous 3D tracking of the construction elements(e.g. workers, equipment, materials), for applications that include progress monitoring. Irizarry and Costa (2016) also identify progress monitoring as one of the potential managerial applications for UAVs' visual assets of the site (photos and videos). McCabe *et al*. (2017) provide a literature review of the potential of UAVs for internal building monitoring.

In general, among the eight papers, the main advantages of using UAVs are their ability to provide high-quality images, recorded from different angles and heights, covering the entire construction site in a quick, economical, and efficient way. However, some limitations are also considered, such as safety issues related to care of tall structures proximity, potential safety hazards to workers for possible distractions, flight limitations imposed by regulations, and the limited flight time due to battery capacity.

CONCLUSIONS

This study presented a systematic literature review and general analysis of scientific papers that discuss the use of the Unmanned Aerial Vehicle (UAV) as a tool to support construction progress monitoring. As a principal contribution, this paper sought to present the current state of the topic, taking into account the main recurrent specific issues among the papers, or those that still need to be explored, as well as to discuss how the papers address the issue of the use of UAVs specifically.

The literature review performed indicates the use and principally the development of automated system technologies as the subject most overly addressed in the studies related to visual progress monitoring. These systems are often presented as being able to improve the progress control process, making it faster, more automated and efficient. In addition, the use of point cloud models for as-built 3D representation and BIM for as-planned are presented as the main visual technologies to aid construction progress monitoring.

However, although the studies searched highlight the potential of visual technologies for progress monitoring improvement, including some of these studies which even mentioned the improvement of production aspects associated to Lean principles, such as increased transparency and collaboration, and non-value adding activities reduction, a gap was identified regarding the lack of studies that effectively integrate the visual monitoring with the construction management systems. Only two papers directly address this subject, showing that there is still low emphasis and frequency in the literature about this topic.

Thus, important issues associated with such a subject still need to be explored more in the studies that address visual progress monitoring, especially with the support of UAVs. Among these, there is a need to propose, apply and evaluate an integrated management system of collecting, processing, analysing and decision making in terms of deviations in construction progress, and also associated with the implementation of corrective actions. It is also necessary to evaluate the impact of this new flow of information within the construction management system, considering aspects associated with Lean principals, such as improvement of visual management, increased communication and collaboration in construction progress management, better compliance with the goals set in the planning and deadlines, increased process transparency, non-value adding activities reduction and maintenance of continuous flow of production.

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EMPIRICAL STUDY ON THE INFLUENCE OF PROCUREMENT METHODS ON LAST PLANNER® SYSTEM IMPLEMENTATION

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ABSTRACT

Previous studies have examined various factors that influence the implementation of the Last Planner System (LPS) in construction projects. However, there is limited documented evidence on the influence of procurement methods on the implementation of the LPS. The aim of this study, therefore; is to understand the influence of some selected procurement methods on the implementation of the LPS using case study approach. Three in-depth case studies were conducted on building and highways projects in the UK. The projects were managed with the LPS principles with dissimilar procurement methods. In addition to document analysis and physical observation, 28 in-depth-interviews were conducted.

The investigation shows that the prevailing traditional mindset exhibited by the designers in the traditional design bid build (DBB) influences the quality of promises and commitments that could be made during the lookahead planning. From the study, it seems no single procurement method is a sure way to the full application of the LPS process on a project. The study observes that irrespective of the procurement route used, a mindset change towards collaboration among the different stakeholders on the project is fundamental to successful LPS implementation. For instance, on projects where DBB was used and the subcontractors were in framework agreement, the LPS implementation worked well among the subcontractors. The study recommends that the procurement approach to be used on LPS projects should not be too firm, but lithe enough to integrate collaborative working among the different stakeholders on the project for a smooth workflow.

KEYWORDS

Lean construction, Last Planner System, procurement methods, collaboration, make ready

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INTRODUCTION

The wrong choice of procurement method has been identified among the factors that contribute to construction project failures (Love et al. 1998). Love et al. (1998) argued that procurement method not only drives the project in term of time, cost, and quality, but also, it contributes to the relationship that develops among the stakeholders on the project. This shows the vital position procurement method occupies in the delivery of a successful project. In this study, procurement is seen as the approached used in the delivery of the entire project right from design to handover. Also, in recent time the application of lean construction techniques, for example, the Last Planner System (LPS) to improve the prevailing approach to construction project management has been suggested by key stakeholders in the industry (Egan, 1998).

The LPS is an approach for managing project production in the construction industry(Ballard and Howell, 1998). Studies have shown that the LPS has been implemented on construction projects in different parts of the world; Middle East, North America, Europe, Asia, Africa, and South America, among others (Daniel et al, 2015; Fernandez-Solis et al. 2012). This shows there is an increase in the rate of implementation of the LPS in construction projects across the world. However, it has also been observed that contextual factors (such as procurement method, contract and culture) within the project environment could influence LPS implementation on a construction project (Daniel, 2017; Heidemann and Gehbauer 2010). On the contrary, there is limited documented evidence to support this assertion. In voicing their concern on this, Fuemana et al. (2013) pointed out that adequate attention has not been given to the influence of procurement methods on the implementation of the LPS. Additionally, Vilasini et al. (2014) argued that procurement process should be the starting point for the integration of lean techniques into the construction industry.

Procurement methods play a central role in the delivery of construction projects. In addition to the increasing use of the LPS in the delivery of construction projects, understanding the relationship between the former and later is essential. The goal of this investigation, therefore; is to explore the influence of some selected procurement methods on the application of the LPS in construction project. The key question is; *What is the influence of procurement methods on the implementation of the LPS in construction projects?* Providing an answer to this question would expose and offer a new insight into how procurement methods(traditional procurement system and design and build) influence the implementation of LPS in construction projects. This contributes to further implementation of the LPS principles in projects.

LITERATURE REVIEW

LAST PLANNER SYSTEM

The LPS is an approach developed for managing project-based production system for practitioners in the construction industry (Ballard and Howell, 1998). The "Last Planner" refers to the frontline supervisors (Ballard and Tommelein, 2016). The LPS is based on five key elements; (1) the master planning or milestone planning, (2) collaborative programming/phase planning, (3) the Make-ready planning, (4) Weekly work plan and (5)

Measurement and learning. These elements are described extensively in Ballard and Tommelein, 2016). Through the application of these elements, the LPS supports the development of a collaborative working relationship and on time delivery of construction projects. However, the LPS has been criticised because the programme used in developing the phase planning is taken from the traditional programme developed with a Gantt chart (Koskela and Stratton, 2010). Nevertheless, the LPS process empowers the stakeholders doing the work to contribute to the phase planning process so as to develop a reliable plan which makes it different from the traditional approach to project management.

LAST PLANNER SYSTEM IMPLEMENTATION AND PROCUREMENT METHODS

There is compelling evidence that the implementation of the LPS is growing (Daniel et al, 2015; Fernandez-Solis et al. 2012).But, at the same time, lean construction scholars have also identified barriers to its implementation in a construction project. Some of these barriers are; resistance to change and human attitude, short-term vision, use of incompatible procurement methods and focus on cost, culture and structural issues within organisations, among others (Fernandez-Solis, et al. 2012; Fuemana, et al.2013). The identification of incompatible procurement methods among the current challenges to LPS implementation cannot be discounted because of the central role procurement methods play in the delivery of construction projects. The procurement method is seen as a major factor that contributes to client satisfaction and the achievement of the overall project goal (CIOB, 2010; Love et al, 1998). However, the choice of procurement method to be used on a project could be tricky and complex as it is usually influenced by external factors, client characteristics and project characteristics (Love et al. 1998).

Lean construction researchers, on the other hand, have always maintained that lean construction principles and techniques are best implemented under a relational contractual framework (Vilasini et al. 2014; Mathews and Howell, 2005). However, in practice, most construction projects are procured using other methods and arrangements such as a traditional design, bid, build; design and build; management contracting; and construction management; among others (especially in the UK and other Commonwealth countries). While the design and build procurement method allows for some integration between design and construction the traditional design, bid, build procurement system (DBB) method does not (CIOB, 2010). Previous studies have speculated that procurement methods could influence implementation of lean techniques in construction projects (Fuemena, et al. 2013; Matthews and Howell, 2005). There is limited documented evidence to support this assertion with regard to specific procurement methods, such as DBB and design and build procurement methods. In the light of this, the current investigation seeks to understand the influence of DBB and design & build procurement methods on LPS implementation using a case study approach.

RESEARCH METHOD

A case study approach was adopted in the current investigation. Case study methodology is usually used when a study seek to examine a phenomenon in a real life environment (Yin, 2014). Additionally, lean construction scholars have also argued that the case study approach is appropriate for investigating the LPS because of its practical nature (Daniel et al, 2015). Their review of over 50 IGLC published studies on LPS found that the case study approach is the most used research method in LPS related studies. In this study, the case study strategy was applied as it allows the investigation to understand how procurement methods influence the implementation of the LPS in real life situation (the project and the context of the physical environment where the LPS is being implemented).

Different techniques were used to collect data from multiple case studies. These techniques include semi-structured interviews, document analysis, and unstructured observation to support triangulation. Unstructured observation was used as it allows the study collect more relevant evidence. Contract documents, construction programme and charts displayed on boards were analysed. Yin, (2014) observes that triangulating data through the use of multiple techniques and methods make the findings of a study robust. However, Yin, (2014) cautions that the study should be designed to ensure all the required evidence is captured. In view of this, three case study projects managed with the LPS and procured with different procurement methods were selected. This was done to enable the study explore the influence of the procurement method on the implementation of the LPS. The case studies were conducted concurrently over a period of 12 months providing an opportunity to collect real world evidence. For the purpose of confidentiality, the case studies are described as CSP01, CSP02 and CSP03 (where C= case, S= study P=project).

Data collection started with observations, followed by document analysis and then semi-structured interview. This enabled further clarification on findings from observation and document analysis. Also, the first author attended monthly Look ahead production planning meetings as an observer. The following research participants were interviewed; senior managers (SM), middle managers (MM), operational managers (OP), and subcontractors (SC). Four of the SM and three of the MM interviewed are from the client organisation. The interview instrument consists of two sections; the background of the respondents and questions on the influence of procurement method on LPS implementation on the particular project. A total of 28 research participants were interviewed, which include; SM = 9, MM = 6, OP = 6, and SC = 7.The respondents were selected because of their extensive experience in the use of LPS. The transcribed interviews were substantiated with results from document analysis and physical observation. The result of the qualitative data gleaned are presented and discussed in the subsequent section. Specifically the impact of DBB and D&B procurement methods on the quality of promising and the level of commitments during the make ready and look ahead planning are discussed.

PROJECT ATTRIBUTES

Table 1 shows the attributes of the case study projects investigated. It can be seen that dissimilar procurement methods were used on the projects providing a comparison of the influence of the procurement method selected on LPS implementation. Additionally, the project durations are all long enough to capture the evidence required to address the research questions. Most of the subcontractors on all the projects are in a framework agreement with the main contractor. The case studies were done concurrently over a period exceeding 12 months. Twenty-eight semi-structured interviews were conducted. The respondents interviewed have 5-20 years' experience in the construction industry and 3-10 years in the use of LPS. They all claim to have been involved in more than one project where the LPS was used.

Table 1: Project Attributes

Project Attributes	CSP01	CSP02	CSP03
Nature of project	Highways and Infrastructure	Highways and Infrastructure	Building construction project
Proposed project duration	30 months	24 months	30 months
Procurement Method	D&B	Traditional DBB	D&B

RESEARCH METHOD

INFLUENCE OF PROCUREMENT METHODS

Influence of DDB on Make-Ready and Look ahead Plan and the Quality of Promising

The investigation shows that build ability issues occurred more on CSP02 where the traditional DBB was used. A research participant stated: "*The barrier here is that the design is not been met. The drawing is not working as expected. Some of the information used in the design was wrong and also client changes his decision at some point***[CSP02, Project Manager]".** This was further echoed by the Construction Manager working for the main contractor: "*The biggest problem we have got is to have a client who does not know what he wants, the client keeps on introducing new things and also the original design is not working* **[CSP02 Construction Manager]".**This reveals the impact of non-involvement of the site team in the design process enshrined in traditional DBB procurement. The consequence of this practice on LPS implementation became evident during the lookahead and make-ready planning. For instance, it was observed on CSP02 that during the lookahead and make-ready planning, identified constraints could not be fully removed or the strategies for removal could not be achieved especially when they were design related. This was because the design team members did not attend the LPS meetings held on the project due to the traditional DBB method used on the project effectively separating designers and constructors.

The programme manager for the main contractor expressed his frustration by saying: "*Some of the designers are based on site, but they will never come to LPS meeting because they were engaged by the client* **[CSP02 Programme manager]".**It is important to note here that it was the main contractor that was leading the LPS implementation on the project. The impact of this was minimised to some extent on the project, as it was observed that the project manager later introduced an ad-hoc meeting with the design team for design-related constraints identified from the lookahead and make-ready planning. The ad-hoc meeting with the design team was made possible because of the client's support for the use of LPS on the project. Again this shows that, although the project was procured with DBB, if the owner is committed to LPS, the design team could still be involved in a way. Nevertheless, the actions of the design team still limited real-time collaborative decision making and reliable promising framework advocated in the LPS. Last Planner System researchers and practitioners have argued that the success of LPS is hinged on having the right people with the required knowledge and capacity to make a decision in the planning room (Malcomber and Howell, 2003; Ballard and Howell, 1998). This means not having the right people in the room limits the quality of promise and commitment that could be made at the production planning meeting. The level of commitment of the design team in the LPS implementation was not full because it was not included in their original contract. According to Daniel (2017) including the use of the LPS in the contract clause encourages all the stakeholders on the project to be committed to the LPS implementation.

Influence of Nominated Subcontractor Traditional Mindset on Quality of Promising

It was observed on CSP02 that the nominated subcontractor appointed by the client was reluctant to participate in the LPS meetings. One of the construction manager interviewed on CSP02 stated that: "*There are some subcontractors employed directly by the client whom we do not pay but we manage them, they tend to be stuck in the old ways and not motivated to participate in the LPS meetings* **[Construction manager]".** This attitude influenced the effectiveness of the production planning and control meetings held on CSP02. Most times, further arrangements had to be made with the nominated subcontractor (NSC) outside the production planning meetings to arrive at a reliable plan. Such arrangement is not without its own consequences especially with regard to the quality of promise that could be made in real time and double handling of information and communication across the team.

While it could be argued that the traditional DBB used on CSP02 could have created a platform for this behaviour flourish; the root cause could be traced to the traditional mindset exhibited by the NSC. Ballard and Howell, (2005) argued that even when a procurement method that could be said to be collaborative is used on a project and the traditional mindset still dominates, collaboration would not happen among the people on the project. This means the traditional DBB is not the only problem. Additionally, the behaviour exemplified by the NSC shows the challenge of integrating two organisations with different organisational cultures in LPS implementation. Liker and Morgan, (2006) observe that alignment of organisational culture is essential in the implementation of lean techniques across organisations.

Influence of traditional DBB on the Level of Collaboration and Communication among the Project Team

The investigation found that long response time from the designers influenced the LPS implementation on CSP02 where traditional DBB was used. Some of the respondents stated that: *"The designers are employed by the client and it does affect the Last Planer System, we only have liaison meetings with the designer rather than LPS meetings to try and focus on the priority, but it does not help. The best way to control somebody is when* *you are paying them. If you are paying somebody, they listen more than when someone else is paying them. It is not as it used to be initially, they try to listen to us a bit. The designers have little appreciation of the commercial implications of what they do and they don't do. It is very difficult but we have to manage it* **[CSP02SC01, PM]".**

This statement reveals the influence of the procurement method on LPS implementation. For instance, the view that designers seem to care less about the financial consequence of their action to the project implies that the design team were only working to achieve their individual goals and not the overall goals on the project. Pasquire et al, (2015) argued that key players in the construction industry are safeguarding their individualistic interest on the project. Similarly, it has been observed that vested commercial interest among professionals has taken away the energy required to drive construction projects to successful completion (Naoum, 2001). The impact of these on LPS implementation is that smooth workflow is hindered as a result of the poor communication and collaboration among them. Pasquire, (2012) asserts that for a smooth workflow in the production system, various stakeholders on the project need to develop a common understanding of the project goal and process.

Furthermore, document analysis and observation on CSP02 revealed that the design team required nine days to respond to a request for information. However, to minimise the impact of this, the nine days waiting period was factored into the lookahead and the make-ready plan on CSP02 which was beneficial. Nevertheless, this still has some impact on the quality of promise and commitment that could be made by other stakeholders in real time in the LPS meetings as bad news early provides better opportunities for problem solving.

Influence of D&B Procurement System on Look ahead and Make-Ready Planning

On CSP01, the research participants interviewed believed that the use of design and build supported the implementation of the LPS on the project. On CSP01, members of the design team were present at the different Last Planner meetings where their input was required. For instance, during one of the lookahead and make-ready planning sessions, the design team made commitments on the delivery of design information for specific work sections in the 6-week lookahead window. The benefit observed in this practice was the clear visual view of the effect of the non-availability of such information on other people's work to the members of the design team. This presents a system view rather than a functional view where work is done in isolation which limits smooth workflow. The system view according to Koskela and Howell, (2002), supports the integration of both design and construction. Some of the respondents stated that: *"Using design and build with early contractor involvement, all the designs are reviewed by the construction team to get things out early. We get value out of the process since we make all the decisions together* **[CSP01SM03, Construction Manager]".** It was also observed that during the lookahead and make-ready planning, the project team was able to identify constraints and make a commitment for their removal in real time. Thus, contributing to the quality of promises made at the production planning sessions.

This implies the use of the design and build on CSP01 supports LPS on the project. This finding aligns with a previous study in New Zealand that shows that collaborative procurement such as design and build could support the implementation of the LPS on a construction project (Fuemana et al. 2013). Additionally, Vilasini et al, (2014) found that procurement methods with some collaborative undertone are the best to adopt in the implementation of lean construction techniques.

However, on CSP03 when a respondent was asked what could have happen if other procurement methods such as DBB were used on this project. The respondent argued that the implementation of the LPS on the project would still work irrespective of the procurement method used. Here are some of their comments:

"I am not sure if things could have worked differently if another procurement route is used. To me, irrespective of how the job is procured we can still involve the people in the LPS process and still have the same outcome. However, if the subcontractors are involved at the tender stage the construction programme will be better" **[CSP03SM, Senior Planner]***"The procurement route helps in the implementation. On this project, we are using standard JCT and D&B contract which actively support collaboration between the subcontractors. It is opposed to NEC contract which is more programme focused and rigid, but with this contract, we rather pull together"***[Subcontractor's Project Manager].**

It was also observed on CSP01 where D&B was used that the team on the north and central section collaborated more which support the implementation of the LPS. However, on the south section of the same project there was in fighting between the construction manager and other members of the team which affected the success of the LPS implementation on the south section. For instance, document analysis showed that while the average PPC for north and central section was between 80-90% while that of the south stood at 50-55%. It is worth to note that CSP01 was divided into three sections and each was independently managed by the LPS. The above statements and observations indicate that the success of the LPS implementation should not be hingedon the collaborative procurement only. This aligned with the position of Ballard and Howell, (2005) where they argued that collaborative procurement method with traditional mindset would not support genuine collaboration. However there are potentials for collaborative procurement to create the platform for collaboration to thrive.

Influence of Collaborative Procurement Strategies on LPS Implementation

The investigation shows that the use of a framework agreement supports the implementation of LPS on the projects. Some of the respondents stated that: *"We are in a framework agreement, we have been working with the M&E, the building envelops subcontractor. We have worked together on four different project which is a benefit to us all on this project. We passed on the lesson learned from the previous projects to this which makes us more successful"***[CSP03; Subcontractor's, Contract Manager]". ***"Each subcontractor on this project has worked together previously, thus, we understand each other's capability and we know we are all working to achieve the same goal"***[CSP01, Subcontractor's Project Manager]**

The long-term relationship between the team supports effective conversation during the LPS meetings on the project on CSP03. Further document analysis on CSP02 reveals that even though traditional DBB was the procurement method used, some of the subcontractors were in a framework agreement and hadworked together on a project where the LPS was used in the past. One of the respondents stated that: "*we have worked with some of these subcontractors in our previous project using LPS, it helps* ***[CSP02 subcontractor]".***Again, all these show that collaborative procurement practice supports the development of a good working relationship with the team which could enhance LPS implementation.

CONCLUSIONS

The aim of this study is to understand the influence of procurement methods (design and build and traditional design, bid, build procurement system) on LPS implementation. The study found that procurement methods have an impact on the application of the Last Planner System. The investigation shows that the prevailing traditional mindset exhibited by the designer in the traditional DBB influences the quality of promises and commitments that could be made during the lookahead and make-ready planning, however the impact of these was minimised because of the client's support for LPS implementation. The study found that, it seems no single procurement method is a sure way to the full application of the LPS process on a project. The study observes that irrespective of the procurement route used, a mindset change towards collaboration among the different stakeholders on the project is fundamental to successful LPS implementation. For instance on project where DBB was used and the subcontractors were in framework agreement the LPS implementation worked well among the subcontractors.

The study recommends that the procurement approach to be used on LPS project should not be too static, but agile enough to integrate collaborative working among the different stakeholders on the project for a smooth workflow. Additionally, the study suggests that the LPS should be included in the contract clause in DBB procurement method to encourage full commitment of all stakeholders on the project especially the design team. This study exposes how the traditional DBB and the D&B procurement methods influenced the implementation of the LPS in a real life project context which provides some empirical evidence for future applications of project production planning principles in the construction industry. This would benefit both lean construction practitioners and scholars. However, the finding is limited to few procurement methods. Future study should explore more procurement method in an international context and examine contract clauses in more detail.

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CONTINUOUS IMPROVEMENT CELLS IN THE HIGHWAYS SECTOR

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ABSTRACT

In line with its performance improvement and Lean Construction agenda, the highways supply chain in the UK has commenced many Continuous Improvement (CI) cells in recent years. The CI cell is a small-group work coordination and improvement technique that is frequently used in many industries as part of their lean transformations. The technique has also its links to some key lean concepts and practices like continuous improvement (*kaizen*), Visual Management and *hoshinkanri* policy deployment.

This paper presents a summary of a detailed research aiming to understand the execution of the CI cells in the highways supply chain in the UK with their associated benefits and challenges through a study of 12 CI cells at the main client organisation. Alongside a set of benefits and challenges, the current CI cell execution mechanism and some suggestions to improve the current practice were also presented in the paper.

KEYWORDS

Continuous improvement, Lean construction, Visual Management, HoshinKanri, highways.

INTRODUCTION

With ambitious performance targets mandated by the government and the main public client, the highways sector in the UK has been under pressure to improve its operations. As one of the resorts for this improvement, the sector has been actively engaged in Lean Construction (LC) since the late 2000s. Alongside the Last Planner System and Visual Management, utilising Continuous Improvement (CI) cells has been a subject of interest for the sector since then. Following the first CI cells in the supply chain, which were started at some construction service providers around 2009, the main client also initiated

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CI cells among its internal teams in 2014. The CI cell is essentially a small-group work improvement mechanism that is used to put the kaizen (continuous improvement) principle in effect through employee participation (Wilkinson et al 1997).

Building on Miron's et al (2016) exploration of the evaluation of CI cells, this paper presents a summary of the initial findings of a research project aiming to understand the benefits of and improvement opportunities for CI cells in the highways supply chain in the UK.

LITERATURE REVIEW

CONTINUOUS IMPROVEMENT CELLS

The CI cell is a small-group task coordination and work improvement technique developed from Quality Circles (QCs), a form of employee involvement mainly used for gradual quality improvement. In the execution of CI cells, a group of three to twelve employees regularly meet under the leadership of their supervisor in order to systematically identify work related problems, analyse solutions, and to solve those problems (Dale et al. 2001; Miron et al. 2016; Barad 2018).The intrinsic CI cell aim of problem solving and gradual work improvement through group effort links the concept to the continues improvement or *kaizen* principle of lean thinking (Brunet and New 2003; Imai 2012; Maaruf and Mahmoud 2016). Alongside quality management (Love and Li 2000), with their regular performance review and improvement motives, CI cells are also classified as part of performance management (Bell 2005; Brown 2013).

As a CI cell regularly exposes the team to the information associated with their work in the form of team performance metrics, team-member availability, work-related issues, the continuous improvement process or work coordination/follow-up, CI cellscan also be included in efforts toward increasing process transparency within Visual Management, an information management strategy that relies on the effectiveness of sensory communication (Suzaki 1993; Bititci et al. 2016). The information presented on CI cell boards of different teams remains accessible to all and by creating information fields, the boards serve as a summary of the team performance and the issues for the interested (Galsworth 2005; Tezel et al. 2016).

Additionally, the importance of having structured team coordination meetings and two-way communication channels from the operational level to the strategic management level and vice versa has been underlined in disseminating organisational strategic goals as part of *hoshinkanri*, a strategic management framework originally conceived in Japan and recognised for developing a deployment process that integrates business strategy and operations execution (Akao 1991; Witcher and Butterworth 2001; da Silveria et al. 2017). CI cells can therefore be perceived as tools to establish that link between the strategic and operational level, in which short-term team targets toward strategic goals are regularly communicated and controlled, and any problems in achieving those targets are resolved in a systematic manner. Figure 1 illustrates this positioning of CI cells at the intersection of the *hoshinkanri*, Visual Management and *kaizen* concepts, recognising CI cells' functional role within each concept. This kind of positioning of CI cells with its roles exposed in different lean related efforts could not be identified form the literature.

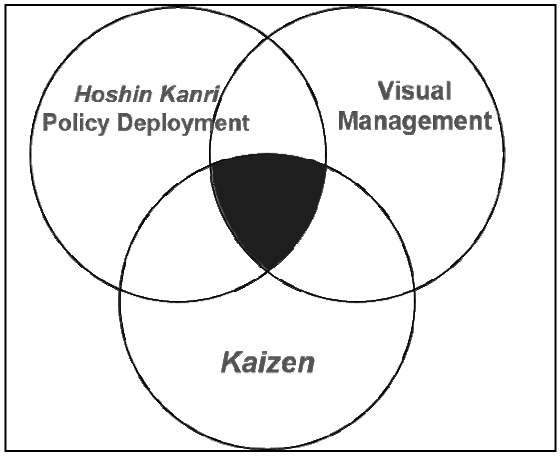

Figure 1: CI cells is a group management technique that can be positioned at the intersection of the *hoshinkanri*, Visual Management and *kaizen* efforts at an organisation.

BENEFITS OF CONTINUOUS IMPROVEMENT CELLS

Most of the discussions on CI cell benefits and challenges are from the QC literature. The following benefits can be achieved by deploying CI cells (Miron et al 2016); (i) job enrichment through involving employees into the decision making process and providing them with greater autonomy (Osayawe and McAndrew 2005; Barad 2018), (ii) cost savings through developing the problem solving skills of employees and capturing work improvement ideas (Pereira and Osburn 2007), (iii) setting a systematic goal-setting and feedback mechanism for employees, which will raise the level of understanding of the work conditions and requirements (Osayawe and McAndrew 2005), (iv) increased participation and team work for employees, which will increase the employee motivation and involve employees in the decision making process (Prado2001), and (v) increased interaction within the members of a CI cell and between the members of different CI cells (Pereira and Osburn 2007).

CHALLENGES FOR CONTINUOUS IMPROVEMENT CELLS

There is an established literature as to the challenges for small-group activities in continuous improvement. Those discussions mostly focus on QCs as the basis of CI cells. QCs were found of limited value in changing employee behaviour and organisational culture (Bradley and Hill 1983). Organisations often experience difficulties in sustaining their QC efforts (Hill 1991). Among other challenges, the restriction of QC activities to a narrow range of issues within the control of the work unit, the tendency to run out of things to do, the lack of training or incompetence of employees, and the managerial attitude and culture leading to a lack of co-operation, notably among supervisors and middle managers (Collard and Dale 1989) come to the fore.

RESEARCH METHOD

Much of the literature concerned with the role of small-group activities and QCs in work improvement date back to the 1980s, when those practices were first adopted from Japan and gained popularity in the West. However, CI cells go beyond the usual scope of QCs by facilitating daily or weekly work planning/ control and by exposing other team related information such as Health and Safety figures or team member availability to the team members. What is more, empirical research on the use and implications of the concept in construction supply chains is scarce. Also, despite the increasing adoption of CI cells in the highways supply chain in the UK, no specific account on the realisation of the current CI cell practices was identified. Therefore, three research questions were posed to explore the condition of CI cells in the highways supply chain:

1) How is the CI cell mechanism executed?
2) What are the benefits of CI cells?
3) What are the current challenges for CI cells?

12 internal CI cells of the highways supply chain's main client were studied using interviews, participant observation in CI cell meetings, CI cell board observations and discussions with the team members. The details of the data collection with each team can be seen in Table 1. As explained in the subsequent section, two main types of CI cells were found in effect; Type I cells Type II cells. There are also real cells in which the team members are co-located and virtual cells, which are executed over the internet, intranet or telephone. The cells were studied in two different headquarters of the main client in Northern England; A and B.

Table 1: Data Collection Methods with Each Team

General Information				Data Collection Methods			
CI Cell No	**Location**	**CI Cell Type**	**Virtual or Real CI Cell**	**Interviews**	**CI Cell Board Observation**	**CI Cell Meeting Participant Observation**	**Discussions with Team Members**
1	A	Type II	Virtual	2 team members	Done	No	Done
2	A	Type I	Real	1 team member	Done	No	Done
3	A	Type II	Real	2 team members	Done	Done	Done
4	A	Type I	Real	1 team member	Done	Done	Done
5	A	Type I	Real	1 team member	Done	Done	Done
6	A	Type I	Real	No	Done	N/A - Team stopped their CI cell meetings	Done

7	B	Type II	Real	1 Lean Team member facilitating the team's CI cell	Done	Done	Done
8	B	Type I	Real	1 team member	Done	Done	Done
9	B	Type II	Real	1 Lean Team member facilitating the team's CI cell	Done	Done	Done
10	B	Type I	Real	1 team member	Done	Done	Done
11	B	Type I	Real	1 team member	Done	No	No
12	B	Type II	Real	No	Done	No	Done

FINDINGS

EXECUTION OF CONTINUOUS IMPROVEMENT CELLS

A CI cell is made up of two things in practice; (i) a regular (daily, weekly or bi-weekly) meeting mechanism led by the team leader, and (ii) a physical (real) board for co-located teams or a virtual medium (e.g. a spreadsheet on the intranet)for dispersed teams with different sections, typically containing the team KPI, task control and coordination, team member availability, health and safety and continuous improvement data, that enables and acts as the visual data record of that meeting mechanism.

Of the two types of CI cells, the Type I cells are more focused on work coordination and planning with minimal or ad-hoc work improvement. There are three sections generally covered in Type I cell meetings and cell boards; (i) team member availability often in the form a team member availability matrix for the week commencing, (ii) a work planning and control section in which each team member can negotiate with other team members and visually declare his/her responsibility for the completion of a task and can provide updates on the task’s completion by using post-it notes, and (iii) a notes section displaying key events or success stories. Some Type I cell boards also display team KPIs.

Alongside work coordination, the systematic execution of continuous improvement efforts in the Type II cells is more conspicuous than the Type I cells. A Type II cell boards contains generally three main sections; (i) a team performance section, in which various team KPIs are collectively reviewed and evaluated by the team members, (ii) a 3Cs section (Concerns, Causes and Countermeasures), in which current and anticipated work issues are captured and discussed with their root reasons and preventive actions. Countermeasures defined as best practices are communicated and disseminated for future use along with success stories, and (iii) a section showing various Human Resources related figures (i.e. team members’ availability, absence statistics, training information etc.). The structure of the Type II cell boards is more standardised. Also, the Type II cells were often initiated and are facilitated by one of the organisation's process improvement staff member. The two types of cells and the 3C can be seen in Figures 2, 3 and 4 respectively.

Figure 2: A Type I cell board containing information on some team KPIs (left), a team member availability matrix (bottom-right) and a task tracking section (top-right).

Figure 3: A Type II cell board comprised of three sections; team KPIs (left), a continuous improvement section with the 3Cs (centre) and the people (Human Resources) section (right)

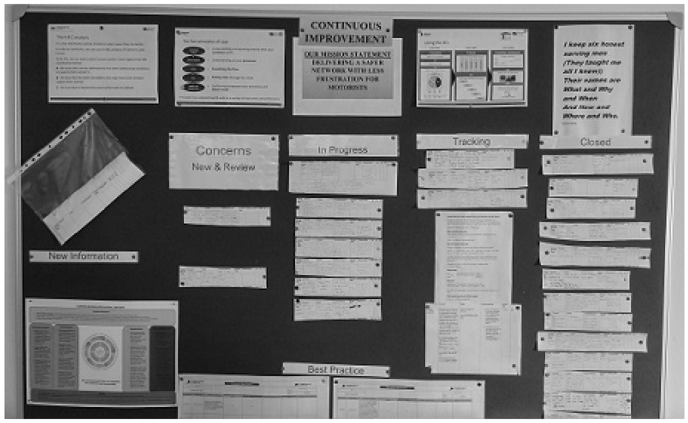

Figure 4: The 3C section of a CI cell board. The continuous improvement function of CI cells has generally been executed and recorded over the 3C template in the highways supply chain.

BENEFITS OF CONTINUOUS IMPROVEMENT CELLS

The following CI cell benefits were identified, in no particular order of importance, from the interviews and participant observations at the client organisation. The findings were compiled from the recurring themes from the interviews, followed and verified by the CI cell meeting observations and the informal discussions with the team members. A CI cell:

- enables having structured and succinct team meeting,
- supports coordination of team work,
- increases team engagement and morale,
- discloses related information to employees,
- increases transparency,
- helps with team building,
- facilitates task ownership,
- prompts team members to make more reliable promises (peer pressure)
- helps teams allocate and level their resources (work balancing/ prioritising)
- serves as a training mechanism for junior and new team members,
- supports task delegation, empowerment and employee autonomy,
- simplifies progress reporting and creating meeting minutes,
- helps save team resources.

CHALLENGES FOR CONTINUOUS IMPROVEMENT CELLS

The main challenges in the execution of the CI cells as identified in the same way as the CI cell benefits are:

- ad-hoc and unstandardized data recording,

- not understanding what to measure and how to measure with respect to CI cell benefits,
- hardships faced in identifying root causes of problems,
- ad-hoc problem solving,
- insufficient standardisation among the teams in their CI cell executions (i.e. the frequency of meetings, the content and design of the CI cell boards, the governance of the CI meetings, some teams' ignoring the continuous improvement function),
- providing the team with only basic training as to the CI cell execution and systematic problem solving techniques,
- root problem causes not being systematically recorded, classified and visualised,
- the lack of senior management engagement,
- the lack of systematic incentivisation practices for the CI cells,
- the limited authority of the teams to make work improvements as they are mostly restricted with their work domains.

DISCUSSION

Both the identified benefits and challenges from the main client match with the existing literature to a great extent. Four additional CI cell benefits stand out; (i) the CI cells act as a training mechanism for junior team members and newcomers, (ii) the cells increase the transparency in team information, (iii) the cells' role in executing focused team meetings and (iv) in simplifying the reporting process. The challenges are mostly related to the lack of incentivisation, proper training, standardisation and engagement of the senior management. It should be noted, however, that further empirical research is necessary to prioritise the identified benefits and challenges.

The captured transparency increasing benefit of CI cells further justifies its role in increasing process transparency and supporting Visual Management (Figure 1). However, some issues in the continuous improvement (*kaizen*) function of the cells like root cause problems not being systematically recorded, ad-hoc problem solving or some teams' ignoring the CI cell's continuous improvement function were identified in practice. Also, due to the fact that senior management do not have their CI cells at the moment, there are issues regarding the two-way flow of information over the CI cells from the strategic level to operational level and vice versa for the execution of *hoshinkanri*. The studied teams' limited capability in making work improvement beyond their control domain can be attributed to this interruption in the information flow between the strategic and the operational level.

As for the suggestions, the client organisation should review its Lean training curriculum to include more of the basic root cause analysis and problem solving methods. A comprehensive audit of the existing CI cells across the organisation to increase the standardisation will be useful. Additionally, the senior management can be prompted to form their own CI cells, which should be linked to their subordinates' CI cells to form a complete information cycle in the organisation over the CI cells. Not only will this help the senior management connect with their subordinates, it will also support the work teams to solve some persistent problems that go beyond their team's authority, control and work domain. Work improvement cannot be ordered but should rather be supported. Also, the teams can be guided on how to record their CI cell data and CI cell benefits systematically.

The CI cells' potential in supporting the continuous improvement objective of and daily huddle meetings in the Last Planner System, which are some of the least executed parts in the Last Planner practices in the UK (Daniel et al. 2017), should also be highlighted. Issues emerging from the Last Planner's weekly meeting can be transferred to and studied for continuous improvement within a CI cell mechanism. Also, site teams can have their daily huddle meetings around their CI cell boards to review their daily work plan and work improvement objectives.

CONCLUSIONS

Continuous improvement (*kaizen*) is a key element of Lean Construction. One of the means to realise continuous improvement in practice is using the CI cell technique. CI cells also can be positioned within other important lean concepts like Visual Management and *hoshinkanri*. However, the CI cell research in construction has remained scarce.

This paper presented a summary and preliminary findings of a research project exploring the execution of the CI cell technique in the highways supply chain in the UK. The identified benefits can be tested and prioritised in the future with data from different organisations and quantitative methods (i.e. design of experiments and action research). The identified challenges are also deemed important in improving the current CI cell adoption. Deploying CI cells in construction supply chains and linking them with other Lean Construction techniques like the Last Planner or Visual Management systems can be also an option in the future for case studies, design science or action research based investigations.

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LAST PLANNER SYSTEM: IMPLEMENTATION AND EVALUATION WITH FOCUS ON THE PHASE SCHEDULE

Flora S. Ribeiro[1], and Dayana B. Costa[2]

ABSTRACT

Phase Schedule is a Last Planner System practice whose role, both from a practical and theoretical point of view, is still being debated in the construction industry. Thus, there is a need for a better understanding of Phase Schedule implementation practices and the impacts of those on production planning and control. This paper presents the results of the implementation and evaluation of the LPS focusing on the Phase Schedule practices based on two in-depth case studies developed from April 2016 to August 2017 in Salvador-Brazil.

The Case Studies involved the implementation of the LPS and the Phase Schedule practices and the analysis of the impact of using those practices on the production planning and control processes. The findings indicated that the cycles of the Phase Schedule improve the constraints analysis, collaboration between those involved, transparency in the planning process, adherence between levels planning by using performance metrics, reliability of plans and commitment to the deadlines. Also, the activities which were initially not analyzed as critical, have strong influence on the performance of the production planning and control.

KEYWORDS

Last Planner System, Phase Schedule, Collaboration.

INTRODUCTION

The development of the Last Planner System (LPS) established several changes in the way construction projects were planned and controlled. According to Ballard (2000), Last Planner can be understood as a mechanism for transforming what SHOULD be done into what CAN be done, forming an inventory of ready work, from which the Weekly Work Plan (WWP)can be formed. The LPS is divided into different planning levels (Ballard andTommelein, 2016):**master scheduling**, which the milestones and phases durations

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and overlaps are set; **phase scheduling**, where the team specify the handoffs and conditions of satisfaction between processes within phases; **look ahead planning**, where the constraints are identified and removed, the tasks breakdown from processes into operationsoccurs and the operations are designed; **commitment planning**, during which reliable promises are made; and **learning**, where plan failures ae analyzed in search of countermeasures.

Since its development, several studies have been conducted to analyze and develop LPS. Daniel et al. (2015) studied the components of the LPS implemented and found that the measuring of Percentage Plan Completed, Weekly Work Planning meeting, and recording reasons for non-completion are the commonly implemented components. Despite this LPS use, Hamzeh et al. (2012) state that in many construction projects, the implementation of the lookahead planning is deficient, resulting in a gap between master scheduling and commitment planning. While lookahead planning is built on master scheduling, a connection is rarely maintained between these two (Choo and Tommelein, 2000).Thus, there is a lack of adherence between planning levels.

Emdanat and Azambuja (2016) affirm that the alignment of commitment planning and master scheduling requires a systematic adherence to the processes of the LPS workflow from Phase Schedule to Weekly Work Planning and Commitment Management, and, the continuous capture of the data in an integrated and uniform way. In addition, Ballard and Tommelein (2016) state that there is a lack of studies which analyze a methodology that standardizes the adherence between the levels of Phase Schedule, lookahead and commitment planning. There is also a need to develop metrics to analyze the LPS performance focusing on the Phase Schedule's plan quality and reliability and measures to avoid plan failures (Ballard and Tommelein, 2016).

Based on the literature review, the research questions raised were: "How to implement the LPS focusing on the Phase Schedule, aiming to integrate the hierarchical planning levels?" And "How to evaluate the LPS performance, focusing on the Phase Schedule?". Therefore, the main objective of this research is to implement and evaluate the LPS, focusing on the Phase Schedule practices. Two in-depth case studies were carried out in Salvador-Brazil to achieve this objective.

PHASE SCHEDULE AND METRICS TO SUPPORT THE ADHERENCE BETWEEN PLANNING LEVELS

The Phase Schedule is one level in LPS, where a phase gets broken out from the master plan, in which milestones define phases, and people responsible for the work in that phase jointly develop the plan (Ballard and Tommelein, 2016).The practices of the Phase Schedule involve the technique of apull planning, whichis used to develop a plan for doing work at any level of task breakdown (Ballard and Tommelein, 2016). Also, it uses post-its and mural highlighting for the weeks that will be planned. Some LPS studies discuss the Phase Schedule, such as Knapp et al. (2006) and Kalsaas et al. (2009), which indicated that the teams better understood their project, their individual roles and what was required for the success of the project and analyzed their constraints in advance.

More recently, studies related to the analysis of metrics that can support the adherence between plan levels in the LPS were presented. Emdanat and Azambuja (2016) analyzed several data from LPS implementations and identified metrics that allow the integration between planning levels. A set of the metrics identified in the literature may support the adherence and integration between planning levels, based on Ribeiro (2018), such as (Figure 1):

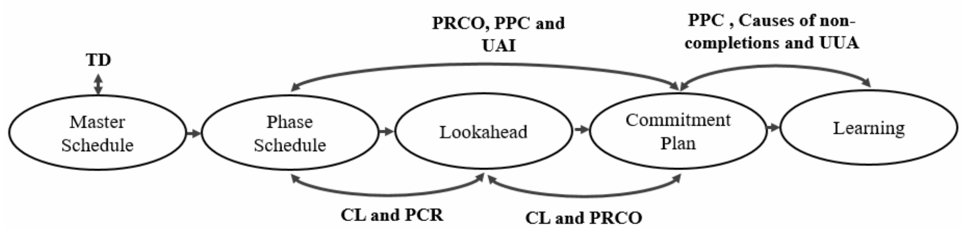


Figure 1: Indicators and interactions between the LPS planning levels

- **Time Deviation (TD):**evaluates the performance of the work, through the relation between the expected deadline and the effective deadline (Costa et al. 2005);
- **Commitment Level (CL)**:evaluates the level of commitment of participants in Phase Schedule meetings to perform planned activities within the defined deadline (Emdanat and Azambuja, 2016). It is measured by the percentage of the ratio between the activities ready to be executed (constraints removed) and the total number of activities planned during the Phase Schedule cycles;
- **Percentage of Constraint Removal (PCR):**evaluates the effectiveness of lookahead planning in relation to the process of removing constraints (Jang and Kim, 2007);
- **Percent Required Completed or Ongoing (PRCO):**evaluates how many of the activities that were ready to be executed were actually completed or are certain to be finalized within the expected deadline (Emdanat and Azambuja, 2016);
- **Percent Planned Complete (PPC)**: is a number of planned activities completed, divided by the total number of planned activities, and expressed as a percentage (Ballard, 2000); and Cause of non-completion plan: investigation of the causes for non-completion of the plans (Ballard, 2000).
- **Unplanned Activities Included in the commitment planning (UAI):**evaluates the percentage of activities included in the commitment planning that were not planned in Phase Schedule(Ribeiro, 2018).
- **Unplanned and Unfinished Activities in the commitment planning (UUA):**evaluates the percentage of activities in the commitment planning unfinished and not planned in Phase Schedule(Ribeiro, 2018).

RESEARCH METHOD

This research was divided into four phases: 1) literature review to find the knowledge gaps; 2) development of the Case Study A to implement the LPS and the Phase Schedule practices; 3) development of the Case Study B to incorporate the LPS and the Phase

Schedule practices; and 4) development of a set of guidelines to implement and evaluate the LPS focusing on the Phase Schedule practices and identification, as well as the identification of the theoretical contribution of the study.

CASE STUDY A AND B

The case study A was developed during the construction of a clinical facility, from April to December 2016, located in the city of Salvador, Bahia, Brazil. The project team had already used elements of the LPS, such as visual controls, daily huddles and PPC metric. However, it was their first experience using the Phase Schedule practices.

The implementation of LPS focusing on the Phase Schedule practices occurred over 33 weeks, which included the Phase Schedule Cycle. The Phase Schedule cycle occurred through the following steps: (a) preparation, that occurred through training sessions and the phase definition; (b) meetings, which analysed the activities of the phase by using techniques (reverse plan, post it and board); and (c) monitoringof the activities and constraints planned, through performance measures and the evaluation of the implementation. A total of five cycles of Phase Schedule implementation was developed for the phases of foundation, structure, masonry, electrical and plumbing installation, facade, ceiling plaster board and drywall system. These meetings were attended by the project engineering team, subcontractors and the research team. Between these construction phases, weekly-basis meetings were heldto monitor the LPS implementation. The Phase Schedule meetings and the monitoring visits occurred at the construction site and lasted for an average of two hours.

The case study B was developed during the construction of a commercial building, from December 2016 to August 2017, also located in the city of Salvador, Bahia, Brazil. The project team already had experience with the Phase Schedule practices from the Study A.

The implementation of the LPS and the Phase Schedule cycles occurred in a similar way to the Study A, over 39 weeks. The meetings were also attended by the project engineering team, subcontractors and the research team. A total of seven Phase Schedule cycle was developed during this period, involving the following construction phases: structure, masonry, electrical and plumbing installation, internal mortar plaster, levelling mortar, facade, drywall system and internal painting. Every two weeks, meetings, with a total of 20 meetings, were held to monitor the LPS implementation during this period. The meetings also occurred at the construction site and lasted for an average of one hour. This reduced time was justified by the learning effect of those involved.

In addition, data from document analysis and interviews were collected during each phase of the case studies (Table 1).

Table 1: Stages of the Phase Schedule implementation cycle – Case Studies A and B

Stages of the implementation cycle	Techniques or tools	People involved in the Case Study A	People involved in the Case Study B
Phase Schedule preparation	Construction projects Master planning in the MSProject tool	1 Production Engineer 2 interns 2 foremen 5 supervisors of the	1 Production Engineer 3 interns 1 foreman and 3
	Excel sheets		

Stages of the implementation cycle	Techniques or tools	People involved in the Case Study A	People involved in the Case Study B
Phase Schedule meetings	Board and Post its Construction projects Excel sheets	subcontractors	supervisors 5 supervisors of the subcontractors
Monitoring of the planned activities and constraints	Excel sheets for the monitoring of what was planned in the meetings		
Process evaluation	Structured Questionnaire		

DATA ANALYSIS

Based on the literature review and the Case Studies A and B, it was possible to understand that the (a) effectiveness of the Phase Schedule practices, which are the techniques used (reverse planning, board, post-it) are concerned to collaboration and transparency and (b) the effectiveness of the processes of the LPS, which are the procedures the team will perform to achieve the defined goals (monitoring of the activities and constraints, use of metrics, etc), are related to adherence between planning levels, reliability of plans and commitment to the deadlines. The metrics selected to evaluate the LPS and the Phase Schedule were presented in the literature review and Figure 1. Thus a set of constructs and variables were proposed for data analysis, defined as follows:

- **Collaboration**: this is related to the team's ability to make joint decisions, based on shared knowledge among those involved, encouraging their commitment to the execution of activities. The variables are:(a) commitment to the execution of activities; (b) joint decision making; and (c) shared knowledge.The main sources of evidence used were participant observation, data analysis and interviews.
- **Transparency**: this is associated with the visualization of the necessary information in a simplified way and improved communication among those involved in the Phase Schedule. The variables are: (a) visual tools; (b) simplification of the information; quick understanding; (c) better communication among those involved; (d) easy visualization of the phase attack plan; (e) and verification of activities that would be performed simultaneously. Participant observation, data analysis and interviews were the main sources of evidence.
- **Adherence between Planning Levels**: this is associated with the uninterrupted flow of information between different planning levels, which can support the decision making at different planning levels. The variablesare: (a) conducting Phase Schedule practices; (b) analysis of master schedule goals; and (c) monitoring of the planned activities at different planning levels – joint analysis of the selected indicators. Participant observation, data analysis, performance metrics and interviews were the main sources of evidence.
- **Reliability of Plans**: aims to examine whether the phase was planned in a real way and was possible to execute as planned. The variables are: (a) execution of activities as planned – analysis of selected metrics; (b) monitoring of what was planned by the team involved in the Phase Schedule meetings; and (c)

commitment to the constraints removal – analysis of selected metrics. Participant observation, data analysis, performance metrics and interviews were the sources of evidence.

- **Commitment to the Deadlines**: aims to verify whether the planned activities have been completed within the established deadline and in accordance with the master schedule, from which the goals were defined. Thevariables are: (a) execution of the activities in the duration planned; and (b) activities completed on the master schedule dates. Participant observation, data analysis, performance metrics and interviews were the main sources of evidence.

RESULTS AND DISCUSSION

CASE STUDY A

Based on the five Phase Schedule cycles carried out with the team involved and the 33 weeks of data collection, a set of lessons learned were identified concerning the factors that promote a more collaborative environment. A good practice identified was the earlier discussions for setting goals among the production engineer and the person in charge for the construction activity in the phase analyzed. Identified during the phase schedule meeting was that the reverse plan methodology and visual tools (post it and mural) support the joint definition of the best way to perform the activities, as well as the verification of possible interferences and constraints of activities. This result was confirmed by the interviewees who stated that the visualization of the project as whole, through the visual tools, simplified the information and made the activities easy to understand. During the execution of the activities, a self-reorganization and better interaction between the team involved in the Phase Schedule cycles when there were changes in the plan were observed as an important achievement.

By the joint analysis of the metrics selected, the analysis of adherence between planning levels were carried out. Figure 2 presents the results of the indicators CL and PCR and the indicators PRCO and PPC. The control cycle adopted for the analysis was 30 days, therefore more than one control cycle could be observed in some of the phases. The phases analyzed were Foundation (FO), Structure (S), Masonry and Electrical and Plumbing Installation (M/EP), Facade (FA), Ceiling Plaster Board and Drywall System (CPB/DS).

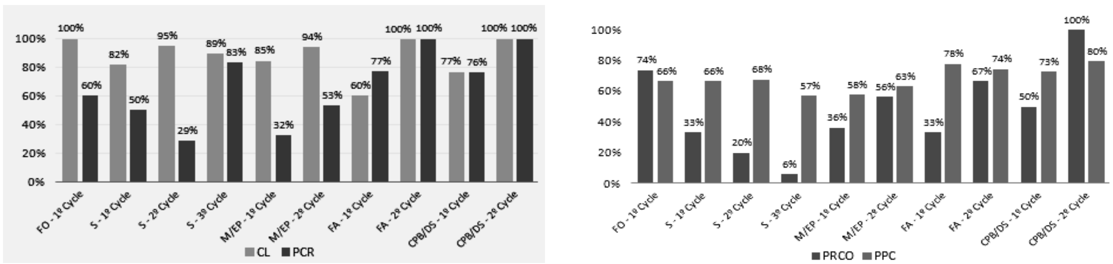


Figure 2: Indicators CL and PCR and PRCO and PPC results of the Case Study A

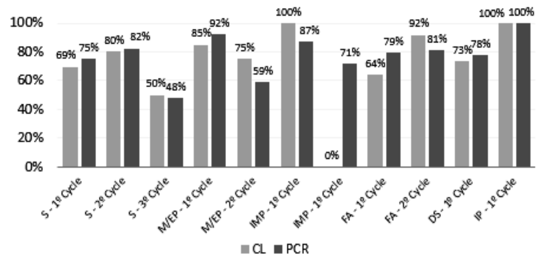
The results of PCR indicator (average of 66%) indicated that many constraints were not removed until the due date established in the Phase Schedule/lookahead planning; however, there was a greater effort by the team to remove the constraints at the last moment (after the due date but before the start date of the activities). This can be seen through the results of the CL indicator (average of 88%),which show the level of commitment of participants in Phase Schedule meetings to perform planned activities within the defined deadline (first commitment), thus improving the reliability of the plans. However, the second commitment, which is to finish the activities on the dates planned, was not attained by the team, evident in the PRCO results (average of 48%). As it was the first time that the team had to define the execution's final dates with a greater anticipation of the execution date, this low PRCO result occurred due to the lackof experience to define the execution's final dates, compromising the deadlines established in the Phase Schedule cycles.

The PPC involved two types of activities: the ones planned in the phase schedule and the ones not planned. The activities not analyzed in the Phase Schedule/lookahead planning had an impact on the PPC average (68%), as can be observed by the UAI indicator results, where 63% of the activities included in the commitment planning were related to those activities. Corroborating this, the UUA indicator results showed that an average of 58% of the uncompleted activities in the commitment planning were related to the activities not planned in the Phase Schedule/lookahead planning. Also, the late hiring of the electrical and plumbing subcontractor caused the delay in accomplishing the deadlines established in the master schedule, evaluated by the TD metric.

CASE STUDY B

As in the Case Study A, a set of lessons were learned based on the seven Phase Schedule cycles and the 39 weeks of data collection. During the execution of the activities, more collaborative teamwork was noticed, because all teams were already aware of their commitments and milestones defined during the schedule meetings phase, thus reducing the transfer of responsibilities on site. In this case study, the phase schedule board with the activities was improved by highlighting the building stories, which provided a more effective visualization of the sequence and parallelism of the activities. As in the Study A, the joint analysis of the metrics selected contributed to the analysis of the adherence between planning levels. Figure 3 presents the results of CL and PCR indicators and PRCO and PPC indicators. The control cycle was 30 days. The phases analyzed were Structure (S), Masonry, Electrical and Plumbing Installation (M/EP), Internal Mortar

Plaster (IMP), Levelling Mortar (LM), Facade (FA), Drywall System (DS), and Internal Painting (IP).



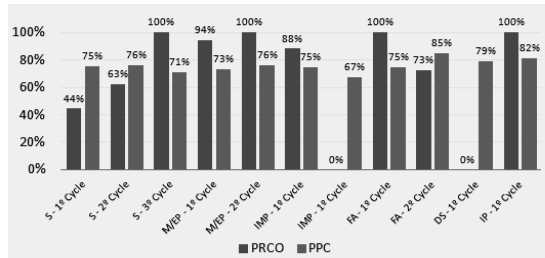


Figure 3: Indicators CL and PCR and PRCO and PPC results of the Case Study B

The team made a greater effort to remove the constraints at the due dates (PCR average 78%) and to make the activities ready to be executed (CL average 72%), probably because of the learning effect. Although the performance of the PRCO (average of 69%) was below the CL indicator, it was noted that the team made an effort to accomplish the second commitment established in Phase Schedule/lookahead planning and to finish the majority of the activities on the scheduled dates, as can be seen in the PRCO results in the Figure 3.

Although the number of Phase Schedule cycles was larger than in the Case Study A, the UAI indicator performance was very high (average 70%), meaning a high number of activities not planned in Phase Schedule/lookahead planning were performed in the commitment planning, which had a strong influence on the PPC result. In general, the unfinished and unplanned activities in Phase Schedule/lookahead planning contributed to a decrease in the PPC performance, demonstrated by the UUA performance (average of 76%). It is important to highlight that the result of CL and PRCO indicators of the first levelling mortar cycle were 0%, because the subcontractor responsible for the activities was unable to make the activities ready to start on the planned dates, influencing the finalexecution date. Also, due to the lack of drawings definition, the milestones of the master schedule were delayed.

EFFECTIVENESS OF THE PRACTICES AND PROCESS OF PHASE SCHEDULE

The effectiveness of the Phase Schedule practices was analyzed based on the constructs defined previously related to collaboration and transparency, and the effectiveness of the processes was analyzed based on the adherence between planning levels, reliability of plans and commitment with the deadlines.

- **Collaboration:** some strengths related to the collaboration construct were identified, such as: plan commitment, joint decision making and shared knowledge throughout the stages of Phase Schedule cycle; previous discussions between the team involved in setting goals; self-reorganization and better interaction between the team during the execution of the activities in the field; and verification of possible interferences and joint identification of constraints in a collaborative way.

- **Transparency:** the strengths identified were: the use of visual tools in the Phase Schedule meetings, allowing the verification of activities that would be performed simultaneously; the simplification of the information to transfer for those involved; and a better visualization of all activities in the phase schedule, facilitating the reorganization and increasing communication on site.
- **Adherence between planning levels:** by analyzing the CL and PCR indicators, a relation between Phase Schedule and lookahead planning was noted, and it was possible to evaluate whether what was planned concerning the start dates of the activities and the due date for removal of the constraints was in fact achieved. The use of those metrics does not show a statistical correlation, since the PCR indicator only verifies the removal of all constraints at the due dates, not associating those constraints with the activities planned. This means that an activity may have several constraints eliminated, causing a high PCR, while another activity may have only one constraint not eliminated, resulting in a low CL performance. Analyzing the CL and PRCO results, there is an adherence between the lookahead planning and the commitment planning. Those provide information as to whether the activities that were ready to be executed during the lookahead were actually planned in the commitment plan and executed within the duration stipulated in the Phase Schedule. According to the results, there is no direct correlation between the CL and PRCO indicators, since other factors may influence the execution of the activities, having an impact on the PRCO results. Analyzing the PRCO and PPC, there is a relation between Phase Schedule and commitment planning, because the activities taken into account in the PRCO are part of the activities analyzed in the PPC, so if there is a high/low PRCO, the PPC will also be influenced by this result. The unplanned activities in Phase Schedule have an impact on the effectiveness of the planning, because there is a high percentage of those activities in the commitment plans that were not concluded. The UAI and UUA indicators complement the analysis of the PRCO and PPC indicators, because both provide information about the activities not planned in the Phase Schedule cycles.
- **Reliability of plans:** the team that participated in the Phase Schedule meetings was also the one that monitored the constraints and activities planned, contributing to the reliability of plans. This construct can be also analyzed through the commitment to remove the constraints, which can be verified through CL and PCR indicators. For example, if an activity has all its constraints removed on thescheduled date, the activity will be executed as planned, improving the reliability of plans.
- **Commitment to the deadlines**: the analysis of the complete activities on the expected dates in the master plan was performed through the analysis of the Time Deviation (TD)metric. Throughout the study, two important commitments were identified during the Phase Schedule cycle: (1) starting the activity on the planned date, which was evaluated by the CL, and (2) ending the activity on the planned date, which was evaluated by the PRCO.

CONCLUSIONS AND FUTURE RESEARCH

This paper aimed to present the results of the implementation and evaluation of the LPS focusing on the Phase Schedule practices based on two in-depth case studies carried out in Salvador-Brazil.

This paper contributes to a better understanding of the Phase Schedule cycles, involving three main steps: Phase Schedule preparation, Phase Schedule meetings and monitoring of the planned activities and constraints. Also, this study established a set of constructs and metrics for the evaluation of the LPS, focusing on the Phase Schedule practices and processes. The constructs adopted were collaboration, transparency, adherence between planning levels, reliability of plans and commitment to the deadlines, and the metrics selected were Time Deviation (TD), Commitment Level (CL), Percentage of Constraint Removal (PCR), Percent Required Completed or Ongoing (PRCO), Percent Planned Complete (PPC), Unplanned Activities Included in the commitment planning (UAI) and Unplanned and Unfinished Activities in the commitment planning (UUA).

The results show that the constraints analysis, the collaboration between those involved and the transparency in the planning processes were improved in both Case Studies. Also, the metrics selected improved the adherence between planning levels, reliability of plans and commitment to the deadlines. Further, the findings show two main commitments made between those involved in the Phase Schedule cycle:to make the activities ready to be executed and to complete the activity within the deadline planned. The results show the activities which were not analyzed as critical for planning in the Phase Schedule had strong influence on the performance of the PPC.There are still opportunities to analyze the role of new metrics identified in the literature to evaluate the LPS, focusing on the Phase Schedule practices.

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MANAGING THE "RECEDING EDGE"

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ABSTRACT

So much attention is paid to starting construction activities, and starting new work at regular time intervals to a beat (aka. takt) that—not surprisingly—work to finish those very activities may fall behind. This paper focuses, not on the start-, the "leading edge, "but on the end of activities, the "receding edge." The receding edge articulates when work is "done-done" and the successor contractor may start their work, unimpeded by their predecessors' unfinished work or "leftovers" (e.g., areas left dirty and cluttered with remnants). This paper describes receding-edge activities related to forming, placing, and finishing post-tensioned, cast-in-place concrete slabs, observed on a project in San Francisco, California. The researchers went to the gemba, described the current situation, and exchanged ideas with the contractor on means to keep the receding edge progressing at the pace of the leading edge, that is: to improve the cycle time from start, to not just finished or "done," but to "done-done" completion of each slab. Findings include the need to define standard processes (e.g., for clean-up work) as those observed appeared defective (one of Ohno's 7 wastes) or none existed, and to designate resources to accomplish them. This paper contributes to knowledge by articulating the receding edge concept, describing challenges in managing it, and documenting lean methods as countermeasures to those challenges. When managed considering the production impact of receding-edge work on the contractor responsible for it and on follow-on contractors, the case for cycle time reduction is easy to make and worth the money.

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KEYWORDS

Cycle time, waste, defect, unfinished work, work structuring, standardization, cast-in-place concrete, takt time planning (TTP)

INTRODUCTION

We define construction activities as bounded by a "leading edge" at their start and a "receding edge" at their end. Both edges are rather fuzzy in practice, especially when an activity comprises several sub-activities. The focus in this paper is on the receding edge, as defined later. Its fuzziness is a problem, e.g., when an activity drags out, the increase in work in process and resource uncertainty may become costly to the contractor responsible for it and to the project overall as follow-on activities may be impeded by "leftovers" (e.g., areas left dirty and cluttered with remnants) from their predecessor.

To explore the receding edge concept and its impact on production system performance, our methodology was to observe, document, question using 5 WHYs, and analyse activities of Webcor, the contractor building the 55 story Transbay Block 8 in San Francisco, California. The building structure is erected using a 3-day takt between floors, with cast-in-place post-tensioned floor slabs, each slab measuring roughly1,600 m^2 (~17,000 ft^2). We also reviewed the literature using concepts related to starting and completing activities.

Construction contractors use metrics to determine progress of their work. One such metric is to account for the amount of work "done" (e.g., volume of concrete put in place, an output of production). Metrics like this serve as their basis for payment. As such, the contractors' workforce places additional efforts to increase performance as measured. That may come at the expense of the quality of their work and quality of their handoff to others. It may lead, e.g., to complications that require the contractor to return to site, thereby disrupting the contractor's work flow and being costly in other ways as well.

This paper first defines the receding edge concept. It then presents related concepts pertaining to activity definition as described in the literature. The section that follows illustrates current practice regarding receding edgework using examples from the project, which the researchers scrutinized by applying Lean Thinking to identify potential improvements. The paper concludes with a summary and questions for further research.

DEFINITION OF THE RECEDING EDGE

The "receding edge" of an activity in a contractor's scope of work includes, by definition, the work that *appears to not necessarily need to be completed* by that contractor in order for them to move on to their next activity (e.g., the next work location), but *must* be completed for the contractor to "handoff" their work to others, have finished their total scope of work on the project, and leave the jobsite. Fuzziness of the receding edge results from the difference between the work being "done" vs. the work being "done-done."

The relationship between an activity's leading- and receding edge may be depicted by a person dragging an anchor. The person is the leading edge, starting activity by breaking new ground and moving forward. The anchor is the receding edge, the final point to touch the ground before activity completion. A presumed ideal is that, when moving forward, the front and back remain connected with a constant distance in-between; this distance or time in-between defines the cycle time of the activity. Reliably achieving that cycle time is key to, e.g., implementing a takt plan and may be accomplished using capacity buffers (Frandson et al. 2015), though that is not the focus of the discussion here. In practice—and less than ideal—as the leading edge progresses, work may increasingly stretch out (it rarely shortens) so that the distance in-between it and the receding edge increases over time.

Examples of receding-edge work are removal of tools, temporary structures, equipment, and materials left behind, rework to address quality issues, and cleaning of remnants and debris. While such work may appear to make up only a small portion of the required work on a project and to not be essential to work progress(i.e., the ability of workers to move on to the next cycle), it is not immaterial. It can cause delay and costs money, especially if workers are required to remobilize and demobilize to get all work "done-done."

Receding-edge costs do not appear explicitly in traditional project controls but rather get lumped-in with various cost codes. This makes them hard to "see" and gauge their magnitude. To offer a sense of their magnitude, looking beyond the Block 8 project in focus, our co-authors from Webcor sampled18 of their structural concrete projects (ranging from $2 to $12 million in work hours) and identified the costs incurred after topping-out (i.e., placing the last floor slab). Receding edge work was embedded in cost codes pertaining to five activities. These activities were performed by unionized workers, carpenters [C] or laborers [L], all working for the concrete contractor:

1. Removing all inventory used for decking, walls, etc. out of the project [L].
2. Performing dry finishes and patching work[L]. This work may be perceived as "needed" (part of the process), but it is rework caused by work not performed earlier and to a sufficiently high-quality standard.
3. Placing concrete curbs [C] and other temporary leave-behind work (e.g., filling hand rail/leave-behind cable column/deck indentations). It may be possible to design the operation to include this scope in the leading edge (e.g., using floating curb forms so that the concrete for the curb can be placed while placing that for the deck).
4. Removing the last floors of re-shore posts [L].
5. Inspecting and cleaning all floors [L].

The division into work performed by either carpenters exclusively or by laborers stems from received tradition and a difference in pay with the latter earning roughly 70-80% of what the former earn. However, division hampers flexibility: lack of multi skilling makes workload balancing and levelling harder to do. It can lead to problems at the handoff between these teams of workers. For example, on the Block 8 project, challenges in concrete finishes that arise when laborers remove formwork can be prevented only during erection of this formwork, which is performed days earlier by carpenters. This division of labor hampers communication (e.g., to proactively develop job-site countermeasures) and discourages workers from taking responsibility for small tasks perceived to be non-crucial (e.g., managing trash). Blame for the occurrence of receding edge work is easily placed on predecessors, and the responsibility for taking care of it is easily pushed down to successors.

The work hours spent on these five activities, relative to the total work hours spent on all concrete work, varied from 4% to 36% and averaged 15%. Of note is that activity 2, finishing and patching, amounted to about ¾ of that 15%, that is roughly-speaking more than 10% of the total work hours. Further study is to indicate how many of these hours could have been avoided, e.g., by adopting lean practices such as building-in quality, redesigning operations, and using standard processes.

LITERATURE ON ACTIVITY START AND COMPLETION

Construction project planning and scheduling means figuring out when to start and finish activities. The still-prevailing conceptualization that uses the Critical Path Method (CPM) involves defining and sequencing activities, and computing which ones are critical vs. non-critical in the project schedule. CPM activities are presumed to have clearly-delineated start- and finish times, as well as unique relationships between them (finish-to-start, finish-to-finish, etc.). However, the presumed “sequential finality” (Crichton 1966 p. 45) is unreal.

Often, activities start despite being “unsound,” as defined in the Last Planner® System (Ballard 2000, Ballard and Howell 2003), or without having a “Complete Kit,” as defined by Ronen (1992) of what is needed to perform them, resulting in workers making-do (Koskela 2004, Formoso et al. 2011). “Starting … with an incomplete kit means more … time to finish the procedure, longer lead time, more ‘work in process’, reduction of throughput, poor quality and impairment of due date performance” (Leshnoand Ronen 2001). Furthermore, on many projects, activities are interdependent and overlap. Such relationships can only to a degree be modelled in CPM by breaking an activity down into smaller ones. At any level of breakdown, concern with the fuzziness of edges remains.

Fireman and Formoso (2013) studied the ocurrence of making-do and articulated “unfinished work” realized by informal work packages (activities). They stressed the need to build quality into the process of doing work and aligning activity completion with quality control (op. cit. p. 520). They also noted that methods for doing work must be well defined (e.g., developed and tested in first-run studies). Specifications of methods to achieve the needed level of process capability, with corresponding worker skill expectations and provision,are inputs to a process.

A process is defective if any of these are lacking, e.g., these inputs are lacking (so the activity itself should not be allowed to start), or the method itself is defective when in execution in a given context the process capability cannot be realized. The here-presented receding edge concept focuses on making-do, not seen as an 8thwaste, but rather as the manifestation of a means to address defects (one of Ohno’s 7 wastes) in execution of an activity, and observable as unfinished work.

Handoffs of work performed by one contractor to another one, and the quality of work required should meet the standards of the contractor doing the work, of the contractor who will perform follow-on work, and of other customers. This means that the receding edge of one contractor is the leading edge of another; if one is fuzzy, the other one is too.

Traditional methods of tracking project costs and progress also overlook important production aspects of the delivery process. Kim and Ballard (2000) argued that project controls using the Earned-Value Method (EVM) fail to account for work flow or for handoffs between trades. The follow-on contractor gets blamed for delays upstream as their predecessor already has earned their value for the work completed. Moreover, the work of the predecessor may be deficient or insufficient for the follow-on contractor(s)to perform and complete their work. Kim and Ballard (2000) also show that EVM considers all hours of work to be identical and treats all productivity likewise. This presumed homogeneity of time and effort is not necessarily an adequate representation of work chunks in general. A key distinction exists between non-value-generating work and value-generating work, which could be essential to project completion. This distinction maybe lost in EVM's consideration of progress and cost. In contrast, the Last Planner® System is all about creating and sustaining work flow reliability, including managing handoffs (Ballard 2000).

Punch lists developed at the close-out stage of construction are a way for the owner, designer, and contractor(s) to capture some of this crucial work. Clean up, spot checking, and other work that must be finished prior to a handoff are included on these lists. However, punch lists tend to include only the end-of-project work, the most notable defects that were left behind, still obvious, and worth noting. Unless a built-in quality program is pursued, the intermediate activities and project phases do not have such lists to ensure such left-behind work is taken care of in a timely fashion. Both of these negatively impact a project, as either the quality of the finished product is compromised, or workers have to waste time and money remobilizing to finish work that should have been completed earlier.

Customers do not want to pay for non-value-added work, it is waste. To reduce its occurrence, quality should be built in the process (Ballard and Tommelein 2014): work must be performed to consistently meet the desired level of expectation, "done-done" the first time around, and never require rework. This is not systematically achieved on projects.

CURRENT PRACTICES& LEAN IMPROVEMENTS

We next detail observations of left-behind work (aka. unfinished work, work in process), i.e., work that is "done" but remains to be "done-done" and thus defines the receding edge. Lean Thinking, specifically the 5 WHYs applied to the unintended, negative consequences, then led to the identification of actionable root causes so the work could be "done-done."

OBSERVATIONS

Forming, placing, and finishing post-tensioned, cast-in-place concrete slabs can be categorized as activities on eitherthe leading- or receding edge. The leading edge is defined by progress made in terms of the number of floors of concrete placed and cured, whereas the receding edge is defined by the number of floors where the contractor has "done" the concrete work, yet clean-up and related processes before handoff to the next contractor(s) are still not "done-done." "Done-done" depends on how "fit-for-purpose" and more generally "quality" are defined for the project (e.g., criteria for exposed concrete ceilings will tend to be more stringent than those for concrete hidden by ceiling tile). Examples observed of work not "done-done" include:

1. **Floor Concrete Finishing**: Figure 1 depicts a floor where concrete work was "done," but still required patching before a smooth surface could be handed off as "done-done" to the finishing subcontractor.
2. **Ceiling and Wall Concrete Finishing**: Figure 2 depicts a wall/ceiling intersection with concrete leakage that occurs at the edge of the floor, causing excess concrete to dribble down and coagulate on the walls of the floor below. The resulting patches of excess concrete must be removed by a returning crew before the floor is cleared.
3. **Left-over Materials and Debris Waste:** Figure 3 depicts a completed floor ("done") where removal of debris and left-over materials is still required in order to handoff a clear space to the succeeding contractor.

Figure 1: Floor concrete holes requiring patching work

Figure 2: Ceiling and wall concrete finish requiring patching work

LEAN IMPROVEMENTS

5 WHYs on Need for Patching

Poor finishes can be addressed using one of two approaches: (1) proactively implement a countermeasure to avoid having bad finishes or (2) reactively implement a process to patch and fix the ceiling surface before handing off the floor.

A 5 WHYs analysis on defects found on the concrete floors (Figure 1) identified as a root cause a lack of cleaning and lubricating standards for concrete formwork panels. A lack of standard process results in chunks of dried concrete remaining after a placement which, if not cleaned prior to the next placement, then cause the panels to stick to the new layer of concrete. This challenge stems in part from the fact that the contractor applies no lubricant to panels (except some on the panel perimeters), prior to the next placement to prevent concrete from adhering to them.

A proactive counter measure is to put form oil on panels (ACI 2018). This is industry practice and the observers were surprised to not see it done on this project. This countermeasure would have another consequential advantage, namely that laborers would gain time and save energy when removing panels. Right now, this is difficult work for them. However, a reason for not oiling forms may stem from a concern for safety. As soon as the deck forms are put in place, other contractors will walk on them to install slab embeds to be cast in concrete the next day. A slippery surface may be hazardous especially to workers hurrying to complete their work in the day allotted. Note that the contractor does clean and thoroughly oil all panels when moving them from one project to the next. Further study to address these concerns with product quality and safety is in order so they can both be met.

As for the reactive approach, the contractor appeared to not have a standard process defining when, how, and who would do the patching. Standardization is the basis for improvement. When a process is standardized and stable, deviation from the standard can be seen and root causes found and addressed. Therefore, a standardized process must be created for patching, and with it comes the need to specify quality assurance and control (built-in quality being the goal). The quality standards must be clear and defined, so that the worker performing the work knows against what standard their work will be compared.

This project did not appear to have a process, when a floor or wall or ceiling must be patched, to ensure the quality standard would be met. A suggested countermeasure is to create reference sheets with pictures of what is or is not acceptable. Laborers performing the patching then will know how their work will be judged. The standards must be defined in accordance with the client's requirements, as the client will judge if the surface is acceptable, and developed with help of current practice and industry standards.

Quality control would happen in several steps. For example, first, when formwork has been stripped, the inspector will take pictures of all finishes that must be improved and pin these locations on a map of the floor. Then, in collaboration with the project manager, they would develop a schedule for the patching crew with dates of completion. A final inspection with pictures would approve (or not) the repairs.

Having a well-defined patching process and quality standards, i.e., defined process capability, has several advantages; without a standard, one cannot notice deviations from it (sic). A standard allows workers to not be in the dark regarding the work they have to perform, how to perform it, and what to expect as output. It gives them a way to judge the quality of their work themselves, so that less or no subsequent quality control is needed.

Of the two approaches mentioned, the proactive one, preventing the need for patching, is preferred over the reactive one, remediating the occurrence by repairing patches.

5 WHYs on Occurrence of Leakage

A 5 WHYs analysis on defects found on walls and ceilings (Figure 2) homed in on panel design and configuration constraints and identified two root cause of concrete leakage at edges. As panels are abutted to each other, there are gaps in-between them and some leakage is expected. However, leakage can be excessive when these gaps get to be too large. One root cause is insufficient consideration given during panel placement in terms of skirting and grading. Another root cause is panels shifting and therebyleaving gaps between edges. We did not investigate approaches to address the first. Approaches to address the latter are(1) preventing the occurrence of concrete drippings and (2) providing a process for removing drippings after they occur.

A preventive countermeasure is to close the gaps between the sides of panels. Figure 4 shows an example of the countermeasure observed on site, covering gaps with duct tape (or metal flashing) to ensure that concrete will not leak. These coverings had to be removed during stripping. Regrettably they also left spots to be patched by a returning crew.

Many formwork accessories exist to prevent concrete leakage. Figure 5 illustrates joint panel strips used to fill gaps between panels or between panels and edges so as to minimize leakage and thereby make it unnecessary for the laborers to later grind concrete down.

The purchase and application of junction panel strips would come at a cost (though small, as the application is only on the edges) and require time to install before concrete placement. In return, elimination of the need to remove any duct tape or metal flashing used currently (Figure 5) to cover cracks, and reduction in leakage would later save time and labor. In tandem with this, a standard process similar to the process mentioned in the previous subsection should be developed within the formwork stripping procedure to ensure that any patchwork can be completed as soon as possible after a placement is complete as concrete hardens over time.

Figure 3: Waste belonging to Webcor Concrete that required removal

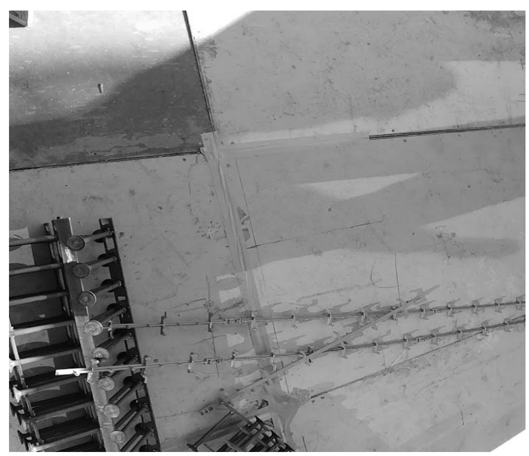

Figure 4: On-site countermeasures taken when gaps between panels are too large

5 WHYs on Left-over Materials and Debris Waste

Waste comprised left-over materials and debris (Figure 3) that laborers must clear off the floor before being “done-done.” These materials were either in excess and needed to be removed, or were supposed to be reused but were left unsorted thereby making reuse harder or misuse more likely. A 5 WHYs analysis on the presence of such waste identified as a root cause that no process was in place, or person held accountable, for cleaning up during work or after the completion of work. No standard was in place to define what is considered a clean workplace, and no process was implemented as work progressed to ensure that no waste would be left over.

Webcor promotes a "clean as you go" process to address the problem of materials left on the floor. However, this process is ill-defined in terms of steps to be taken and control to be exercised to ensure the process is performed in a timely fashion and has been performed correctly ("done-done"). The presence of waste is costly because it is potentially hazardous, it obstructs the passing of workers and handling of materials, and it impedes handing off a clean floor to incoming contractors.

Suggested countermeasures are to facilitate cleaning work on a continuous basis, a part of a built-in-quality process. Every worker, when she or he has things no longer needed, should put them in a designated cart or personal trash container (e.g., Figure 6 illustrates a personal trash container used on a project in Norway). Carts and trash containers should be on wheels and be readily available to any worker. Carts must be labelled so that workers can sort reusable items immediately when they put them down. To promote sorting practices among workers, cleaning should be brought up in daily meetings by the foreman and practices must be systematized. For example, if at the end of one day, the foreman sees waste left on the floor, the next day they would mention it. New workers should be trained so that they know that "clean as you go" is, indeed, the rule and everyday practice. This built-in-quality process should in the long term sustain itself with self-inspections, but other inspections would probably be necessary at the beginning, while worker habits develop.

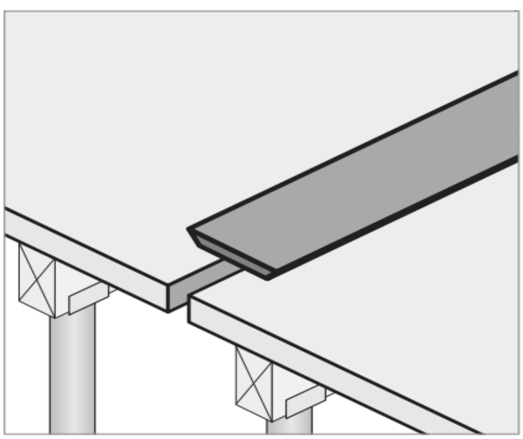

Figure 5: Example of how joint panel strips work in model (Frank 2017)

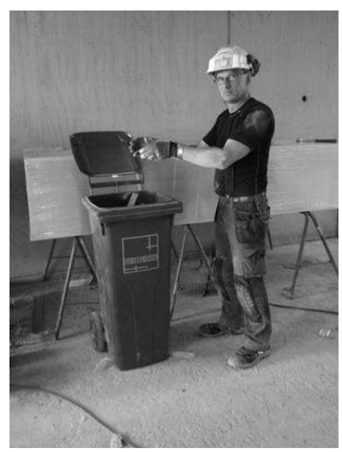

Figure 6: Use of personal trash container (Veidekke 2017)

CONCLUSIONS

Contractors tend to focus on starting work, the first and most visible part of what they are hired to do. While obtaining good production rates on their "leading edge," however, their "receding edge" with less visible work (e.g., repairing defects and cleaning) may fall behind. The consequences can be costly because this work requires crews to stay on or return to site at the end of their project scope.

This paper presented examples of receding edge work pertaining to cast-in-place concrete slabs that were "done" but not "done-done." The receding edge has not been the focus of research until recently, when Fireman and Formoso (2013) began to study"unfinished work." Observed as work-in-progress, receding-edge activities may be the consequence of defects (one of Ohno's 7 wastes) in execution due to lack of inputs (so the activity itself should not be allowed to start) or due to defects in the method itself when, in a given context, its process capability cannot be realized. A key finding is that methods must be better specified and standardized all leading- or receding edge work alike.

This study raises several questions for future research. It was presumed desirable that leading-edge and receding-edge work keep pace with each other. Under what circumstances is this the case and why? As trade specialization may hamper workload balancing and levelling, when is the division of labor "penny wise, but pound foolish" as it relates to production system performance? How can receding-edge work be made more visible (e.g., it is now embedded in various cost codes) and more manageable?

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THE LAST PLANNER® SYSTEM PATH CLEARING APPROACH IN ACTION: A CASE STUDY

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ABSTRACT

The "Last Planner® System" (LPS) is commonly viewed as the foundation of Lean Project Delivery. It is increasingly used in certain parts of the globe. However, LPS implementation often fades off due to issues reported at organisational, project and external levels. The LPS Path Clearing Approach (PCA) offers an antidote to these issues.

The goal of this paper is to outline how the LPS-PCA helped restart a stalled implementation of the LPS through a "shallow and wide" organisational approach rather than a more traditional "narrow and deep" project approach. The LPS-PCA in action is documented within an on-going UK case study organisation. Action and covert research methods were used to introduce LPS principles, thinking and language without attributing them to LPS in response to resistance to the actual LPS. The 15 step actions within the LPS-PCA are expanded from a past, current and future state perspective. The study found that the LPS-PCA's 15 step actions were useful as a benchmark to continuously remove constraints that blocked the implementation of the LPS. In summary, the use of the LPS-PCA is recommended before, during and after organisations engage with LPS Consultants if organisations are serious about sustaining the implementation of the LPS.

KEYWORDS

Last Planner System, Path Clearing, Lean Leadership, Facilitator, Shallow and Wide

INTRODUCTION

LPS can facilitate better project outcomes in the right environment and is a gateway to desirable Lean behaviours (Gehbauer, 2008; Fauchier & Alves, 2013). Successful LPS implementations have resulted in many direct and indirect benefits such as reduced schedules (Fauchier & Alves, 2013; Drysdale, 2013); continuous knowledge development within teams (Skinnarland & Yndesdal, 2012); better collaboration, communication and

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understanding (Fuemana & Puolitaival, 2013); simplification of design management, facilitation of better coordination and collaboration, improved schedules by reducing rework (Ebbs, 2015); and creating a more stable workflow with better matched availability of labour force and increased productivity (Barbosa et al., 2013). Therefore, the correct implementation of the LPS appears critical to successfully embedding Lean in Owner, Architecture Engineering, Construction and Facility Management (OAECFM)organisations. While the benefits of LPS are well documented in the literature, how to sustain implementations through a standard approach and how toover come barriers during the implementation are not as prevalent. The goal of this paper is to report how the LPS-PCA's 15 Step Actions (Daniel, 2017) were used in action for the first time to address the gap in the literature on how to overcome resistance to the LPS by abstracting LPS principles, thinking and language from the LPS and using them to address organisational culture constraints. This paper does not report how to implement the LPS per se or the LPS-PCA in detail (see Daniel, 2017 and Daniel & Pasquire, 2017 for more robust guidance on the LPS-PCA). Rather how the LPS-PCA was used to remove prevailing current state issues to create the right environment and culture required to support LPS is documented.

Several studies (Daniel et al., 2016; Daniel, 2017;Brady et al., 2011; Hamzeh, 2011; Alarcónet al., 2014; Dave et al., 2015) together with the authors' field observations show that the implementation of the LPS varies. The motivation behind Ballard and Tommelein's *Last Planner System Current Process Benchmark* (2016) was to address misconceptions and inconsistent approaches to implementations and poor results of implementations (G. Ballard personal communication 28 February 2018). Additionally, the authors' observed how some aspects of the LPS are discontinued over time without sufficient leadership, coaching and guidance which resulted in benefits not being fully realised. For instance, the case study reported here identified that if senior management insisted on implementing the LPS without sufficient buy-in and leadership from the Project/Site Manager to actively use the LPS, the implementation faded off once the external LPS facilitator stepped back. Additionally, several barriers were experienced in Organisation X (the case study)which prevented a sustainable implementation of the LPS. However, these did not surface until after the implementation of the LPS stalled six months later. This is when the LPS-PCA's 15 Step Actions were used as a benchmark to identify what actions were being addressed and what future actions were required to embed LPS principles, thinking and language through an alternative organisational wide approach called the Business Delivery Meeting (BDM) which will be expanded on later.

The LPS-PCA was developed to guide construction stakeholders (owner, main contractor and trade partners) with step actions to improve the success rate of LPS implementations (Daniel & Pasquire, 2017). The LPS-PCA is not a guide to describe the LPS, rather it is an approach to identify and remove constraints that have stalled past implementations. It is a non-prescriptive approach that integrates 15 Step Actions at four levels - organisation, pre-project, project and external. "Path Clearing" refers to the removal of the implementation constraints identified through a recent study of the UK construction sector (Daniel, 2017). The following pages describe the first practical application of the LPS-PCA Step Actions within a case study organisation (X) who deliver a range of projects on behalf of a UK government body. The projects are delivered in a highly regulated engineering environment and typically include civil, mechanical, electrical and demolition designers and contractors to coordinate desired action with various internal and external stakeholders and departments related to Organisation X. Approx. 50% of staff are direct employees (n=75), the rest are contractors (QS, PM, Project Engineer, Clerk of Works, Planner, Operations etc.).

RESEARCH METHODS

A researcher was embedded within Organisation X and along with the principal investigator are collectively referred to as NTU in this paper. The research was undertaken over two years to design, develop and test a Lean Project Delivery System to improve the reliability of schedules. Fundamental to this was the LPS. In advance of the NTU project commencing, an internal LPS champion (a Toyota trained Continuous Improvement (CI) Manager directly employed by the organisation) made two unsuccessful attempts to implement the LPS. In early 2016, NTU kick-started LPS after the unsuccessful attempts. In hindsight, more attention should have been paid to the factors contributing to failure at this point before restarting LPS with NTU. This would have provided a more holistic understanding of the underling social and technical architecture and prevailing issues (current state).

To identify prevailing issues qualitative research methods were used including interviews and focus groups (n=18), observation, listening, open surveys on “Last Minute Requests” (n=20), and thematic analysis. According to Creswell, (2009)qualitative approaches enable a study to develop a deeper understanding of the problem from the people’s perspective. An action research approach was also taken to implement interventions in practice so their effect could be clearly monitored and measured for effectiveness. Finally, as a result of initial findings covert research methods (Lugosi, 2006)using direct questioning (Socratic Method), listening, and introducing new language around commitments were used to counteract the passive resistance and innovation, initiative and meeting fatigue embedded in Organisation X. Although, covert research methods have been criticised for ethical reason (Herrera,1999), Lugosi (2006) argued this may not apply to all covert research approaches.In this case, the covert action was simply not using labels such as Last Planner System, Lean, Visual Management, Standard Work, Just-in-Time, etc. to describe what was being implemented as these labels had been used previously which set up a resistance with the organisation.

At the start of the NTU project, internal LPS champions’ in Organisation X requested NTU to immediately implement the LPS in order to generate a quick win and buy-in for the LPS to counteract significant passive resistance to ongoing Continuous Improvement (CI) initiatives. However, prior toNTU engaging with the team, the CI Manager (without relevant construction, engineering or LPS experience) made two unsuccessful attempts to implement the LPS. As a result, and by the time the NTU project started, Organisation X’s employees viewed the LPS as just the latest fad. Some of the initial comments included: “LPS won’t work here because we are different… we tried it already and it did not work… we don’t have Last Planners (trades) here… our delays are at the front end and LPS is only for construction trades, but I can see how it would work for them… our projects are not complex enough." Many of the comments were from informal leaders who had privately and publicly dismissed the LPS before NTU were engaged because of prior negative experiences with the CI Manager.

LPS-PCA 15 STEP ACTIONS

The Step Actions in Table 1were not designed to be used in a linear or hierarchal manner as many of them require interaction with each other. Numbers 1 through 15 describe the level where the step action applies together with a reference letter P or B which is related to a process (P) or desired behaviour (B) required to influence a process i.e. Step Action #1 requires Lean Leadership (B) and also a process (P) to educate leaders at organisational level to enable the smooth flow of other processes. Brackets and numbers show where the relevant step actions in Table 1 are discussed in the following paragraphs e.g. (#9 & #14) denotes where the physical space & infrastructure were created (#9) and where external LPS expertise was engaged (#14). Upon reflection the only LPS-PCA Step Action present from the outset of the NTU project was Organisation X engaging with proven LPS experts (#14 i.e. NTU). The next section outlines the context behind the first use of the LPS-PCA in Organisation X & highlights were step actions were missing.

Table 1: LPS-PCA Step Actions (after Daniel, 2017)

Level	#	P	B	Description
Organis-ation	1	√	√	The imperative for LPS& Lean leadership
	2	√		Identify and understand the need for LPS
	3	√	√	Strategic capability and commitment to support implementation
	4	√	√	Behaviours arising from the contract
	5	√		Create awareness of Step Action #3
Pre-Project	6	√		Develop and realise implementation strategy
	7	√		Review current planning practices
	8	√		Evaluate and review Step Action #7 using LPS principles
	9	√	√	Create physical and human enablers for implementation
	10	√	√	Adopt a standard approach
Project	11	√		Implement LPS
	12		√	Instil desired social behaviours in the team
	13	√		Gauge LPS practice
Ext.	14		√	Engage with proven LPS experts
	15	√		Feed learning continuously back into the system

The LPS kick-off workshop for Organisation X involved a hands-on one-day training session with Organisation X's projects department and some of their supply chain (#14). The LPS was introduced using the Villego® simulation with a brief overview of the LPS in the morning. A milestone and phase plan for a live project was created with the team in the afternoon (#10 &#11). The Project Manager (PM) acknowledged during the de-brief how the afternoon application of LPS flushed out many constraints (problems) previously not identified. However, the implementation of LPS paused following the workshop and the researcher was unable to coach the project team for a further 10 weeks until the team and physical infrastructure became available (#9). At the LPS restart (3rd), the existing phase plan had become irrelevant and a new phase plan was created. This was not well received by the team but they acknowledged the time lag as the key factor. A six week make ready plan was then created. Subsequently, the researcher facilitated a number of sessions and began coaching the PM on LPS (at his request) in order to transfer "ownership" of the LPS to the team. However, it became very clear that the required "buy-in", Lean Leadership and strategy for LPS (#1, #3 &#5) were missing and the 3rd implementation of the LPS stopped (this project was finally completed 10 months later than originally planned at the kick-off workshop).

Following this, leadership within Organisation X decided to abandon the implementation of the LPS on that project and start it again during the procurement phase of a land remediation project. Lessons from the previous implementation were learned (#15) and the next implementation was progressing well. The team were turning up autonomously to daily huddles and to update the make ready boards and the PM (different to previous implementation and initially resisting LPS) publicly acknowledged how LPS was beginning to deliver great benefits which included reducing the schedule by 25% and how the team gained a much better understanding of each other's roles, responsibilities and activities through effective conversations at the wall (#2). It appeared a corner was turned and the narrow and deep approach was working (Arbulu and Zabelle, 2006). However, the biggest learning was yet to come.

A request (pull) was made to produce facilitator checklists and a "plan for Last Planner" (#10 & #13) to help the team while NTU were off-site. Eight of the various checklists were subsequently used but once the Head of Department was on holiday (#1) the team stopped using LPS and decided they would pick it up again once the physical works began. Despite such early positive results and feedback on the LPS the 4th implementation of the LPS had stalled by the time the researcher returned to site three weeks later. The internal LPS champion (unfamiliar with the LPS) requested NTU drive (push) LPS forward again – the request was declined and NTU stepped back to investigate why it had stalled yet again. The LPS-PCA was introduced at this point and covert research methods began using bi-weekly team hub meetings to introduce LPS principles, thinking and language but removing any direct references to the LPS and Lean (#10).The LPS-PCA step actions in Table 1 were used to design a covert approach to embed LPS thinking in Organisation X and influence future actions.

LPS-PCA IN ACTION

During the first two months of the NTU project the initial investigation of the current state and subsequent findings were more general in nature. While these findings influenced interventions during the course of the two-year project, the interview questions were not directly related to Organisation X's approach to production planning (#7). In hindsight, this was an error but a great learning point for future LPS implementations. NTU identified Step Action #7 as the place to restart LPS in order to identify the need and understand the benefits of LPS (#2), and to evaluate and review current practice with respect to LPS principles and thinking (#8). NTU crafted interview questions to really understand what the current issues related to planning were and why

LPS kept stalling when the NTU team stepped back. The interviewees (n=13) were from different functions in Organisation X who had taken some part in prior LPS sessions. The interviews were semi-structured and the results provided clear evidence that current production planning and control methods were insufficient. Pasquire and Ebbs (2017) outlined the themes identified during this data analysis. The findings triggered a review of the P6 schedules for eight projects during the next action research cycle in order to establish the average PPC (Percentage of Promises Completed) across the business. This was effectively 25% of the total number of items on the schedules. Additionally, 67% of the items on the P6 plans were not being worked on - essentially P6 plans were not reflecting actual work. Furthermore, P6 plans were only stored on a PC and were not readily accessible or transparent i.e. no visual management.

The review and evaluation of the transcripts (#7 &#8) provided rich data that influenced future interventions and presented some compelling evidence to encourage those passively resisting LPS to become more engaged. At this point, LPS-PCA Step Actions #2; #4; #6, #7, #8, #9, #10, #11, #13,&#14 were being used to implement the LPS on some of Organisation X's projects. However, the narrow and deep approach was not working primarily due to a lack of Lean Leadership (#1),little awareness of strategic capability and a lack of commitment to support the implementation (#3 & #5), and discipline to adhere to a standard approach (#10). During the 4th LPS implementation a procurement officer asked "if LPS is so good, why are we the only ones using it? Why are the rest of the organisation not using the LPS?" A covert "shallow and wide" approach and LPS implementation strategy (#6) followed that abstracted LPS principles, thinking and language but removed any references to Lean or the LPS.

BI-WEEKLY TEAM HUB MEETINGS: A COVERT APPROACH TO LPS

The projects department already had morning meetings to share planned activities. However, these were unstructured, inconsistent and of little value to attendees. About a month after the 4thLPS implementation stalled NTU began a more covert unknown to the majority of participants. NTU began by replacing the morning meetings with bi-weekly team hub meetings and abstracting the following elements from LPS:

- Standard agenda and approach based on LPS thinking (#10 & #11)
- Stand-up meetings
- Visual management of plans (#9)& ownership of promises i.e. only the PM's wrote and updated their project's activities (a step towards Last Planners)
- New language around making reliable promises
- Rules for making commitments (Macomber and Howell, 2003)
- Tracking PPC and variance i.e. Reasons for Missed Commitment (RMC)
- Timekeeping – start and finish meetings on time
- Gauging practice through facilitator checklists (#13)
- Using meeting ground rules and rotating the facilitator (#9 & #12)
- Experimentation through plus/deltas (#13)& taking action of deltas
- Identifying constraints/support requests (making ready)
- Prioritising work/support across projects where conflicts arose

- Cross functional participation in the meetings

Action research cycles were used to improve the structure and output of the meetings. Additionally, the meetingsalso provided an opportunity to gather RMC data and refine the categories through which the RMC were recorded against (#10).RMC is more commonly known as RNC (Reason for Non Completion) or Reasons for Variance (RV) in the literature. However, NTU decided that "commitment" was more powerful and a covert opportunity to introduce Lean language. The original plan with the bi-weekly team hub meetings was to use the projects department as a pilot, refine, and then roll out across Organisation X. However, another bottom up approach emerged that built on the success of the team hub meetings and encouraged LPS thinking by other departments/functions.

THE BUSINESS DELIVERY MEETING: LPS THINKING& METRICS FROM AN ORGANISATIONAL PERSPECTIVE

Covert methods were re-employed with some middle and senior management using the book *Team and Teams* through a Study Action Team (SAT) format. SAT's are an alternative approach to create a shared mind (Hill, Silvon, & Draper, 2007; Silvon & Macomber, 2010). In *Team of Teams* McChrystal et al. (2015) reported how silos were broken down between organisations fighting the same war against Al Qaeda by creating an environment to freely share information in order to deliver on a common purpose. They developed a daily meeting were 7,000 people heard the same information at the same time – similar to a daily huddle or weekly coordination meetings in the LPS but with significantly more people present. "[Their] thinking was that the value of this information and the power that came with it were greater the more it was shared" (p.167).

The BDM emerged from the SAT discussions through direct questioning on how similar concepts in *Team of Teams* would work at Organisation X. The BDM was a cross functional weekly coordination meeting based on LPS thinking but from an organisational view rather than a project view. The facilitator rotated between the Head or Projects, Operations and SHEQ. Others facilitated in their absence (#1).The Project or Department Manager's report out followed the same structured agenda listed below (#10):

- What is your project's PPC for last period i.e. # tasks promised: # tasks completed?
- What are you doing to address missed commitments?
- How many promises have you got for next week?
- Which of these are your priorities?
- Who do you need to support you with these?
- Is there anything that will stop you from fulfilling your promises over the next 2 weeks? What can we do to remove any constraints?

Metrics sheets displayed project level metrics such as PPC & RMC trends. However, they were also collated for business KPI's & to emphasize systems thinking. Actions, parking lot topics not relevant to the meeting and plus/deltas were also captured and any important issues for escalation was discussed in smaller groups at the end. The shallow and wide approach to the LPS through the BDM ultimately had a number of effects:

Firstly, it suggested that LPS thinking and principles from an organisational perspective were effective to improve business delivery performance. PPC trended above 70% as a result of the BDM - a significant improvement on the 25% PPC alluded to earlier.

Secondly, to direct appropriate CI, the need to collect reliable data from a system perspective but from as close to the source possible was highlighted. It transpired during a Root Cause Analysis (RCA) workshop on the trending RMC at the time(not prioritised/bad planning) that RMC data and RCA must be collected and actioned at the project level. Furthermore, the PM's realised that the "promises" recorded on the P6 schedules at the BDM were not theirs. Rather, they were their colleagues' activities which were also not "promised" or made ready. The P6 schedule was producing the promises and when the PM asked the team if they were ok to deliver on the schedule, the usual "yes" was always heard. The weekly promises from the majority of PM's respective teams were often not captured on P6 and the BDM team realised this i.e. P6 was still not accurately reflecting on-going or planned work. The Department Heads along with the PM on the $50m land remediation project agreed to use Post-its® on rolling wave six week make ready commitment boards along with the standard BDM agenda for each project team member to use at their weekly project meetings in order to bring LPS thinking, principles, language and metrics down to those closest to the work i.e. the Last Planners.

Finally, the BDM participants recognised and challenged unreliable language and began to understand that reliable promises were the pre-requisite for reliable workflow and ultimately reliable project delivery. For instance, where phrases such as hopefully, fingers crossed, that should happen etc. were heard, clarification was typically sought through the question "what makes that a yes or no?" (J. Klous personal communication 25 August, 2017). A PM recently noted that what was not heard anymore in Organisation X was "I did not know anything about that."

CONCLUSIONS

This paper contributes to knowledge and practice by outlining how covert research methods were used to support a shallow and wide implementation of LPS thinking, principles, language and metrics in an organisation (X) to counteract resistance to the actual LPS. However, while positive results were recorded at an organisational level by abstracting LPS principles, thinking and language by implementing through the BDM, the study is incomplete and the use of the LPS in its true form has not yet been fully embedded at project level. Results of this will be reported in future IGLC proceedings.

We conclude that to create the environment for sustainable success caution must be drawn to a number of important observations. 1) Lean Leadership for the LPS and engaging with proven LPS experts are critical step actions. The success of the BDM was largely due to appropriate Lean Leadership from PMs and Department Heads (#1) and because Organisation X engaged with the NTU team (#14).Without appropriate Lean Leadership (including informal leaders) LPS should never be pushed unless an organisation is willing to pay consultants to facilitate every LPS session. However, this will not build any capacity or ownership to sustain the LPS going forward.2) Organisations without a Lean Strategy Team (with CI Departments)do not foster the required Lean Leadership to sustain Lean transformations – informal leaders, senior and middle managers must be fully engaged to maintain momentum. Otherwise the responsibility for CI and LPS will be passed on rather than led from the top. 3) For example, beware that a Toyota trained expert in Lean with a manufacturing or production background is unlikely to be an expert in LPS. Relevant design and/or construction experience of the LPS facilitator is highly desirable in order to build credibility with the team. 4) The LPS or any associated LPS infrastructure such as the room, meeting, boards, metrics etc. should not "belong" to anyone. The team needs to own the system and be willing to learn and improve how they use it. A key sustainability test is when the proven LPS facilitator steps back and the team keep up momentum.5) Depending on the Lean maturity of an organisation the level of difficulty implementing LPS will differ. Step Actions #7 & #14 are safe places to start.6)Do not rush the implementation of the LPS. Carefully consider the most appropriate approach for each project/organisation. Before designing a Lean Project Delivery System identify the current state issues related to production planning in order to clearly understand the problem and demonstrate the need for LPS (#7 & #2). 7) In summary, the use of the LPS-PCA's 15 Step Actionsis recommended before, during and after organisations engage with competent LPS Consultants if they are serious about sustaining the implementation of LPS.

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MAKE READY PLANNING USING FLOW WALKS: A NEW APPROACH TO COLLABORATIVELY IDENTIFYING PROJECT CONSTRAINTS

Paul J. Ebbs[1] and Christine L. Pasquire[2]

ABSTRACT

Many authors identify flow and pull as key lean production principles. In lean construction (LC)these principles are embodied within the “Last Planner® System” (LPS) to create more reliable workflow which is the heart of Lean Project Delivery. LPS has continued to evolve and develop over the last 25 years with pull planning – identifying what tasks SHOULD be done - the last major elementadded. However, “pull planning” is often misunderstood as the entirety of LPS and frequently referred to as “Last Planner”. The remaining levels of the Last Planner “System” – CAN; WILL; DID and LEARN - are not being used as originally intended by LPS developers Ballard and Howell. The struggle often begins with Make Ready Planning (CAN).

This paper is the first output of a two-year research project focused on implementing the CAN; WILL; DID; LEARN levels of LPS within organisation (X). It outlines how the 8 Flows of Lean Project Delivery andthe“Flow Walk” are being used as a structured approach to collaboratively identify constraints and incorporate them into the risk registers and Make Ready Planning. This approach was effective to identify constraints and also create a shared understanding of project scope within project teams.

KEYWORDS

Last Planner System,Make Ready, Flow Walks, Constraints, Risk Management

INTRODUCTION& BACKGROUND

Koskela (2000) proposed the Transformation, Flow, Value (TFV) theory of construction production and stressed it should be seen from these perspectives, rather than simply the conversion of raw materials to a product. However, project teams are typicallyonly focused on maximising local productivities (optimising the piece), for example using

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Work Breakdown Structures (WBS) (Ebbs, 2015; Ballard et al., 2012) rather than optimising the whole through work structuring.Sarhan et al. (2017)also recognised this narrow perspective within the safeguarding activities of procurement systems.Discrete contracts do not typically consider the interaction and interdependence between project stakeholders promoting the management of projects by enacting contracts in silos where performance is measured in isolation from whole project purpose and value. Individual interests prevail in an attempt to minimize the risk of one stakeholder versus another (Howell & Koskela, 2000; Macomber & Howell, 2003; Slivon et al., 2010). A prevailing belief is that this optimisation of individual pieces of the project through the management of discrete contracts creates resource efficiencyand that this optimisation is achieved through the elimination of waste.Some, such as Cooke and Williams (2009) even propose lean construction simply as the elimination of waste from the production cycle. However, this belief set is a flawed understanding of lean principles representing a reductionist view heavily criticised by Green (1999). The extent of this belief set was tested by Ebbs et al. (2015) as follows:

Table 1: Understanding of Lean Construction through thematic analysis (n=84)

Code	**Total (84)**	**Arch (12)**	**Eng (5)**	**Con (18)**	**QS (10)**	**Ac (38)**	**Owner (1)**
Reduce waste	**40**	4	2	9	6	19	-
Holistic process	**22**	4	2	5	4	7	-
Reduce material waste	**17**	-	-	2	3	11	1
Reduce time	**16**	-	-	4	1	11	-
Reduce labour/resources	**15**	1	-	-	5	9	-
Reduce cost	**14**	2	1	5	-	6	-
System	**7**	-	1	1	-	5	-
Sustainability	**7**	2	-	1	2	2	-
Philosophy/concept	**6**	1	-	-	-	5	-
Continuous Improvement	**5**	2	1	2	-	-	-
Quality	**4**	-	-	1	-	3	-
Value engineering	**4**	-	-	2	2	-	-
Flow	**2**	**-**	**1**	**-**	**-**	**1**	**-**
Culture	**2**	-	-	1	-	1	-
Safety	**1**	-	-	-	-	1	-

Key: Arch – architect; Eng – engineer; Con – contractor; QS – quantity surveyor; Ac - academic; Owner – owner/client

This finding correlates somewhat with the reductionist perspective and indicates a minimal consideration of flow or value. This is interesting as both Womack et al.'s (1990)5 Lean principles and Liker's (2004) 14 Toyota Way Management Principles are leading texts informing industry and academia; neither offers the elimination of waste as a method for efficiency but rather discuss waste reduction as an outcome of achieving flow. Eliminating waste to maximising resource efficiency is often a focus of lean literature, however helping materials, information, people and product flow is the critical concept to grasp (Koskela, 2014; Rother, 2010; Bertelsen et al., 2006; Modig, & Ahlstrom, 2015; Umstot & Fauchier, 2017; Pasquire, 2012; Pasquire & Court, 2013; Pasquire & Ebbs, 2017). Simply striving to eliminate waste will not necessarily create value as eliminating waste from one task may increase it in another. Therefore, it is important to optimise the whole not the individual pieces. In other words, flow efficiency beats resource efficiency because the consequence of stopping the flow of work is far greater than having spare resource capacity (slack) on hand. Workflow is stopped or interrupted by constraints some of which have a bigger impact on a project's production system.

Within a project the various team members act as "customers" and "suppliers", constantly passing information to each other through conversations. However, information flow becomes difficult without explicit shared understanding of each other's requirements and constraints (Pasquire & Ebbs, 2017). Often, rework is required because the information is misunderstood, incomplete or incorrect. This stops the flow of work. Having shared and common understanding of the next customer's requirements (which includes constraints) is critical to improving flow (Pasquire, 2012) because often these constraints are already known by a member of the project team.

The first part of effective problem solving is to clearly identify the problem. Similarly, before removing a constraint or mitigating a risk, it must be identified. This drives appropriate action in the make ready process to prepare for flow.

The following pages introduce a new approach to collaboratively identify constraints and risk from both project first thinking and different stakeholders' perspectives. Called a "Flow Walk" it was developed within the framework of the Last Planner® System to influence desired action and to support project planning at Milestone, Phase and Make Ready Planning levels of the LPS in order to improve the reliability of schedules (Pasquire & Ebbs 2017).The Flow Walk improves the safety and quality of assignments by replicating the effective conversations that take place during pull planning. Customers and suppliers share their understanding and conditions of satisfaction related to constraint removal and risk mitigation. The research methodology used in its development, how it has been used in practice along with some preliminary results and opportunities for future research are discussed in the following sections.

RESEARCH METHODOLOGY

The Flow Walk was designed, developed, and tested through six action research cycles within a 27 month, funded UK case study within an Organisation (X) and through external workshops at the NTU Centre for Lean Projects 2nd Annual Research Showcase Day and LCI UK's Annual Summit in 2017. Each of the six action research cycles of the Flow Walk informed the development of the next.

FLOW WALK DEVELOPMENT IN PRACTICE: ACTION RESEARCH

The purpose of designing and developing the Flow Walk was primarily to provide a structured and collaborative approach to firstly identify project constraints at milestone level planning and secondly, to provide the context for desirable action to remove constraints within the framework of the Last Planner® System at Milestone, Phase and

Make Ready Planning. We define a constraint as anything that would stop or disrupt the flow of project delivery in an organisation or on a project. A risk on the other hand may not transpire but could impact the production system if environmental conditions change.

Six workshops were conducted over 16 months. They combined divergent and convergent thinking to encourage essential conversations between the team and create a shared understanding of constraints and project scope. The workshops happened in this order: 1) Organisational constraint identification (June 2016) [3] .2) NTU Research Showcase Day to refine the process steps with industry practitioners and academics (February 2017). 3) Project constraint identification on a new $5 million concrete raft with in-house project staff from Organisation X (June 2017) followed by 4) same project but with the preferred construction partner only (June 2017). [4] 5) A $50 million demolition and land remediation project with staff from Organisation X during scope definition, strategy outline, feasibility and pre-risk register stage (September 2017). 6) LCI UK Summit Training Day Workshop using a sample "build this room" project to share the updated process and incorporate learning from the previous action research cycles (October 2017).

FLOW WALK PRE-WORK: DIVERGENT THINKING

To gain a holistic understanding of constraints to project delivery, the first step was to solicit individual perspectives of constraints to each of the 8 Flows by simple questioning and discussion. During Flow Walk #1 we identified the constraints through a mini brainstorming workshop (n=3) using a dedicated flip chart and coloured Post-it®[5] for each flow. While many constraints were identified they were only from three perspectives (one of those being the embedded researcher). In order to collect more perspectives, a broader group of people were provided with an excel spreadsheet in advance of the 3rd, 4th, and 5th Flow Walk workshops within Organisation X. Consequently, over 200 individual constraints were identified from an average of seven people at each of the Flow Walk workshops. Figure 1 is a compressed example of the A3 excel sheet used to gather the data from participants using the colours of the 8 Flow conceptual model documented by Pasquire and Ebbs (2017).[6]

1) Information - Blue	2) Equipment - Pink	3) Materials - Light Blue	4) People - Yellow
5) Prior Work - Green	6) External Conditions - Red	7) Safe Space - Orange	8) Shared Understanding - Purple

Figure 1: Sample Flow Walk Pre-Work Sheet

3 Pasquire and Ebbs (2017) documented the output from this workshop in IGLC 25 proceedings.

4 Separate workshops were held because the contractor was not in contract.

5 We refer to Post-its as tags in this paper also.

6 Flow Walks #2 and #6 (Research Showcase Workshops) were unable to use pre-work. Instead we had the participants write their constraints to the sample project directly onto a tag and place on the flip charts at each of the 8 Flow stations.

The individual constraints collected in advance were transferred from the A3 pre-work sheets onto Post-its and then onto their respective flow sheet by the researcher ready for further development(see the flip charts in Figure 2& 3).Similar constraints in each flow were grouped together by the researcher and assigned a category name[7]. The purpose of the researcher doing this was to ensure the workshop was focused and structured from the start and to keep the teams engaged during the developmental experimentation.

Figure 2: Flow Walk Participants at LCI UK Summit 2017

FLOW WALK ROUNDS: DIVERGENT TO CONVERGENT THINKING

In rounds 1 through 5 of the Flow Walk the participants addressed each of the bullet points listed below in order to move from divergent to convergent thinking. Conversations on the constraints in both a structured way and also from different stakeholder perspectives leveraged the participants' experience. Figure 3 illustrates the output of rounds 1, 2 & 3 from the 6thFlow Walk.

Round 1: Individual Flow Walk - Validation

- Validate categories (these were originally chosen by the researcher).
- Identify any constraints that impact other flows.
- Identify each multiple impacting constraint with a yellow dot and write the reference number of the impacted flow(s) on it (1 through 8).
- Turn the tag of any constraint that is either unclear/vague or requires clarification into a diamond shape.

Round 2: Group Flow Walk - Consensus

- Clarify all constraints on diamond shape tags.
- Agree on category content & name.
- Add any additional constraints (extra tags).

[7] Similar constraint categories were found in multiple flows. We will discuss this more later.

Round 3: Individual Flow Walk – Prioritise& Total Categories

- Each participant has 16 red dots to place on the constraint(s) they perceive to have the biggest Level of Impact (LOI) i.e. place 2 red dots on any two tags for each flipchart (flow) but you are also allowed to place both red dots on a single tag.
- Total the categories in each flow by adding the #tags +#red dots + #additional flows (numbers inside the yellow dots in Figure 3) on each line.

The diamonds in Figure 3 represent the constraint category name within each particular flow. The numbers on each category relate to the output from Round 3 which totalled the number of references to each category i.e. #tags + #red dots + #yellow dots. The yellow dots relate to where the participants' perceived the constraint impacted another flow. For example: #4 impacts the people flow and #8 impacts the flow of shared understanding. The numbers on the diamond tags are meaningless per se. However, they helped trigger conversations to gain an understanding of different or opposing concerns between the participants. This resulted in some constraints being removed at the wall during the conversations. Furthermore, participants agreed that a reciprocal understanding of project scope and strategy began to emerge.

Figure 1: Flow of information output from LCI UK Summit Training Day 2017

Round 4: Group Flow Walk – Combine

- Ask the participants to remove the diamond tags from each flow and bring them to a fresh sheet of plotter paper on the wall. Place the constraint category tag with highest LOI to left hand side (L/H/S)of the plotter paper.
- Add similar tags from other flows and name the new group category by consensus.
- Repeat the process until all thediamond summary tags are removed from the flip charts (flows)and are placed within their new group categories on the plotter paper.
- Total each new group of diamond tags.
- List out new group categories in order of LOI (Green ink in Figure 4&Table 2).

Round 5: Poll Time – Level of Confidence

The final round of the Flow Walk workshop requires the participants to individually rank each group category between 0 and 10 regarding the team's Level of Confidence (LOC) in their ability to remove the constraint where 0 is outside team's control and 10 is fully within the team's control. However, the perceived LOC for each constraint category illustrated on the L/H/S of Table 2 was identified from group rather than individual perspectives and sufficient time for discussion was not allowed.

Individual ranking of constraints was solicited from the participants during the 5th Flow Walk because the collaborative output was being used to develop a project risk register. During Round 5 the participants are asked to:

- Total the individual responses and record the range and the average response to each group. For example, from 3 to 9 with an average of 7.8.
- Insert the LOC rating in the orange triangle beside each group category (Figure 4 & Table 2).
- Discuss the lowest and highest individual ratings and any differences of opinion.

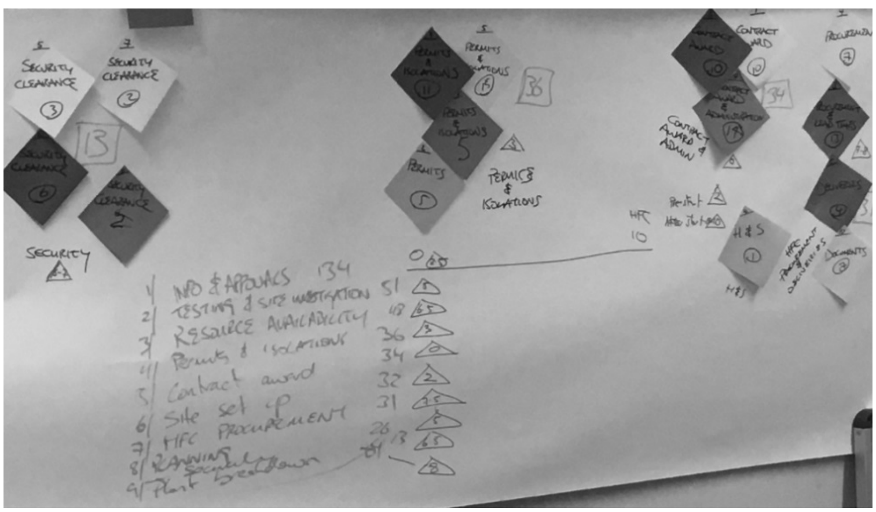

Figure 2: Output from Flow Walk #4 with Organisation X's Construction Partner

Figure 4 illustrates the combined results of Rounds 4 and 5.The output after Round 5 is the result of convergent thinking. The diamonds in each group category illustrates how similar constraint categories appeared in & are perceived to affect other flows. The output of Flow Walk #4 is illustrated in the Contractor Constraint Categories section of Table 2.

The outputs from Round 5 of Flow Walks #3 & #4 were combined by the researcher. Table 2 illustrates the summary of these results. Similar group categories emerged regarding communication, information, understanding, approvals, contractor equipment, site access, material procurement, and contractor resources. These categories are denoted by a tick (√**)** to the L/H/S of the LOI column. Table 2 illustrates how Organisation X identified 7 additional constraint categories and the contractor added a further 4 categories not previously identified by their respective peers.

Table 1: Flow Walk Group Categories of Constraints

Rank	LOC	Organisation X Constraint Categories		LOI	1	2	3	4	5	6	7	8
1	10	Communication & Information Understanding	√	66	X			X	X	X	X	X
2	10	Approvals & Signatures	√	56	X	X		X	X	X		X
3	6 to 9	Documentation		53	X			X	X	X		X
4	2	Phase 2		45				X	X	X	X	
5	7	Availability of Owner reps		37				X	X		X	
6	5	Contractor equipment	√	23		X			X			X
7	10	Owner equipment considerations		21		X		X	X			
8	10	Material specs		19	X		X					
9	5	Site access & interface	√	19			X		X	X	X	
10	8	Planning Permission, Conditions & Approvals		19	X				X	X		
11	3 to 5	Material procurement	√	19			X	X		X	X	
12	0	Unforeseen	√	17			X		X	X	X	X
13	10	Unclear or changing scope		14	X				X	X		X
14	5	Contractor resource	√	8				X	X	X		
Rank	**LOC**	**Contractor Constraint Categories**		**LOI**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	2.5	Information & Approvals	√	136	X	X	X	X	X	X	X	X
2	5	Testing & Site Investigation		52	X			X	X	X		X
3	6.5	Contractor Resource Availability	√	52	X	X	X	X		X	X	
4	3	Permits & Isolations		36	X			X	X	X		X
5	0	Contract Award & Admin		34	X			X	X	X		X
6	2	Site Set-up & Access	√	32	X	X	X		X	X	X	X
7	5	Planning, Problem Solving, Collaboration & Understanding	√	27	X			X	X	X	X	X
8	7.5	Contractor Procurement & Deliveries	√	24	X		X	X		X		
9	6.5	Security Clearance		13	X			X	X	X		
10	3	Weather & Unforeseen Events	√	12	X	X	X	X		X		

FINDINGS

During the 3rd Flow Walk workshop, pipe saddles were identified as a major constraint. However, the saddles were only identified by one safety representative during the pre-work. During the workshop the PM and team quickly recognised the impact. The procurement, manufacture, delivery, and installation of the bespoke saddles would have prevented the operation of the raft (its original purpose) once the construction phase was completed. The cost of the saddles was circa $65,000. However, many suspected the time delay to operations would have been several months. Evidence subsequently emerged how constraints are contingent on project purpose. It turned out the saddles were no longer required as the original purpose (use) of the raft changed after 25% of the raft was poured because of a business change within Organisation X's Parent Organisation. While unclear or changing scope (purpose) was identified as a major risk during Flow Walk #3 by Organisation X and this was recognised in Table 2 as being fully within the control of the team, it turned out that those with intimate knowledge of this possibility were not involved in the Flow Walk pre-work or workshop. As a result, the risk was not specifically identified. However, specialised and expensive modifications to equipment required to operate the raft were identified as significant constraints in the Flow Walk, but this equipment became redundant as a result of the change in project purpose.

During Flow Walk #4, breakdown of the concrete batching plant was identified as a risk that would disrupt the flow of the project. However, this was only identified by the contractor's planner and the risk to the project delivery schedule was not deemed significant. The risk became a reality and project production stopped for 2 days due to the concrete plant breakdown from cold weather (external conditions) and equipment failure. Furthermore, while slack and set-based thinking were suggested by NTU so spare capacity was available (i.e. another plant), single source procurement was preferred to maximise resource efficiency. The primary purpose of the 5th Flow Walk was to develop a risk register. The participants' found that this approach probably doubled the number of risks identified over a traditional risk workshop principally because the traditional approach lacks the depth of collaborative engagement & therefore range of knowledge and expertise.

CONCLUSION

The LPS has added "CAN" and "WILL" to traditional planning. "CAN" through the make ready process to screen tasks for constraints and "WILL" through commitment planning and control, but, reliable commitments are only possible if effective make ready planning has occurred. Consequently, the LPS is only truly effective when used in its entirety(Ballard, & Tommelein, 2016; Koskela, & Howell, 2002). During the case study it was observed the struggle with LPS began with make ready supporting previous observations that pull planning or just tags on a wall are often described as "Last Planner"(Daniel, 2017).While pull planning is helpful to identify sequence, dependencies and constraints and is a pre-requisite to the make ready process, the success of make ready is ultimately never known until the person waiting for the work declares their satisfaction. In the case of the saddles or the availability of concrete this would not have been known for 6 - 9 months. The impact of the saddles and equipment modifications on the project was a significant amount of unnecessary work and overburden to a project team – types of waste that impact flow and value creation. This example illustrates how the impact of constraints is contingent on project purpose being clear and communicated sufficiently and emphasized the importance of having the right people in the room during project definition phase (Ballard, 2008) to ensure purpose or alternative purposes (using set-based thinking) are well defined from the outset in order to plan for flow efficiency.

Additionally, risk is currently not explicitly considered during make ready planning. Risk is by definition uncertain. This may help explain why teams often struggle with make ready planning as resource efficiency is favoured because incorporating something that may not happen into the planning system is not valued (i.e. upfront cost allocation and planning for flow efficiency). We conclude that the "Flow Walk" is an effective approach to identify constraints and risks as well as creating a shared understanding of project scope, strategy and purpose. Furthermore, the success of a Flow Walk could be gauged by the examining data collected from missed commitments to understand how effectively constraints and risks were identified and removed. Future research will focus on developing the Flow Walk so that risk can be pulled into production planning. Essentially, this calls for a new approach to risk management where risk is embraced rather than passed on. A research question remains: how can teams measure something that never happens? i.e. if the constraint or risk never impacts the production system because it was made ready?

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GUIDELINES TO DEVELOP A BIM MODEL FOCUSED ON CONSTRUCTION PLANNING AND CONTROL

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ABSTRACT

Information pulled from 4D simulations may be used to compare construction scenarios as well as to support decision-making in production planning and control. Different projects, software, tools and planning methods result in a diversity of inputs that should be considered while trying to fulfil 4D simulation needs. If those are not properly addressed, it may lead to inconsistencies and lack of suitable information. The existing literature on 4D BIM does not provide much advice on which information should be considered to develop a 4D simulation. The aim of this paper is to propose a set of guidelines to devise BIM models to support production planning and control with emphasis on Lean Construction principles and concepts. Design Science Research was the methodological approach adopted in this investigation, which was based on three empirical studies. The main contributions of this study are concerning with understanding the sources of information for3D modelling and how information should be gathered so that 4D BIM model scan effectively support planning and control decisions. A model based on these guidelines should provide relevant information to support decision making, and consequently contribute to reduce variability, increase data reliability, eliminate non-value adding activities and reduce 3D modelling time.

KEYWORDS

Modelling inputs, 4D simulation, production planning and control, lean principles.

INTRODUCTION

Construction planning is the production of cost estimates, schedules, and other detailed specifications of the steps to be followed and the constraints to be managed in project execution (Ballard and Howell 1998). Once production begins, managers should make efforts to control, i.e., monitoring performance against those specifications, to perform

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corrective actions whenever needed to achieve a desired performance(Ballard and Howell 1998). The effectiveness of production planning and control in construction depends significantly on the reliability and timeliness of resource information (equipment, labour and materials) (Dave et al. 2011).Any improvement in information quality, which is used as inputs for planning processes, should therefore positively affect planning quality, planning outputs and possibly improve predictability of project delivery(Gledson and Greenwood 2017).

According to Crotty (2012), Building Information Modelling (BIM) can be usedto improve the quality of building design information and to establish mechanisms and procedures by which information is communicated and shared amongproject team members. Fundamentally, a project team cannot produce great results without trustworthy information and reliable workflows (Fosse et al. 2017). Sacks et al. (2010)pointed out that there are several interactions between Lean principles and BIM functionalities that support the argument that several synergies exist between them. This implies that to enhance lean outcomes, the adoption of BIM should be considered (Sacks et al. 2010).

4D simulations consist in assigning tasks from project schedules to 3D BIM elements in order to visualize the construction process over time (Boton et al. 2015). These enhancements should enable planners to produce more reliable schedules and communicate planning decisions more effectively (e.g. construction sequencing). This effective communication enables directing the plan recipient toward the exact location of work content and even visualize impacts of resource movement and site logistics(Gledson and Greenwood 2014).According to Eastman et al. (2011), even though planning and scheduling processes may vary depending on the tools adopted, there are several issues that any planner or 4D modelling team should consider while preparing and developing a 4D model.

Research efforts have pointed out advantages of BIM, especially by using 4D simulation to support production planning and control, such as analysing the use of construction site space (Heesom and Mahdjoubi 2002), planning resource utilization (Li et al. 2009), planning for safety (Sulankivi et al. 2010), improving construction site layout (Zhang and Li 2010), analysing and monitoring construction progress (Kim et al. 2013), and planning workflows(Li et al. 2014).Those studies have focused on practical applications of 4D existing tools or in the development of new solutions, integrating the 4D environment to other software tools. However, only a few of those studies have explained clearly which information should be considered to build up a BIM model for 4D simulations. Moreover, most of them have not emphasised the efforts required and possible problems that modellers may face. Based on that, the aim of this paper is to propose a set of guidelines to devise BIM models to support production planning and control with emphasis on Lean Construction principles and concepts. These guidelines are based on three empirical studies carried out in different construction sites.

RESEARCH METHOD

Design Science Research (DSR) was the methodological approach adopted in this study. The goal of DSR involves the development of an innovative artefact to solve a practical problem at the same time it produces scientific knowledge (Holmström et al. 2009), and making also a theoretical contribution (Kasanen et al. 1993). Even though this research adopted DSR, the empirical studies were carried out as Action Research (AR) studies: representatives of the companies were fully engaged in the implementation of changes, and there were several learning cycles during the research process.

For each empirical study the research process was divided into the following phases: understanding the problem, development of the artefact, and analysis and reflection. The first phase consisted in understanding companies' context and production planning and control methods adopted. In Empirical Studies 1 and 3, as there was no BIM model available at the beginning, the research team defined the purposes, strategies and criteria to develop BIM models. In Empirical Study2, the model was made available by the architectural design firm. In the development phase, the 4D BIM model was built to support production planning and control. The development of the 4D BIM model was based on stakeholders needs and intended use. Finally, the analysis and reflection of the results were made and as a result of this phase, a set of guidelines was proposed.

Data from three empirical studies were retrospectively analysed and are the background and source of information for the guidelines established. Some key information regarding these empirical studies are compiled in Figure ,indicating the software used, whether the model was developed or provided by the company, companies' description, brief description of the projects, as well as the sources of evidence used.

	Research A		Research B
	CASE 1 (12 months)	**CASE 2 (5 months)**	**CASE 3 (11 months)**
Software	**3D model -** ArchiCAD 20 **4D simulation** - Vico Office R6.1	**3D model** - Revit 2018 **4D simulation** - Vico Office R6.5	**3D model** - Revit 2017 **4D simulation** - Synchro Pro
3D model	Researchers developed the 3D model based on 2D CAD drawings of the architectural design	Company provided the architectural 3D model developed	Researchers developed the 3D model based on 2D CAD structural design drawings
Company	Construction company focused in the residential buildings segment	Construction company focused in the residential buildings segment	Company delivers complete solution of prefabricated structures
Project	Residential condominium consisting of 99 houses with 5 different layouts located in Porto Alegre, Brazil	Residential condominium consisting of 5-storey towers with 30 apartments each located in Porto Alegre, Brazil	University campus located in Porto Alegre, Brazil
Source of evidence	**Document analysis (including 2D designs, 3D models, and planning and control data)**		
	Interviews carried out with project stakeholders		
	9 unstructured interviews carried out with external consultants to discuss the plans, the BIM model needs, its development and 4D simulation	4 semistructured interviews with project manager, project planning responsible and the architecture firm which developed the 3D model to identify if it would attend 4D simulation	6 unstructured interviews carried out with concrete prefabrication company and Company C
	Site visits	**Meetings with site manager with the support of 4D simulation**	
	7 site visits to compare the 3D model to the construction site	5 meetings to discuss the master plan using 4D simulation	26 meetings to discuss loading plans using 4D simulation
	Participant observations in short/medium-term planning meetings to discuss construction progress		
	11	5	5

Figure 1: Description of the empirical studies

In each empirical study, researchers attempted to identify a diversity of inputs that should be considered while developing or adapting BIM models to use for supporting production planning and control, i.e. inputs stemmed from projects characteristics, software and planning methods.

RESULTS

EMPIRICAL STUDY 1

In the empirical study carried out in Company A, the demands from the stakeholders involved in production planning and control (project manager, quality managers, subcontractors and external consultants) were established regarding which information should be modelled. The intended use of the BIM model was to perform 4D simulations of the construction integrated to the line of balance planning method, visualize construction sequences, verify whether scheduling was correctly done, as well as report and promote abetter understanding of the plan. It was defined which elements had to be more detailed (with higher LOD[4]) and which of them had to have more rigour while modelling to meet those needs. Therefore, the model elements were built up at LOD 200-300.

Before modelling the whole project, only one of the five house typologies was modelled and imported to Vico Office to see how effective the software communicate and share data, and which information was relevant to be modelled. The modelling process of the project was cyclical, and the BIM model was validated by the project manager and external consultants during visits carried out to the construction site.

The BIM model (Figure) was formed by11 independent models (five of these refer to five different house typologies, and the other six refer to infrastructure and communal areas of the project). As these house types were repeated throughout the project, each of them was modelled as a '.mod' file. A module can be replicated in all corresponding locations and if any modification had to be done into the original house type file, it would reflect in all replications.

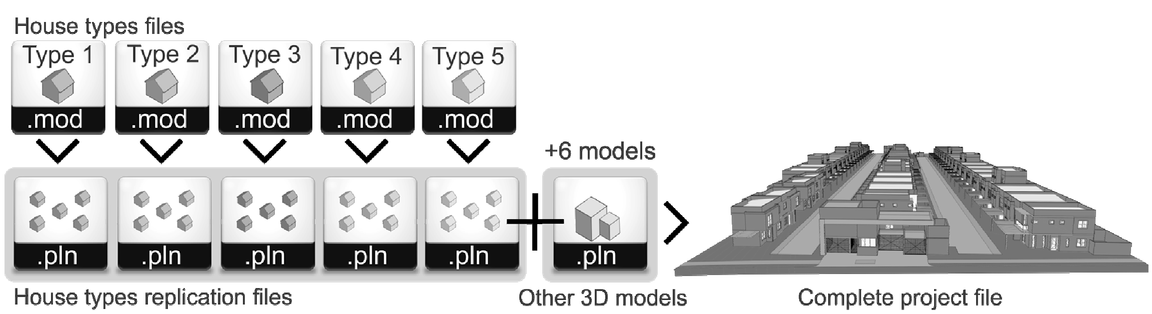

Figure 2: BIM model of the whole project and its files

The 4D software adopted in this empirical study for enabled categorizing 3D model elements according to the information inserted while modelling (e.g. material, layer). This reduced the time spent organizing elements to link them to tasks and fit the schedule.

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4 Level of Development is the degree to which the elements geometry and attached information has been thought through(BIMForum 2015).

Moreover, the 4D software splits elements geometry according to the defined locations without interfering in the BIM model, eliminating the need to decompose elements while modelling to link them to the schedule and enable performing different 4D simulations. Furthermore, using different location systems (a way to create different location breakdown structures for the same model), allowed elements to be decomposed differently depending on tasks needs.

EMPIRICAL STUDY 2

In this empirical study, Company B defined that the main usages of the model would be: (i) project documentation; (ii)early detection of project problems using the BIM model; (iii) help planners to understand the whole project; (iv) help cost estimators to perform quantities take-off.

The analysis of the BIM model enabled researchers to identify that all basic architectural elements necessary to simulate the master schedule were modelled. These elements were built up at LOD 200-300, and the BIM model was composed of four different files, merged in another one created for this purpose. In this file, the same tower was replicated five times, by using the '.mod' file (Figure 1).

Figure 1: BIM model

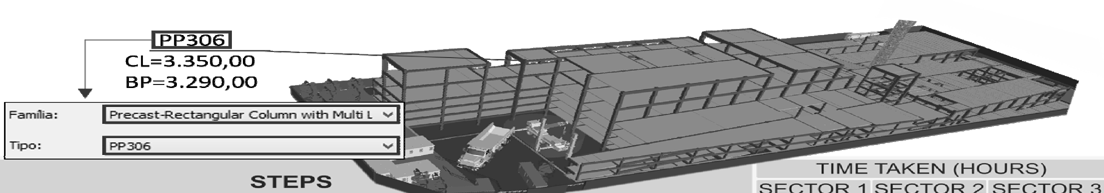
The 3D BIM model was not initially developed with the aim of supporting production planning and control. However, 4D simulations were performed to find a suitable solution for the long-term plan so that the phased delivery schedule of the apartment towers was feasible. In order to achieve that, it was necessary to synchronize the cycle time of different crews, changed work sequences, perform buffer analysis, and analyse resource utilization using the 4D model. To be able to perform a more precise 4D simulation, some adaptations were necessary, such as: (i) the walls were modelled as composite elements and the 4D software recognize those grouped layers as a single layer instead. In order to link different layers of the wall to different schedule tasks, it was necessary to model a combination of basic walls representing these different layers; (ii) The existing furniture in the model was not useful for 4D simulation and ended up being deleted from the BIM model; (iii) elements were wrongly assigned to certain typologies of elements, and could cause confusion while grouping and categorizing elements to link to the schedule (e.g. knobs modelled as doors, chimneys modelled as columns).

EMPIRICAL STUDY 3

In this empirical study, the 4D model was used to support decision-making with focus on planning and control of prefabricated concrete structure assembly tasks. The 4D model potential user was the site manager and it was used in planning meetings to support collaborative processes, in which different stakeholders took part (project coordinators and engineers from other companies, foreman, subcontractors and workers). The relevant information was related to concrete components' identification data, location and orientation according to defined axes, as well as to the construction site (e.g. pathways, inventory areas, and equipment).

Families of prefabricated components were created, and a specific identification code for each of them was inserted into 3D elements according to company standards (Figure). These codes were an important identification throughout all company controls (manufacturing, expedition and assembly).

The project was divided into three assembly sectors that enabled segmentation of the execution deadline and the control of milestones, and consequently, the BIM model was segmented into three modelling batches. The prefabricated elements were modelled at LOD 300 and construction site elements were modelled at LOD 200.Figure shows the steps taken in this study and the time spent on each of them. Based on that, it is worth noting the reduction of time spent in sector 2 and 3, due to the use of families of components.



STEPS	TIME TAKEN (HOURS)		
	SECTOR 1	SECTOR 2	SECTOR 3
Modeling prefabricated components	15	8	8
Modelling construction site (e.g. temporary facilities, pathways and equipment)	6	4	4
4D modeling (assignment of resources to activities and insertion of equipment)	20	16	12
TOTAL	41	28	24

Figure 4: Component code in the BIM model and the time spent in each modelling step

GUIDELINES FOR 3D MODELLING TO SUPPORT PRODUCTION PLANNING AND CONTROL

Based on the analysis of the empirical studies, it was possible to identify the origins of 3D modelling demands in order to address required information to support production planning and control (Figure 2). In this paper, these were named inputs for 3D modelling. The decisions that impact these inputs (Figure 5)were divided into general and specific, as well as 3D modelling inputs were divided into categories.

The inputs from the 4D software are concerned with implications and limitations of the software used, which may be related to the method adopted for scheduling work. It is important to identify that if the 4D software enables element geometry splitting (divide elements into parts) and how this is done. Also, it is important to determine if information inserted into the BIM model can facilitate elements categorization (renaming, grouping and ungrouping) to assign them to schedule tasks (e.g. use two different layers to divide a single element typology that must be assigned to two different tasks). Furthermore, information inserted could be standardized (e.g. elements name, layers and codes) to facilitate schedulers work. Additionally, it is important to define how information is going to be used and which are the 4D model outputs (e.g. videos, snapshots, BIM model manipulation for dynamic visualization).

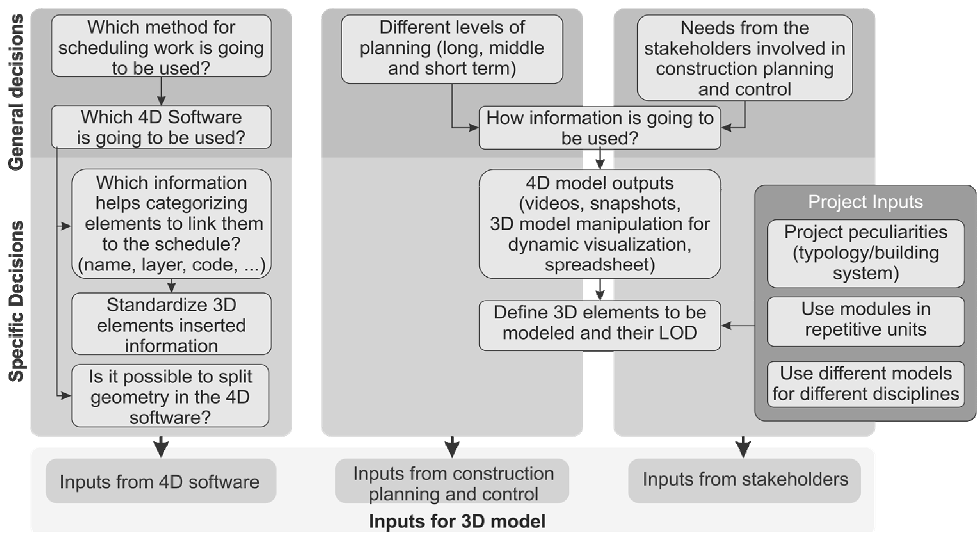


Figure 2: BIM model development inputs origins

The inputs from production planning and control are related to how detailed the task is, which is a consequence of the planning system decisions (e.g. hierarchical planning system). So, it is important to define 3D elements' LOD according to schedule needs (e.g. wall as a singular layer or composed of bricks, mortar, plaster and painting). Moreover, it is important to identify inputs from stakeholders involved in production planning and control (e.g. quality managers, subcontractors, engineers, project manager).Authors could not find a generic solution to define which elements have to be modelled and their corresponding LODs to any case. To help that, the modelled elements along with the LODs adopted were presented in each empirical study.

The inputs from projects are related to project peculiarities, for example, project typology (horizontal or vertical building) and building system (prefabricated components or conventional construction), intrinsic characteristics from repetitive projects (e.g. repetition of floors, houses, apartments or even parts of it). If the project has repetitive characteristics and these are addressed, it can reduce rework while modifying only the original repetitive module. Furthermore, individualizing BIM models (different design disciplines) can make it easy to reinsert the model by only importing the modified information.

Based on the origins of 3D modelling inputs, researchers proposed a set of guidelines to be addressed in order to develop a BIM model to support production planning and control. Furthermore, an analysis was undertaken on how these guidelines addressed lean principles based on evidences obtained in the empirical studies content. The starting point for this analysis was the article of Sacks et al. (2010), which explores the interactions between BIM functionalities and Lean principles. Figure 3provide some evidences of these interactions, obtained from the empirical studies. The guidelines are explained in Figure 4.

<table>
<tr><th rowspan="2">Guidelines</th><th colspan="3">Main evidences related to the empirical cases</th><th rowspan="2">Lean principles</th></tr>
<tr><th>Case 1</th><th>Case 2</th><th>Case 3</th></tr>
<tr><td>Standardize elements according to planners use</td><td colspan="2">Information was standardized to easily identify and categorize elements inside 4D software to link it to the schedule</td><td>Information was standardized so components code could be extracted to a production sheet</td><td>Standardize</td></tr>
<tr><td>Define 3D elements to be modelled and their LOD</td><td colspan="2">Use of videos and snapshots of master plan's sequencing (process)</td><td>Use of videos and snapshots of assembly sequencing (method and process)</td><td>Use visual management to visualize methods or processes</td></tr>
<tr><td rowspan="2">Identify stakeholders needs related to production planning and control, and the appropriated 4D output for them</td><td colspan="3">Understanding phase of DSR - understand company's context and analysis of the production planning and control methods adopted by the companies</td><td>Ensure comprehensive requirement capture</td></tr>
<tr><td colspan="3">Stakeholders understood more easily the plans by using different 4D outputs</td><td>Increase output value</td></tr>
<tr><td>Standardize elements according to planners use</td><td colspan="2">Elements categorization got easier to perform because elements were modeled with information that enabled grouping and ungrouping elements</td><td>Automatization of extraction of the components production and assembly information</td><td rowspan="4">Reduce non value-adding activities</td></tr>
<tr><td>Define 3D elements to be modelled and their LOD</td><td colspan="3">Modelling only necessary information reduced time spent on it</td></tr>
<tr><td>Identify repetition inside the project</td><td>Simplify 3D modelling by using repetitive houses</td><td>Simplify 3D modelling by using repetitive apartments and building</td><td>Simplify 3D modelling by using repetitive components</td></tr>
<tr><td>Define the method for scheduling work that is going to be used and then if the 4D software chosen enables dividing elements into parts</td><td colspan="2">As the 4D software enabled geometry splitting, it was not necessary to do it while developing the 3D model. Whenever necessary it was possible to split elements differently inside the 4D environment.</td><td>-</td></tr>
<tr><td>Define 3D elements to be modelled and their LOD</td><td colspan="3">Necessary information was available to support decision making</td><td>Reduce variability</td></tr>
<tr><td>Define to which level of planning (long, middle or short term) 4D simulation will be used and establish 3D model LOD according to it</td><td>4D model was used to simulate master plan</td><td>4D model was used to simulate master and mid-term plans</td><td>4D model was used to simulate master, mid and short term plans with</td><td>Select an appropriate production control approach - Level the production</td></tr>
<tr><td>Define if operations are going to be simulated and if so model inventory areas, equipment, temporary facilities and accesses</td><td>-</td><td>-</td><td>4D simulation of planning and control logistics operations such as loading and unloading components, equipment movement and site inventories control</td><td>Reduce cycle time</td></tr>
</table>

Figure 3: Lean and BIM interactions based on evidences from the empirical studies

Standardize elements according to planners use	The standardization can facilitate and reduce planners working time by addressing their specific uses, and also reduce planner non-value adding activities, by reducing time to perform planning related activities.
Identify stakeholder needs related to production planning and control and the appropriated 4D output for them	Addressing relevant information by enhancing requirements capture can increase the output value to stakeholders as they understand the processes and methods more easily.
Define to which level of planning (long, middle or short term) the 4D simulation will be used and establish elements LOD according to it	These definitions can reduce production variability by visualizing and understanding workflows, which can be simplified by a visual output. Moreover, it can improve planning by forcing planners to think about production levelling, which can be supported with enough information from 4D models.
Define if operations are going to be simulated and if so model inventory areas, equipment, temporary facilities and accesses	Modelling important elements to operations enable logistics simulation and consequently helps reducing cycle time by minimizing non-value adding activities related to these operations.
Define 3D elements to be modelled and their LOD	These definitions allow planners to visualize construction processes and methods with the level of detail needed. Moreover, it provides enough information for planners to detect and solve problems using 4D information before these problems interfere in the production planning.
Identify repetition inside the project	The identification of identical repetitive modules enables modeller to reuse model`s information.
Define the method for scheduling work that is going to be used, then chose the 4D software and identify if it enables splitting elements geometry	Identifying if the 4D software allow splitting elements geometry eliminate modellers need to split elements while developing the 3D model. By contrast, if the software does not do it, output value can be increased if modellers split them into the 3D software, as it enables more construction simulation options.

Figure 4: Guidelines do develop BIM models focused on production planning and control

CONCLUSIONS

The basis for the discussion and establishment of the set of guidelines emerged from the attempt to identify the inputs to build up BIM models that were used to support planning and control processes. Some interactions between Lean principles and BIM functionalities that were identified in the empirical studies support the idea that the adoption of these guidelines to develop BIM models can enhance Lean outcomes. As a contribution, the authors have identified an increase of collaboration, while people tried to express their needs referring to the model. The understanding and engagement in the project by all parties involved increased the process transparency since it made clearer to people which information was relevant to the model and why it was not necessarily highly detailed. Moreover, results from the empirical studies showed that the application of these guidelines can help eliminating non-value adding activities, increase output values, and reduce the time spent in 3D modelling. During the analysis and reflection phase, it was possible to identify that to support production planning and control, the BIM model must be modelled with relevant and sufficient information according to its particular use, project peculiarities and stakeholders needs.

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UNDERSTANDING THE EFFECTIVENESS OF VISUAL MANAGEMENT BEST PRACTICES IN CONSTRUCTION SITES

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ABSTRACT

Visual Management (VM) is a strategy for information management strongly related to one of the core concepts of Lean Production Philosophy, the increase of process transparency. VM is especially important to support continuous improvement and it relies on the effective transmission of information at different hierarchical levels. However, there are some challenges in the implementation of VM in construction: each construction project is unique, site layouts are dynamic environments, and the construction itself might become a visual barrier. This paper aims to analyse the role of a set of VM best practices to support production management, understanding the features that distinguish these practices as advanced ones, i.e. the reasons behind the effectiveness of some VM systems. It is based on two case studies carried out in leading companies in the implementation of Lean Construction in Brazil. Differently from previous studies on VM, this investigation explored the integration of those practices in managerial processes that might use a set of visual devices; whether visual devices are used dynamically in order to support decision-making, especially in collaborative processes. Another contribution of this paper is concerned with classifying VM best practices according to the degree of integration to the managerial routines.

KEYWORDS

Visual Management, Transparency, Lean Construction, Production Planning and Control

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INTRODUCTION

Construction sites are usually large and dynamic environments where different crews move around, the layout suffers several modifications throughout the project, and the construction itself might become a visual barrier (Formoso et al. 2002). In comparison to manufacturing, these characteristics represent a major challenge to implement Lean Production Philosophy core principles such as process transparency.

Process transparency makes the main process flows visible and comprehensible from start to finish, through public display of information, organizational and physical means, and measurements (Koskela 2000). It is defined as the ability of a production process (or its parts) to communicate with people (Formoso et al. 2002). Transparency aims to support participatory decision-making, empowering stakeholders with the aim increasing their participation(Greif 1991).

Visual Management (VM) can be defined as a sensory strategy for information management, which is used to increase process transparency (Tezel et al. 2016).If process transparency is successfully implemented, most problems, abnormalities, and waste are easily recognized (Igarashi 1991). VM involvesa set of visual devices that are intentionally designed to enable the sharing of information between people, including messages communicated through any of the five senses (Galsworth 1997). It is a democratic way to extend access to information for a group and not just for an individual (Greif 1991).

Although the core objective of VM is to increase process transparency, it is also related to the reduction of variability (Formoso et al. 2002) and to the implementation continuous improvement (Bernstein 2012), other core Lean Production principles. Besides, VM simplifies production control (Koskela 1992) and allows faster understanding and response to problems(Bateman et al. 2016).

Despite the challenges of implementing VM in construction sites, a large number of VM practices used in manufacturing have been adapted to this industry. In fact, some of VM practices are fairly simple visual devices, such as boards that contain procedure information, production drawings, or performance metrics(Heineck et al. 2002), while other practices are more advanced and require planning and stability within the production system(Tezel et al. 2015).

It is worth considering the idea of implementing practices beyond the idea of routine, as pointed out by Gherardi (2009), i.e. practices can be related to social processes and can be seen as a recurrent pattern of socially sustained action. Therefore, successful implementation of VM practices depends on how people interact with visual devices and how processes are designed or changed due to the support of visual tools. Understanding how a visual practice works require a deep understanding of the context and that is why it is difficult to simply implement a visual practice devised elsewhere, as related social processes are often neglected.

Although several taxonomies have been proposed for VM practices in the literature(Tezel et al. 2016),not much has been discussed on the reasons behind the effectiveness of VM systems. Moreover, the application of VM practices in construction sites at the operational level is still relatively limited. In fact, most visual devices found in construction sites are meant to support managerial decisions, usually in the site office, while in working areas mostly health and safety warning boards are found(Tezel et al. 2016),a very basic type of visual tool that is focused on 'information giving' (Galsworth 1997).Moreover, visual devices should not be regarded as an end in itself, but are rather means to improve the performance of production systems(Nicolini 2007).

This paper discusses the role of a set of VM best practices to support production management, emphasizing the features that distinguish these practices as advanced ones. It is based on two case studies, carried out in distinct Brazilian leading companies on the implementation of Lean Construction concepts and tools. The practices selected were explored in terms of their integration with managerial processes that use a set of visual devices and whether these visual devices are used dynamically, i.e. amenable to be changed (rather than static), according to the taxonomy of visual devices suggested by Bititci et al. (2015). They were also analysed according to the ability to support decision-making and to encourage collaboration between stakeholders. Another contribution of this paper is concerned with classifying the VM best practices identified according to the degree of integration to the managerial routinesand processes.Similar to the concept of standardised work(Martin and Bell, 2011), VM best practices were defined according to the best current way of VM practice inside the context in which it is used, but always having in mind the need for continuous improvement. As this paper intends to contribute for understanding the reasons behind the effectiveness of VM systems, some ideas could be adopted as a reference for companies that intend to improve and refine their VM systems.

RESEARCH METHOD

Design Science Research (DSR) was the methodological approach adopted in this investigation. It is a way of producing scientific knowledge that involves the development of an artefact (or a solution concept) to solve classes of problems (Holmström et al. 2009). DSR seems to be an appropriate approach for conducting construction management research, because it promotes the development and implementation of innovative managerial concepts and tools, addressing different practical field problems and providing gains to several stakeholders (Rocha et al., 2012). However, designing useful artefacts is a complex task, as it involves the need for creative advancement in areas where the existing theory is generally insufficient (Hevner et al. 2004).

This research project was divided into three stages. The first stage consisted of an empirical study carried out in construction site of a company in Brazil (named Company A), well known as a leading on the implementation of lean production concepts and practices, such as the visual management system adopted in the site assessed. The empirical study was carried out in a healthcare construction project located in Porto Alegre and an overall assessment of the visual managerial tools that had been implemented in the construction site was conducted in six visits. A protocol for data collection was used to analyse 37 visual devices, including the content, type, and function of information displayed, the target group, the visualization format, the managerial area supported by it, and the static or dynamic format of the visual device. The data were organized in a spreadsheet, which made it possible to generate some quantitative results, related to the function performed, as well as information providers and users for the visual devices.

The second stage of the investigation consisted of an empirical study carried out in a company from Fortaleza, Northeast of Brazil (named Company B). This company develops and builds commercial and higher middle-class residential building projects, being also a leading construction company in the implementation of Lean Production concepts and practices in Brazil. This second empirical study was based on data collected in four construction sites: three residential projects and one healthcare and commercial project. The study in Company B was conducted in six visits and had a more descriptive character. It was focused on a small set of practices with the aim of exploring the role of visual devices in managerial routines, especially in terms of supporting coordination and collaboration. A protocol was also devised for data collection and processing, but no quantitative measures were used in this analysis.

Multiple sources of evidence were used in both initial stages: (i) interviews with workers at different hierarchical levels (e.g.: site managers, foreman and labour workers); (ii) direct observation and photography register of the construction site; and (iii) analysis of documents, such as plans, visual schedules, inventory sheets, and standard operating procedures. Also, in Company A, participant observation was made in a planning meeting, and in Company B some data were informally collected in participant observations, as one of the authors worked for a five-year period as an innovation manager in that company.

The third stage consisted of a cross analysis of the data from the two empirical studies, based on a set of VM practices that were considered to be the most advanced ones. The aim of this cross analysis was to understand the reasons behind the effectiveness of VM systems. Moreover, it supported the creation of a taxonomy to classify VM practices according to the degree of integration to the managerial routines and processes.

The following questions were used to guide data collection in the third stage of the research:

- Is the VM practice use integrated with other visual devices?
- Does the VM practice have dynamic characteristics?
- How does the VM practice support decision-making?
- Does the VM practice promote a collaboration?
- What is the degree of integration of the VM practice with managerial routines?

RESEARCH FINDINGS

ANALYSIS OF VM BEST PRACTICES

As described by Valente et al. (2017), based on an overall assessment of 37 visual management devices in Company A,a classification of the visual devices was proposed according to the functions performed and type of information displayed, similar to what Eppler and Burkhard (2007)suggested. It was possible to observe that a large number of the visual devices identified in the Company A had basic functions, being used just to identify (30%), to inform something (25%) or to assist an activity's execution(17.5%) in a static way of representation. Few advanced VM practices intending to increase the impact of visual devices in work standards could be observed: only 12.5% were used to control, 5% to alert, 5% to plan and 5% to guarantee an action by using an error-proof device. In relation to the type of information displayed in visual tools, most aimed to identify or inform, matching the findings of functions performed. Another characteristic observed was the low level of participation of the labour force in conceiving or updating visual devices, resulting in a high workload to some managers, who had to do most of the work related to visual management. One of the recommendations of this study was that Company A should assess the utility of existing visual devices, selecting the most effective ones for supporting decision-making and encouraging reflection and collaboration, offering more support for production planning, control, and improvement (Valente et al. 2017).

Among Company A VM best practices, it is worth emphasizing some. Spray markings were one of the most used visual devices in the construction site. Colour coding was used to point out whether tasks have been approved (green, blue, yellow). An explanatory sheet was available with the meaning of markings (Figure 1). Similar Spray markings were used by the electrical and hydraulic service teams for communication. Symbols were defined according to the type of task to be executed in a particular location. However, no record of these markings is usually made, representing a parallel control in relation to the quality management system.

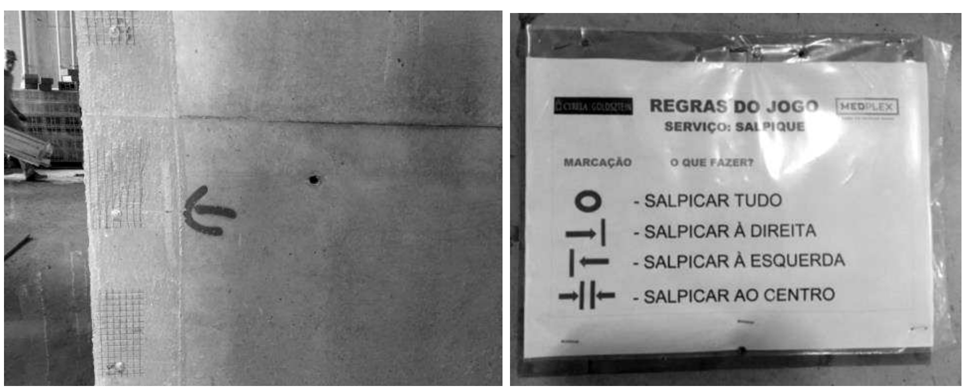

Figure 1: Example of spray marking of the kind of rough cast and it explanatory sheet

It is worth highlighting that some practices are isolated, such as the Spray markings. In other words, these are not well integrated with managerial processes or to other visual devices, and do not support collaborative processes. Despite these limitations, they had a positive impact, as they were dynamic and promoted autonomy among inspectors and the work force, supporting decision-making at the operational level. By contrast, there were practices combining sets of visual devices, which supported collaborative processes, forming what can be named as VM sub-systems. As described by Valente et al. (2017), it is the case of the VM sub-system developed for the installation of drywall partitions, which combined *kanban* for supplying materials (gypsum and aluminium uprights), visual schedule for each floor, standard operating procedure flowchart, material control sheets, physical prototyping, templates, and inspection sheets. This sub-system, in general, presented several good practices, such as dynamic visual tools integrated into the process. Nevertheless, some improvement opportunities were identified in this subsystem, in order to make it more easier to use. As a result, there was a reduction in gypsum plasterboard waste, reduction in the time spent counting components, higher productivity of the material supply teams, better organization of inventories, and increase in the motivation of the employees.

Company B had a larger number of VM practices and sub-systems that can be considered as advanced, i.e. dynamic tools that supported decision-making, being well integrated with managerial routines. These were: *Kanban; Andon*; Standardised work visual routine cards; Visual board for communal areas; Customization choice board; Visual performance and planning boards; and Physical Prototyping. Those practices and sub-systems were assessed according to the following attributes: the main purpose, people responsible for inputting and updating information, users, and impacts.

For instance, as suggested by Fernandes et al. (2015),Standardised work visual routine cards contains the day, shift, schedule, operation, and production batch for each task, inside the concept of the standardised work. Also, pictograms are sometimes used when employees are illiterate. The innovation manager is the person responsible for creating new cards and updating them, working in close collaboration with operational teams. This kind of device aims to facilitate the understanding of the sequence of operations for employees and supervisors, and due to that, production teams are engaging in the process of continuous improvement. Despite the collaborative creation, Standardised work visual routine cards are a practice and not a sub-system, since its use is not integrated with other visual devices.

Regarding the customization choice board, its content is updated by the customization manager to inform about choices in residential units demanded by the clients, by using a colour scheme (green for the company first choice standard unit, yellow for company's second choice standard or client's purchase, and red for not executing a particular task in the apartment). This device works as a boundary object among different stakeholders, such as the customization manager, site managers, material supply and logistics managers, also clients. By definition, a boundary object transfers and translates information to better collaboration among different stakeholders (Koskela et al. 2016). Therefore, it can be considered a VM sub-system and not only a practice.

Visual performance and planning boards contain the main indicators for each area and also a plan of activities produced by using post-its, containing "to do", "doing" and "done" activities with the purpose of balancing the activities of the team, since each colour represents a team member (Figure 2). They can inform key devices elaborated by other departments of the company, and also indicators, and both look-ahead and weekly work plans, being very flexible to fit information needed by the users. Each department is responsible for its own board and for inputting information to construction site boards, which can be used by several head office departments, as well as by site management. In this specific context, those boards can be considered as VM sub-systems due to the key role in supporting collaboration and the use of a set of integrated visual devices.

Figure 2: Visual performance and planning boards

DISCUSSION

A cross analysis was made between the best practices of Company A and Company B, with the aim of understanding the reasons behind the effectiveness of VM systems and why some of them can be considered as advanced. The following criteria were established: (i) whether a practice is integrated or not with other visual devices - this determines if it is only an isolated VM practice or a VM sub-system; (ii) whether a VM practice can be used dynamically (rather than being static); (iii) ability to promote collaborative processes and support decision-making; (iv) whether a VM system promotes autonomy to the workforce; and, finally, the degree of integration with the managerial routines and processes. Based on that criteria, a taxonomy was proposed to classify VM best practices and subsystems. In that taxonomy, the degree of integration to the managerial routines was classified into three main categories: one-to-one, coordination, and collaborative. These three categories are important to understand the role of VM practices in process transparency. Those practices might have different and complementary roles, and do not represent a ranking in terms of significance.

One-to-one category is the most basic form of incorporating visual devices in production processes, in which information must be rapidly and easily understood, being the visual device a clear communication channel between a sender and a receiver. The visual device simply makes public performance measures or instructions to perform a task, using resources such as sound, icons, physical barriers, and color-coding. However, collaboration might not exist in task execution, but only in visual devices' development. The Spray markings of Company A, and *Kanban*, *Andon*, and Standardised work cards from Company B fit well this category. Several simple visual devices that work in isolation can also be classified in the One-to-one category, as these do not promote collaborative processes, nor represent a VM sub-system.

The VM sub-system for the installation of drywall partitions from Company A, combining several visual devices, the Visual board for communal areas and the Customization choice board, from Company B, are VM sub-systems that can be included in the Coordination category. These are used to share information and coordinate activities between several stakeholders, usually producing routine information. These visual devices are relevant to work routine as they summarize chunks of information in compact formats such as graphs or tables and act as boundary objects.

Finally, the Collaborative category corresponds to the highest level of integration. VM devices enclosed in this category intend to support collaborative processes among different departments or hierarchical levels as well as a specific group of users. They usually are dynamic devices, especially important in environments where innovation and flexibility have a fundamental role, such as the VM sub-system of Visual performance and planning boards of Company B, and others involving cooperative practices such as planning and control, quality assessment, and accident prevention meetings.

Depending on the goal and the way they are used, some VM sub-systems such as Physical Prototyping can be classified into different categories. As exposed by Saffaro et al. (2006) in many companies, this kind of practice does not support any type of collaboration, being considered Coordination category. By contrast, in Company B, Physical Prototyping can be classified in the Collaborative category, as a meeting involving people of many departments (design, sales, and production) is used to share experiences and to define improvement measures.

Figure 3 summarizes the analysis of VM best practices from Company A and Company B.

Example	Company	Integrated use with other visual device	Dynamic characteristcs	Support in decison-making	Promotion of collaborative process	Degree of integration with managerial routines
Spray markings	A	No (VM Practice)	Yes	Yes	No	One-to-one
Kanban	B	No (VM Practice)	Yes	Yes	No	One-to-one
Andon	B	No (VM Practice)	Yes	Yes	No	One-to-one
Standardised work visual routine cards	B	No (VM Practice)	No	Yes	No	One-to-one
Installation of drywall partitions	A	Yes (VM Sub-system)	Yes	Yes	Yes	Coordination
Visual board for communal areas	B	Yes (VM Sub-system)	Yes	Yes	Yes	Coordination
Customization choice board	B	Yes (VM Sub-system)	Yes	Yes	Yes	Coordination
Visual performance and planning boards	B	Yes (VM Sub-system)	Yes	Yes	Yes	Collaborative
Physical Prototyping	B	Yes (VM Sub-system)	No	Yes	Yes	Collaborative

Figure 3: Advanced VM practices and advanced VM sub-systems

CONCLUSION

The use of Visual Management in construction sites is strongly linked to a set of Lean Philosophy principles, including increase process transparency, variability reduction, and continuous improvement. The more dynamic, collaborative and well-integrated into managerial routines and processes, supporting decision making, the more advanced a VM practice or VM sub-system can be considered, being these the reasons behind the effectiveness of VM systems identified. From a more practical point of view, this paper analysedexamples of some visual practices that support production management and that have been successfully implemented by Lean Construction best-practicing companies from Brazil. A taxonomy was proposed to classify them according tothe degree of integration to managerial routines.

Both construction companies had good examples of VM practices and sub-systems, despite the complexity and challenges of this environment. In general, Company B had most advanced VM practices and sub-systems, well integrated into management processes, while in Company A some improvement opportunities were pointed out. Moreover, with the exception of the Standardised work visual routine cards, none of the most advanced practices was developed or implemented with a strong participation of the operational teams at the construction site. This fact points out to the need for greater involvement of the workforce and operational management in Visual Management, which can be initiated through training and collaborative activities. Classifying the advanced VM practices and advanced VM sub-systems into categories, according to the degree of integration to the managerial routines (One-to-one, Coordination, and Collaborative) was a way to better understand the level of collaboration and the effectiveness of VM systems.

Finally, it is worth emphasizing the importance of understanding visual devices as directly and specifically associated with each process context and users in production management. In order to improve continuously VM sub-systems, it is important to address some existing communication problems, the information needs of the target audience, and the way the device can be integrated into the company routine.

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PROMOTING COLLABORATIVE CONSTRUCTION PROCESS MANAGEMENT BY MEANS OF A NORMALIZED WORKLOAD APPROACH

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ABSTRACT

The research project »COCkPiT« - Collaborative Construction Process Management - aims at developing methodologies and tools to enhance time and budget control in construction projects, with a focus on small and medium-sized companies. The hypothesis is that the interplay of the three main phases of project management - planning, scheduling, and monitoring - can be improved by collecting highly detailed information early on in each phase, and making it available to the other phases at a high frequency. COCkPiT builds upon previous experiences in façade installation, where significant time and cost savings have been obtained by applying a normalized workload approach based on a collaborative process planning routine, an approach which is currently hardly supported by commercial project management tools. Thus, the objective of COCkPiT is to develop a methodology that supports i) collaborative process modelling as a basis for ii) a short-term rolling wave planning considering iii) real-time measurement of the progress on-site, to create highly reliable schedules and accurate forecasts. The focus of this paper is to present the conceptual fundamentals of integrating the modules of modelling, scheduling and monitoring, as well as involving the lean construction community to current considerations regarding the implementation in a self-containing IT-solution.

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KEYWORDS

Collaboration, Production System Design, Process modelling, Job sequencing, Monitoring

INTRODUCTION

In traditional construction projects, budget overruns are often identified too late, which hinders the effective application of recovery actions. This is partly caused by a coarse planning and management of the construction execution process. The Italian construction industry consists of a great amount of small and medium sized companies (SMEs) that makes the sector highly fragmented (Cacioli, 2017). In consequence, in construction projects most of the participating companies are crafts with an artisanal organizational structure. Therefore, limited resources are available for planning and managing the execution process. Moreover, stakeholders are often characterized by limited knowledge about construction management theory and sophisticated IT-tools for planning and management of the execution process. The management of a construction project is traditionally organized in three main phases (Sears et al., 2008): 1) planning, 2) scheduling and 3) monitoring. *Planning* is usually managed by considering historical experiences without involving the responsible actors for execution, resulting in schedules with unreliable information(Jeong et al., 2016). *Scheduling* and assignment of tasks on-site then are mostly carried out in a non-systematic way or even just by acclamation of the foreman(Dallasega et al., 2018). As a result, the focus on value adding tasks and the optimal saturation of workers on-site is seldom achieved(Dallasega et al., 2018). Moreover, a non-structured and detailed scheduling of tasks to be performed on-site makes it difficult to request the right type and quantity of material when it is needed(Bell and Stukhart, 1986; Dallasega and Rauch, 2017).*Monitoring* of a construction project in a SME context is generally done by rough progress estimations of the foreman on-site. By operation of law, other important information, like workers present on-site, detailed labour-consumption, descriptions of performed tasks as well as weather conditions are recorded in the so-called construction log-book. However, this information is neither recorded in a quantitative way nor connected directly to the construction schedule (Dallasega et al., 2016).As a result, a frequent comparison of scheduled and actual data is not possible.

As a reason for these current weaknesses, the presenting researchers have identified a lack of systematic work planning and schedule routines which incorporates also an exact progress monitoring and is at the same time suitable and accessible for SMEs by means of easy-to-use IT-tools. The research questions thus arising, is to define the methodological foundations for such a system and how it must be designed in order to address SMEs requirements and to integrate it into their day-to-day business. The here proposed methodology consists of a normalized workload approach embedded in collaborative planning routines, which is aimed to be transferred into a supportive IT-solution.

STATE OF THE ART

At present, there are several production planning systems flying the flag of the lean movement, aiming to make work plans in the construction domain more reliable and robust, to increase productivity, to minimize waste and ultimately to contribute to satisfying project results from the customer's perspective. In this context, one of the most frequently used method in the execution phase of a construction project is the Last Planner System (LPS) (Kenley and Seppänen, 2010 in Gao and Low, 2014, 1261). LPS, as a method for work planning and control (Ballard, 2000a), aims at creating and managing networks of commitments of involved players for successful project delivery. Process stability and thereby schedule reliability are indicated by means of the Percent Planned Complete value (PPC), which is the percentage of actually-fulfilled to committed-to-be-fulfilled tasks with respect to a defined timeframe. Hence, in an ideal – but unrealistic - case, the PPC value would be always 100 %. In addition to this methodological approach, LPS also includes a social process that can lead to open discussions among the parties and companies involved, joint learning for continuous improvement and an increase in mutual trust (Gao and Low, 2014). However, even though LPS has been applied successfully in numerous construction projects(Kim and Ballard, 2010; Lindhard and Wandahl, 2013), accompanied by significant process improvements, more predictable workflows and increased schedule reliability, it does not offer a direct possibility to measure progress in absolute numbers and therefore cannot be used as a stand-alone approach for monitoring and coordination of the construction site.

Recently, LPS has been applied with the so-called Takt Planning (TP) approach which is referred to as a work structuring method (Bolviken et al., 2017; Frandson et al., 2014).According to Frandson et al. (2014) LPS and TP are mutually supportive. TP could expand the mechanism of commitment management of the LPS by means of standardized work batches striving to continuous work flow(Frandson et al., 2014). By aiming at disruption-free handovers between trades, TP would methodologically represent a 100 % PPC approach in the LPS perspective (Bolviken et al., 2017).The formal methodology of TP consists of a clocked scheduling where so-called "time-harmonized" work sequences are used to coordinate activities. Therefore, construction projects are structured into "Takt zones" where repeatable and non-repeatable construction elements are defined previous to execution(Altner, 2016).The rhythm of the construction progress is defined by the "Takt time" principle known from lean management (Altner, 2016). For reasons of practicability, a typical order of magnitude for Takt times in the construction domain is one working week (Altner, 2016). In each Takt zone, there is only one trade working at the same time for a precisely defined period of time, which reliably avoids mutual obstructions and reduces the control demand for site management(Altner, 2016). When all involved trades consent to the alignment to a common work rhythm with a corresponding amount of work and work sequences, a very continuous working speed can be achieved (Haghsheno et al., 2016).Insufficiency of this approach consists of the nearly exclusive applicability to repetitive construction works that consist of almost identical work sequences with high recurrence rates (Haghsheno et al., 2016).Nonetheless, recent efforts have been made trying to find some repetition in non-repetitive construction works on the basis of work density to solve this problem (Tommelein, 2017). However, practical applications of such cannot be found often and the conceptual framework is not available in textbooks yet (Tommelein, 2017).

Another production planning system that is highly regarded but also used primarily in repetitive construction projects is the Location-Based Management System (LBMS) as a recent methodology based on Location-Based Planning (LBP). As opposed to activity-based methods (i.e. CPM, PERT), LBP focuses on tasks that repeat in different locations to reduce the movement of resources in space. Thus, location is considered a critical variable, on par with time and activities (Kenley and Seppänen, 2010). LBMS has been proven successful at implementation in reducing project duration and balancing resource usage (Seppänen et al., 2014). Nonetheless, the methodology does not consider learning from process feedback for optimizing the planned schedule and updating the forecast(Dallasega et al., 2018), since Kenley and Seppänen (2010)argue that, the learning curve in construction operation remains mostly linear after the very first improvement. Moreover, to a similar extent as TP, LBMS can also be considered complementary to LPS, since LPS covers social aspects in a production planning system, which are being mostly neglected in LBMS (Seppänen et al., 2010). The overlooking of these social considerations makes either LBMS or TP less suitable in the context of SMEs, where fragmentation of actors working on the project, and thus communication and sociality, are crucial factors.

THE COCKPIT PROJECT

The here proposed approach for an improved **Co**llaborative **C**onstruction **P**rocess Managemen**t** (COCkPiT) respects the advantages of the Lean Construction methods presented above, as well as adapts and expands them by significant new aspects.

APPROACH AND COMPARISON TO THE STATE OF THE ART

Looking at LPS, essential for its successful application is an appropriate definition of the single tasks at the execution level by the Last Planners. Ballard(2000)mentions the following important features: (1) The task must be well defined, (2) tasks must be arranged in the right sequence, (3) the selected extent of work must be right and (4) defined tasks must be feasible. But even underlying these principles, the open question remains: How do we have to specify workloads quantitatively? The COCkPiT approach proposes a normalized workload approach (NWA) which consists in the first step of collaborative estimation of production rates and association of required number of workers for each task as well as work sequencing considering the expertise of Last Planners. This step is termed *modelling*. Production rates are then normalized to a certain time interval (e.g. one working day). This principle of normalizing workloads is referred to as "pitching" known from Lean Manufacturing and has already been worked out in previous studies and successfully applied to façade construction(Dallasega et al., 2018, 2015). The dimension of the pitch for a specific construction area (CA), and a respective task, considering the associated quantities and crew size for a certain time interval, is the following:

$$Pitch_{CA_i, Task_j, Crewsize_k} = \frac{Quantity_{ij}\,[MU_j]}{time\ interval} \quad (1)$$

The dimensional analysis in formula (1) denotes the definition of a pitch as the quantity indicated in the respective measuring unit (MU) of the task *j* (e.g. 20 m² of parquet) that can be installed by the dedicated crew of the size *k*(e.g. two workers) in the CA *i*(e.g. floor 1) within a defined time interval (e.g. one working day).

$$Pitch_{Floor\ 1, Parquet\ laying, 2} = \frac{20\,m^2}{working\ day} \quad (2)$$

An inherent advantage of the NWA over LPS is that the job assignments have a clearly defined measurable and understandable extent in terms of both labour demand and quantities to be installed. The precognition of single and total quantities (e. g. via quantity take-off from BIM models) enables accurate determination of the construction progress at any time in almost real time (on condition that the extent of the pitch completion is reported daily). Extending a production system like LPS with this essential functionality, known key performance indicators (KPI), such as PPC describing process stability, can be maintained without incident. Analogies of NWA to TP can be seen apparently, whereby the chosen time interval (e.g. one working day) can be interpreted as the Takt time in which one pitch of a certain task should be fulfilled. Notable difference to TP here is that after one “Takt”, the crew does not have necessarily to move on to the next planned location, given that the number of pitches varies from different trades and CAs. This results in a high degree of flexibility, which in turn does not limit the applicability of the presented approach to repetitive projects only, but potentially also suits non-repetitive projects. At the same time, however, high degrees of freedom in terms of project type require great diligence and coordination work to parallelise and balance the workers on the construction site to achieve a continuous workflow that considers the varying "pitch-load" of the individual CA’s and trades. To this end, the approach of collaborative process planning with responsible Last Planners is pursued with similarities to the phase scheduling of LPS. However, work structuring in the modelling module of NWA represents a clear distinction to LPS’ phase scheduling, since reference is made to normalized production rates independent from durations, whilst LPS’ phase scheduling explicitly foresees the application of durations to each activity (Ballard, 2000b). Moreover, the exact labour demand is considered from the beginning on and not just assigned during execution. To further illustrate this difference, Figure 1 was created on the basis of Ballard's (2000a) well-known scheme of the LPS.

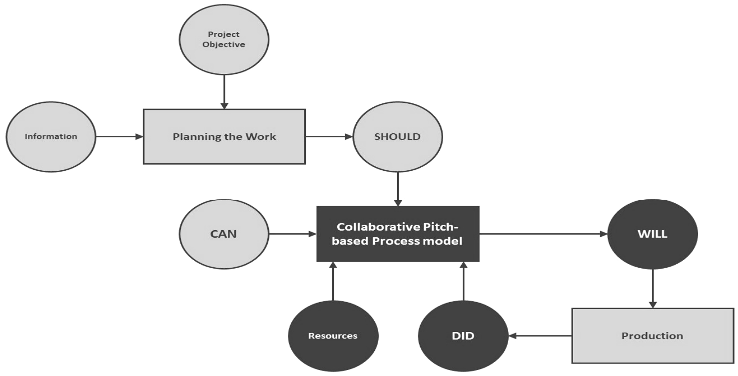

Figure 1: COCkPiT approach - representation based on Ballard(2000a)

The process model forms the basis for automatic scheduling, which respects previously defined dependencies and constraints of tasks and locations. The subsequent monitoring during execution incorporates systematic feedback loops to update initially estimated production rates and labour consumption automatically in the model (pitch update), which in turn triggers a very targeted continuous improvement process (CIP). In addition, employees' confidence in the methodology is systematically increased, because the generated schedules for defined short-term look-ahead windows only include an extent of work that corresponds to their own performance that has so far been monitored. If daily goals defined by the pitch cannot be met, analogously to LPS, reasons for non-completion (RNC) can be collected, bringing with it all well-known advantages in terms of enhanced transparency and CIP. The schematic flow of the NWA in the COCkPiT project is illustrated in Figure 2, indicating also the feedback loop by means of the monitoring module.

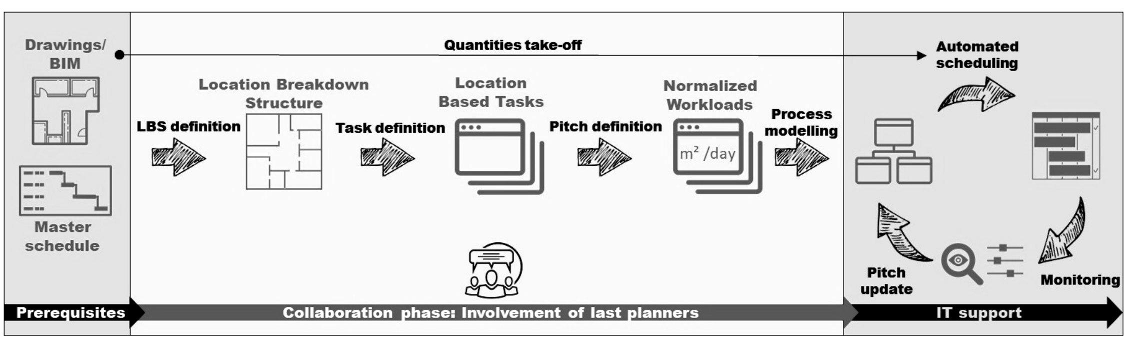

Figure 2: Schematic workflow of NWA

OBJECTIVES

Within the presented research project, it will be aimed at covering the three main building phases: shell, envelope and interior. The main outcomes to this project will be a NWA-based methodology, as the theoretical framework for an ensuing IT-prototype, to support three main aspects: i) a **modelling** of the process, comprehensive of all relevant project information, ii) a short-term **scheduling** module, suggesting possible schedules automatically, which are computed based on the information in the model in (i), and iii) a real-time progress **monitoring** tool, to both control the site operations and progressively adjust the model (i), and subsequently the schedule (ii) to the concretely achieved pace.

The **modelling** module foreseen in COCkPiT aims at supporting the collaborative definition of the execution process. More precisely, this corresponds in defining i) the main tasks that need to be executed, and for each of such tasks ii) the resources required by it, iii) the locations where to perform it, iv) the pitch, and v) the dependencies (such as precedencies) on the execution of the tasks in the locations.

The aim of the project is to develop a methodology and a formal framework supporting the definition of a process model. This latter is often ignored in construction, where a process is modelled by directly defining a plan. The difference is that a process model would represent only the requirements that a plan must satisfy (e.g., task A must be performed in location l any time before task B is performed there), without already committing to sequences and dates on the execution of the tasks. The definition of a model involves different competences from the different trades participating to the project. Therefore, great benefit can be achieved if it is defined collaboratively. To this aim, within the project a graphical language to support a process model definition will be defined, along the line of Marengo et al. (2016).

In the **scheduling** module, based on the process model collaboratively defined, short-term schedules can be derived. A short-term schedule represents a commitment to one among the possible plans compliant to a process model. To compute the duration of a task and the number of labour resources needed, the system relies on the concept of pitches defined in the process model, which contains implicitly the commitment of the executors due to its collaborative, bottom-up determination. Importantly, the schedule for a certain period is based on up-to-date information on the executed tasks (information that is collected in the monitoring phase). The project aims at developing IT-tools for this module, both supporting a manual definition of a schedule and automatic generation of them (optimizing some criteria of interest). This will be done by relying on constraint satisfaction techniques.

The **monitoring** module aims to control the construction progress in a quantitative way and in a real-time frequency. Here, the pitches will be used to measure the construction progress by collecting information with regards to which extent the pitch of every activity has been actually achieved. Up to now, experiences with façade installations(Dallasega et al., 2015)showed that in repetitive working environments the construction progress measurement could be performed by considering the measuring units of single façade fields. In a non-repetitive working environment, a project with a high variety of construction locations, in terms of size and technology content, differentiated units of measurement must be determined. Here, the aim is to define for every task applicable measuring units (like number of pieces, square meters and running meters). Moreover, pitches are used not only to measure the construction progress in a quantitative way but also to forecast in a reliable way the labour demand until project completion. Previous research has shown, that by applying the pitching concept to forecast the labour demand until project completion, the planned and used amount of budgeted men-hours can be kept in sync and as such budget overruns can be avoided (Dallasega and Rauch, 2017).

RESEARCH METHODOLOGY

To increase the practical feasibility of the project outcome, SMEs from Northern Italy have been engaged in the research stage. Hence, the COCkPiT project follows an applied research approach, which was initiated with a preceding literature review and anew analysis of the previous application of NWA in façade installations (Dallasega et al., 2015). As a following step interviews with the industry partners were held to investigate and analyse the current way of working in their represented domain by studying a variety of historical reference projects with a special focus on production planning. The results from this analysis phase were then used for deriving requirements for a methodical and IT-based implementation of the NWA approach as starting point for the conceptual development, which took also into account the previous findings from facade installations(Dallasega et al., 2015). These efforts resulted in a first prototype as MS Excel workaround which will be used as a basis for further development. For this purpose, an agile development approach is pursued, which enables the research team to quickly deliver testable intermediate results and to react very flexibly to the changing requirements derived from field tests. Field tests are currently being initiated in two case studies: (1) renovation of a fire station and (2) construction of a winery (both located in South Tyrol, Italy). In this way a high acceptance of the future system of the industrial partners is expected. As a final result a web based software is targeted, which will be validated through pilot construction sites at the end of the project. The research methodology and process is visualized in Figure 3.

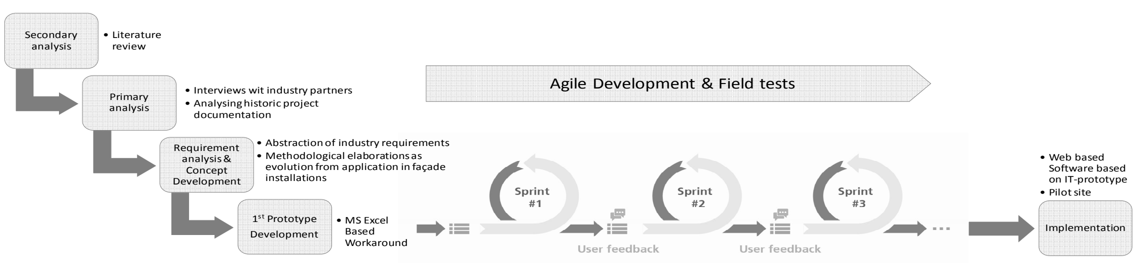

Figure 3: Research process

CONCLUSION & OUTLOOK

In this paper, the COCkPiT project and the underlying methodology of a normalized workload approach incorporated in the three modules of modelling, scheduling and monitoring as well as the general research approach were introduced. The here presented current study as part of the entire research project familiarizes the Lean Construction community with the general concept of NWA and investigates the applicability of the methodology and the usability of the first IT-prototype (as a MS Excel workaround) through field tests with the industry partners to (1) proof the general concept and (2) trigger the upcoming agile software development cycles.

The presented workaround prototype (Figure 4) provides for the modelling of location based construction tasks in an MS Excel sheet, which is used as input by a constraint solving engine. Based on a-priori defined constraints (task and location dependencies) and external conditions (e.g. minimize overall duration or optimal resource saturation) schedules are automatically generated, which in turn are converted into an MS Excel sheet. This sheet is then used on the construction sites for work planning and progress monitoring. Eventually it will be used in a short-term cycle to update the model data.

Preliminary feedback acknowledged the benefits of a model that supports automatic scheduling. However, it was argued that the modelling part should take place as far as possible in the backdrop and that later working with the tool should recall as much as possible the handling of a Gantt chart. It follows that in the coming development sprints, attention must be paid to the effects of user events (influences of changes to the Gantt chart representations on the underlying model) and how the model data can be brought into the system in the simplest and most intuitive way possible.

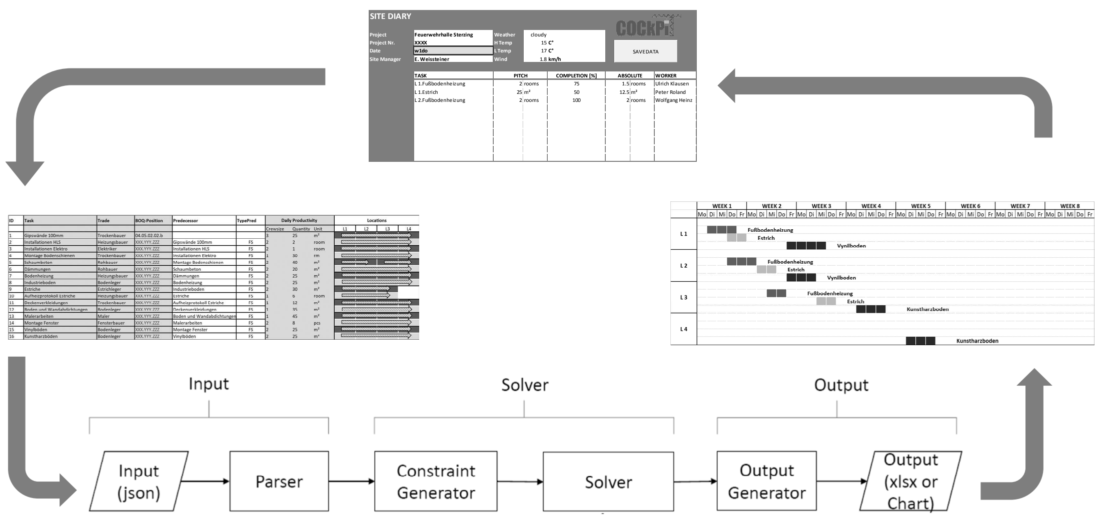

Figure 4: Prototype Workaround

In this respect, the current study will provide valuable guidance, which will be followed and refined in the upcoming sprints. Furthermore, this study serves as a basis to find out how the pitches for the different trades must be defined so that the work can be reliably planned and measured, since the pitching concept is new to most of the participating trades.

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COMBINED APPLICATION OF EARNED VALUE MANAGEMENT AND LAST PLANNER SYSTEM IN CONSTRUCTION PROJECTS

Mark Novinsky[1], Claus Nesensohn[2], Nadia Ihwas[3] and Shervin Haghsheno[4]

ABSTRACT

The application of the Last Planner System (LPS)in the construction industry is increasing more and more. Reviews in the literature report that by applying LPS project performance is improving. However practical experience shows that there is some lack of structure in daily work. Further more researchers are still looking for feasible process measurement.

This paper aims to contribute to the described challenge by developing a concept for the combined application of the two following methods. One is Earned Value Management (EVM), a project control method that combines data regarding scope, schedule, and resources to assess project performance and progress. The other one is LPS, a Lean Construction method for production planning and control. In LPS project workflow is developed and controlled collaboratively within a team. Through the combined application of these two methods based on the structure and a transparent production plan the project’s workflow can be measured by objective metrics like Percent Plan Complete (PPC), Schedule Variance (SV) and Cost Variance (CV) to highlight the need for potentially necessary corrective action.

KEYWORDS

Lean construction, last planner system, earned value management, process measurement, work structuring.

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INTRODUCTION

In many construction projects a lack of project structure and the fact that project progress regarding cost and schedule efficiency is not measured are major challenges. Due to lack of transparency for stakeholders during the design and construction process, deviations from the planned process are not forecasted and measurement of deviations is often taken into account too late.

Tools and methods already exist which both facilitate structuring projects and measuring their progress. Such methods are e.g. Earned Value Management (EVM) and the Last Planner System (LPS)(Ballard 2000),a Lean Construction method. The two methods differ in their application and their output: Whereas EVM allows to measure project progress and project efficiency by specific key figures focusing on schedule and cost, LPS fosters collaboration of all participants and process reliability is measured by key figures like the Percent Planned Complete (PPC). The joint application of the two methods can result in a holistic system for the measurement of project progress considering both economic aspects and process quality in terms of collaboration and quality of workflow. Both a more transparent and effective progress measurement and a better project structure can be achieved.

The combined application of EVM and LPS and the potential benefits for construction projects have been analysed by only a few studies so far. This paper will provide a detailed analysis of the impact of the combined application of EVM and LPS on construction projects as a whole and on their process quality in particular, on a theoretical basis. Results of this paper shall provide a solid ground for further analyses and case studies.

THEORETICAL FOUNDATIONS OF EVM AND LPS

EVM is a project control system that enables the measurement of project progress and project efficiency. In a first step, the project is structured into work packages by creating a Work Breakdown Structure (WBS). Secondly, an earnings plan is derived and finally, project progress is measured by comparing the earnings plan with the actual work accomplished(Project Management Institute (PMI) 2008).EVM was developed by industrial engineers of the US Department of Defense (Fleming and Koppelman 2010).

In order to measure project progress, specific key figures (Table 1) are collected during the project and are gradually analysed(PMI 2008). Relevant key figures are explained in

Table 1: Key metrics of EVM (based on PMI 2008)

Metrics	Alternative designations	Interpretation
Planned Value = PV	Budgeted Cost of Work Scheduled = BCWS	Indicates how much work should be done to date. Actual project progress is measured against the PV.
Earned Value = EV	Budgeted Cost of Work Performed = BCWP	The value of work performed expressed in terms of the approved budget assigned to that work.
Actual Cost = AC	Actual Cost of Work Performed = ACWP	Are the total costs that have actually incurred in a given time to accomplish a certain amount of work.

Since control systems focus on metrics that are most relevant for the success of the respective projects (Sumara and Goodpasture 1997), EVM aims to provide an integrated cost/schedule progress monitoring system(Fleming and Koppelman 2010). Therefore, two variances are derived from the key figures shown above in order to measure project progress accordingly (Cândido et al. 2014). In general, variances measure deviations from planned values and their corresponding indices allow to compare the performance of different projects(PMI 2008). Relevant variances and indices are shown in Table 2.

Table 2: Variances and Indices of EVM (based on PMI 2008)

Variance or Index	Formula	Interpretation
Scheduled Variance = SV	SV = EV – PV	Measures deviations from schedule
Schedule Performance Index = SPI	SPI = EV / PV	Indicates overall time efficiency and how efficient time is used by the project team.
Cost Variance = CV	CV = EV – AC	Measures deviations from budget
Cost Performance Index = CPI	CPI = EV / AC	Indicates overall cost efficiency and how efficient financial resources are used

EVM is typically applied based on the Critical Path Method (CPM) that supports the push system, whereas the LPS supports the pull system. In the developed model the metrics of the EVM are used, but the pull system of the LPS is applied.

LPS was developed by Ballard and Howell and is currently the most common method in Lean Construction (Mossman 2015). Lean Construction is the transfer of Lean Thinking, which is based on the philosophy of Lean Production and the Toyota Production System, to the construction industry: The construction project shall be delivered through maximizing customer value and eliminating waste during production(Ballard 2000).

During their extensive research Ballard and Howell found out that these objectives are achieved if production is based on a high-quality commitment-based planning system (Ballard and Howell 1998). For this purpose LPS was developed. The Last Planners within LPS are those project participants who actually realize the planned work on site (e.g. sub-contractors, craftsmen etc.) (Ballard and Howell 1994). Within LPS, they jointly plan their work based on a pull system and make their own commitments(Mossman 2015).

During weekly meetings, the Last Planners measure the reliability of their commitments with the key figure Percent Plan Complete (PPC) (Ballard 2000). PPC is “attained by dividing the number of completed assignments by the total number of assignments each week” (Ballard and Howell 1998). Hence causes for deviations are discovered and discussed among the Last Planners. Based on these findings they are able to respond appropriately to difficulties and to improve their processes (Ballard 2000).Other metrics like Task Made Ready (TMR) and Task Anticipated (TA) are also used to analyse the planning process (Hamzeh et al. 2016) but are not focused for this model.

The LPS basically divides a project into four main planning levels. Per each level, the degree of detail increases.(Ballard 2000; Hamzeh et al. 2008; Mossman 2015; and others). Those four levels are also the basis for the designed model and are shown in Figure .

RESEARCH METHODOLOGY

This research is based on a combination of a systematic literature review, which established the context of the current state-of-the-art regarding EVM and LPS in a combined application within the construction industry, and an empirical study, which made use of experts (Arriagada and Alarcón C 2014) to provide a more fundamental understanding of the combined use of EVM and LPS.

Therefore a case study driven research with two rounds of semi structured interviews took place. This is a strong and flexible method to understand the experience of individuals(Fontana and Frey 1994). They also enhance the depth and breadth of the phenomenon under investigation, having been seen to be particular useful for research within the construction sector(Shehu and Akintoye 2010).

The case study project is the design phase of a new build pharmaceutical production plant with a project volume of 215 million € in which EVM and LPS were jointly implemented. Both rounds of interviews utilised a purposive sampling to select the relevant participants(Bryman 2012). The interviewees of the first round have been four experts with professional experience of the use of EVM within the construction industry as project manager or consultant. Each interview was conducted with a standardised interview guide which was pre-tested to ensure quality(Fontana and Frey 1994) and suitability of the allocated interview time (Häder 2015; Schnell 2012). The guidelines were sent in advance to the interviewees for preparation. The advantage of this approach is the flexibility in asking potential questions which are outside the guideline. This enables to explore the knowledge of the participants in depth. The interviews lasted approximately 60 minutes and were tape-recorded and transcribed afterwards. These transcripts have been analysed using a systematic approach called the "framework approach"(Ritchie and Lewis 2003).

Based on the literature research, experience from observations during the case study and a first round of interviews a model for implementing the combination of EVM and LPS in design was developed. The second round of interviews was used to ensure validity by so-called member checks. For this purpose the experts involved in the data collection of the original research were interviewed to ensure the interpretation of the data was accurate.

MODEL AND IMPLEMENTATION CONCEPT

Based on the first findings of the research, an abstract model for the combined application of EVM and LPS was developed as shown in Figure 1. The model consists of four workshops equal to the four planning levels of the LPS.

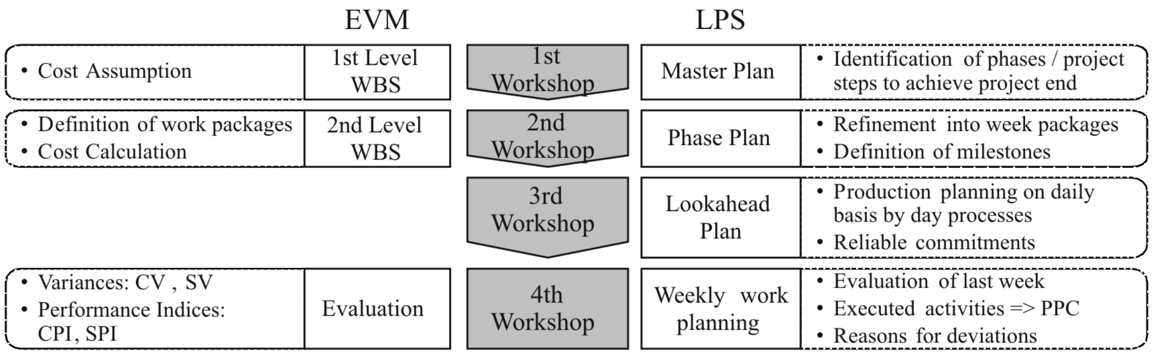

Figure 1: Abstract model of the combination of EVM and LPS

A concept was derived from the model to implement both methods in a project. In the following section the implementation process is explained by the example of a design project.

FIRST WORKSHOP: MASTER PLAN

In the first workshop, representatives of all disciplines collaboratively define the objectives that should be achieved at the end of the project. As shown in Figure 1, the relevant phases are identified on the first level of planning. The phases are planned backwards beginning with the project's end from right to left and they identify the relevant tasks that have to be completed in order to achieve the project's objectives(Ballard and Howell 2003).

In the next step the phases are broken down in process steps to define which disciplines are involved. At this level a rough planning of quantities is conducted without consideration of time aspects. Based on this a first cost assumption by the stakeholders is made, generating a first Planned Value. Additionally, the expected workload can be roughly assessed at a very early stage of the project.

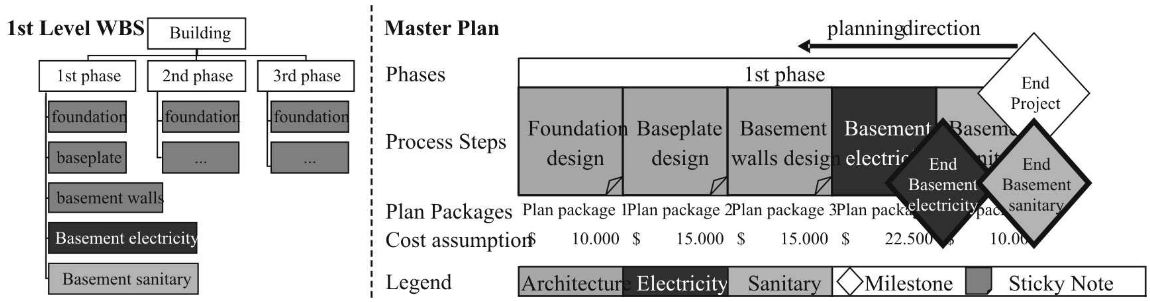

Figure 1: WBS and Masterplan with Plan Packages and process milestones

The end of every process step is marked by a milestone which, by adding a budget, turns into a budget milestone (framed by black line).By assigning coloured sticky notes to each discipline a better visual overview is achieved. The Master Plan must have a 1:1 relation to the WBS to guarantee a clear project structure and hierarchical order of the work packages to measure physical process (Emblemsvåg 2014).

SECOND WORKSHOP: PHASE PLAN

During the second workshop, a phase plan is developed in order to further refine the WBS and to arrange the process steps of the master plan in a suitable time sequence(Ballard and Howell 2003). As shown in Figure 2: WBS and Phase planning with Quality Gates

the process steps are divided by discipline into Week Packages and added to a timeline of project weeks. To guarantee a clear structure, elements on the higher level must be completely explained by lower elements.

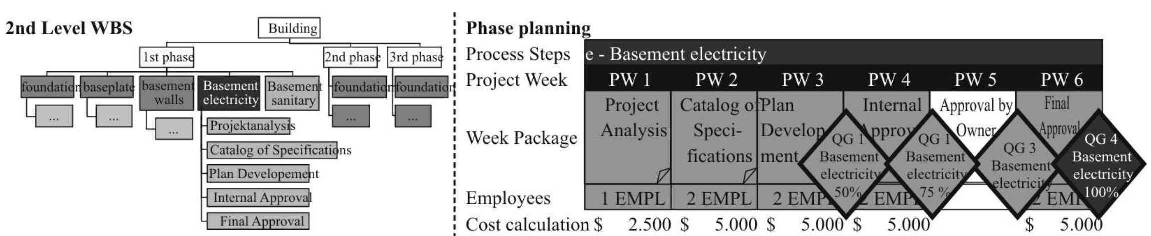

Figure 2: WBS and Phase planning with Quality Gates

During the design phase of a project processes usually last for a longer period. Therefore so-called Quality Gates (QG) are defined. They equal intermediate milestones defining a specific status of the plan package e.g.: (1) Document created, (2) Document internally approved, (3) Document released by owner, (4) Document finally released.

Based on the expected overall workload of a plan package, a share of the expected workload respectively of the available budget is assigned to each QG. Consequently, a process step is completed by 100% if the last precondition of a QG is met.

At this level the resource planning is conducted by assigning the number of employees to a work package. By adding the budget milestones to the Phase Plan a first baseline is created being a precondition for the Planned Value.

THIRD WORKSHOP: LOOK AHEAD PLAN

In the Look ahead Plan the processes planned on a weekly basis are broken down into Daily Processes. This can be realized by sticky notes on a planning board in a central meeting room. In the example as shown in Figure 3: Productionplanning in the Lookahead Plan with Quality Gates fifteen commitments are necessary to achieve the black-framed QG 1. In the 1st project week there are 5 commitments. The Planned Value of this week is 5/15 commitments, which are budgeted by 33,3% of the budget of completion of the QG 1. In the case that the number of employees is varying, the Budget At Completion (BAC) is divided by the total number of employees and multiplied by the number of employees per week to get the weekly budget. While establishing the look ahead plan, it was discovered that for achieving the planned work packages additional employees are necessary compared to the phase plan.

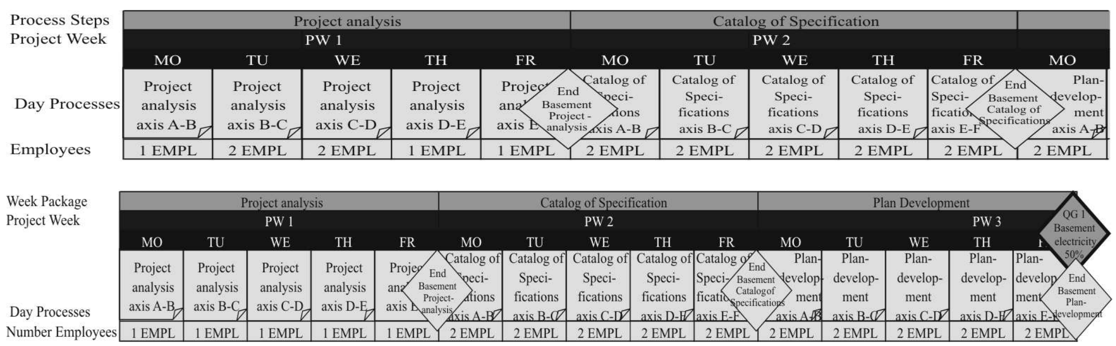

Figure 3: Productionplanning in the Lookahead Plan with Quality Gates

FOURTH WORKSHOP: EVALUATION

In a weekly meeting the past week is evaluated. Therefore, it is measured which of the planned activities have been completed. By the ratio of the planned and completed activities the key figure PPC is calculated(Ballard 2000). In Figure 4 it is shown that three out of five activities are executed, leading to a PPC of 60%.

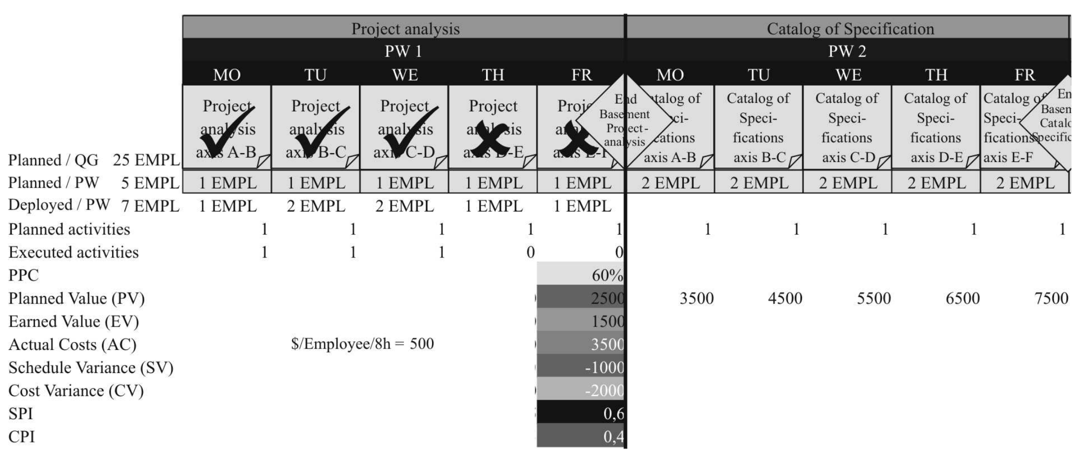

Figure 4: Evaluation of the Lookahead Plan with calculations of the EVM

The Planned Value with regard to the Phase Plan was at 2500 $. With the PPC of 60% we get to an Earned Value of 1500 $. By the difference of EV and PV a negative SV-value is calculated indicating that the project is behind schedule.

In the phase plan, the need for five employees was assumed. But the lookahead plan had revealed, that actually seven employees were needed. With a calculation of 500$ per employee per day costs of 3500$ were generated. The difference of EV and AC results in a negative CV. With the calculated numbers we obtain the efficiency indicators SPI of 0,6 and CPI of 0,4 as shown in Figure 5.

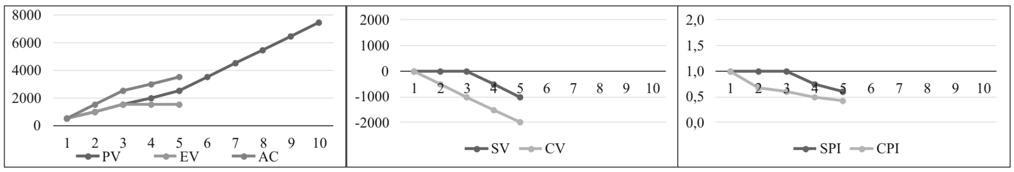

Figure 5: The measures of the EVM after the first project week

With these numbers the project team receives a good impression of their performance, not only regarding their planning reliability but also with respect to the parameters Schedule and Cost. By receiving a nearly alarm signal in the case of variances, countermeasures can be initiated properly.

After the evaluation of the past week the upcoming week is revised in the Lookahead Plan. As shown in Figure 6the unfinished daily processes are rescheduled. If processes have not yet been monitored, these processes are also added to the original workload. Therefore, it must be evaluated if those additional processes can be realized together with the originally planned workload as shown or if the entire process step needs to be shifted to the future together with the budget milestone. The same case occurs if tasks are added that have not been planned yet. Since at the time of budgeting the whole budget was already allocated this leads to additional costs. Figure 7 displays that with the additional employees the SV of the first week was caught up, demonstrated by the SV line going towards 0. But with the additional costs the CV line is following a downward tendency.

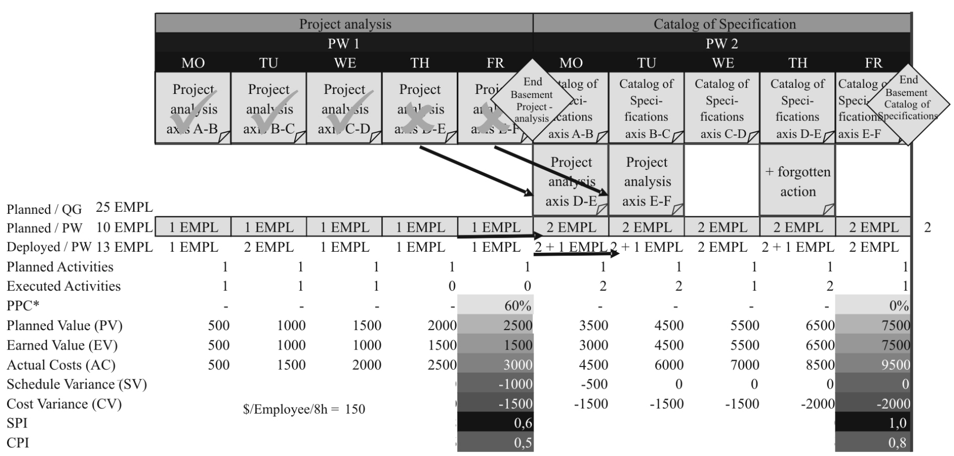

Figure 6: Production planning of the 2nd project week after the evaluation with rescheduling of the not fulfilled commitments

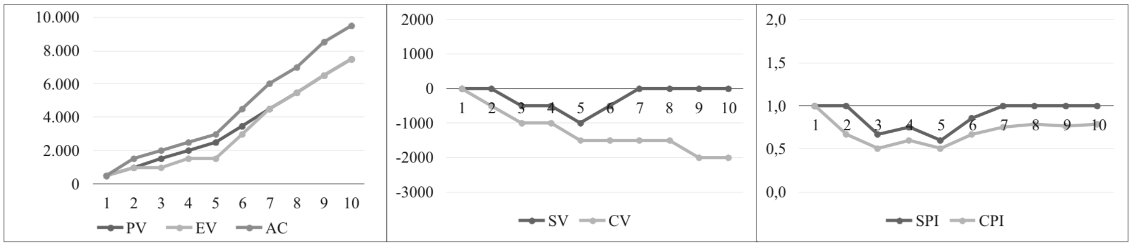

Figure 7: The measures of the EVM after the second PW

VALIDATION

Through the second round of expert interviews the potential of the concept was evaluated. EVM practitioners, not being familiar with LPS, expressed that they see great value due to the fact that a detailed production planning is implemented. They are getting a more transparent and less subjectively planned process and a greater reliability of the numbers.

Additional reasons for variances can be extinguished on an early state and facilitate the team to implement early countermeasures. LPS practitioners see in the concept a good chance of eliminating the lack of process measurement. By using the system, the cost estimations can be evaluated and a learning process for further projects is being applied.

Despite the mentioned advantages it is questionable, whether the concept can be implemented in an analogue system like LPS which is currently often used. By using sticky notes for production planning there is no automated alignment to a cost account system. With further research towards the digitalisation of LPS a high potential could possibly be generated. Additionally, different opinions were stated regarding the question, up to which level the WBS should be graduated. In bigger projects a level of detail of one week might be sufficient, whereas in smaller projects the tracking of daily tasks can be reasonable.

CONCLUSION

Both EVM and LPS are project control systems, but both systems focus on distinct aspects. LPS focuses on the measurement and optimization of workflow. With LPS the reasons for deficiencies are becoming more transparent. But cost or schedule performance in particular are not directly measured. Nevertheless both factors are of great interest for the customer to have an idea of the current status of the project. Therefore EVM could complement LPS since it focuses on measuring and controlling project progress with regard to schedule and especially costs. Consequently, the joint application of EVM and LPS could lead to a holistic progress measurement of a project considering both quantifiable metrics like schedule and costs but also factors like quality of work flow and collaboration. Analyses in this paper have shown that the combination of both systems offers indeed high potential to improve both process quality and performance of construction projects.

In this paper, a concept for implementing a combined control system of LPS and EVM was devolved in a design project but based on the survey there is no limitation for the implementation in construction projects as well. Key aspects of both methods were combined, and the concept was developed and finalized on basis of a case study and expert interviews. The case study revealed that a long pre-planning phase is required to implement the suggested concept. Companies, which decide to implement both EVM and LPS, need to establish a strong standard that supports the application of this concept. To achieve this, not only commitment of the Last Planners is required, but also commitment of the management is essential for the successful implementation.

Additionally, expert interviews revealed that the measurement of the Earned Value is getting more objective by the transparent production planning of the Last Planner. Nevertheless, without the support of IT Systems the data collection for performance measurement will end up in time consuming processes, which may impede the implementation. Ponz-Tienda et al. 2015 developed a model that can serve as a basis for further analyses.

If standards are properly set and processes are controlled regularly, the joint application of EVM and LPS can lead to better project performance. Since the concept was developed and validated within the design phase, a further case study or action research within projects with both design and construction phase would be beneficial. All in all the developed concept offers a sound basis in order to initiate the next steps.

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OPTIMIZING FLOW PROCESS THROUGH SYNCHRONISATION OF CYCLE TIME

Pawan Pandey[1], Somil Agrawal[2], and J. Uma Maheswari[3]

ABSTRACT

Construction projects can be modelled, using TFV theory of lean construction, as combination of main activity network that are primarily transformations and feeding flow processes which supply input material to main activities. These feeding processes may include one or more sub-processes/ and operations with varying cycle time (C/T). The lack of synchronization between these sub processes/ operations results into construction bottlenecks which delay the execution of main activities. Mechanization of few processes/ sub-processes or operations in isolation create large variation in cycle time and shifts the location of bottlenecks. Thus, limited benefits accrue from mechanization, automation, etc.

The present study proposes a framework to locate the bottlenecks through hierarchical process analysis and discrete event simulation. These bottlenecks can be eliminated through modifying cycle time of selected sub process /operation by changing resources allocation and by eliminating waste with the ultimate aim to enhance overall productivity. The proposed framework is demonstrated utilizing data from an automated railway track construction project. The substantial improvement in construction productivity was observed after synchronization of cycle time.

KEYWORDS

Lean construction, cycle time synchronisation, construction bottlenecks, discrete event simulation, automated railway track laying.

INTRODUCTION

Construction project are complex, executed in a dynamic environment and broken into work packages (WPs) for efficient management. These WPs generally have one main conversion activity supported by a set of sub-processes/ operations to produce measurable output. These main activities are logically sequenced against logic and resource constraint for efficient execution. Often these WPs are assigned to different process heads whose focus is more on ensuring high local productivity than overall project performance. Often varying degree of mechanization are introduced at different level in view of

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competing needs of different process heads, special conditions of contract for quality assurance, etc.

In one of the ongoing railway track laying project in India, automated pre-stressed sleeper manufacturing was adopted to expedite track laying. However, daily progress remained slow (i.e. 200m per day) since because track laying was being done manually. The sleeper casting beds remained idle for prolonged period due to low demand from track laying crew. The introduction of automated New Track Construction (NTC) machine was then introduced to speedup track laying process which had daily capacity to lay 1.5 km but the achieved progress was only 1.15 km as sleeper production could not match the desired progress. The delays were random and unpredictable at different activity level. The variations in C/T amongst the sub processes (i.e. sleeper production C/T was 47.3 hrs and track laying C/T using NTC was 10 hrs for 1.5 km track work) and operations within these feeding processes were causing construction bottlenecks. These bottlenecks not only reduced construction productive but also delayed the entire project. It is apparent that mechanization of few processes/ sub-processes or operations in isolation, yields limited benefits and shifts the location of bottlenecks. Therefore, the present study is aimed to develop a framework to enhance overall construction productivity by balancing the flow through identifying and eliminating of likely construction bottlenecks.

RESEARCH BACKGROUND

The theoretical understanding of construction have evolved progressively from transformations model to flow model and then to TFV (i.e., Transformation, Flow and Value) theory for lean construction Koskela (2000). The TFV theory assumes construction project as combination of transformation and flow activities which progressively add value to meet customers need. Diekmann et al. (2004) through a set of case studies highlighted the need to eliminate/ optimize flow activities which consumed almost 70% of the time and resource. Despite waste reduction, variability in construction flow process is inevitable due to variation C/T of its components. This variability leads to penalties i.e.,need for buffers and sub optimal resource utilization (Hopp and Spearman 2001). Despite known benefits, few researchers have attempted to reduce flow variability (Bertelsen et al. 2006). Ballard and Tommelin (1999) proposed tools and techniques for continuous flow process (CFP).‘Last Planner’ system minimizes in flow variations through commitment based execution planning (Ballard and Howell 1994). Binninger et al. (2016) investigated applicability of work process levelling tools to achieve rhythmic production. Pawan et al., (2017) presented a case study to balance flow process using multiple crew and crew multi-tasking.

Since construction project are complex (Oglesby 1989) and involve plethora of flow processes (Bertelsen et al. 2006), all project components cannot be structured in CFPs (Ballard and Tommelin 1999). The situation becomes even more complex when part mechanisation is introduced in a process without careful planning and disturbs existing flow balance. Thus, a framework is needed to systematically analyse the existing flow process, identify likely bottlenecks and indicate the extent to which adjustment in C/T is needed for rhythmic production. The use of charts and tables may be adequate for simple processes. However, discrete event simulation (Alzraiee et al. 2015) will be needed for complex projects. Removal of these bottlenecks in successive steps during planning and scheduling stage can improve project performance in cost effective manner.

RESEARCH METHODOLOGY

Exhaustive literature survey was carried out to understand theoretical framework of construction project and root cause behind formation of construction bottlenecks. TFV theory of lean construction and continuous flow process (CFP) design concept are utilized to formulate the research hypothesis "*synchronization of C/T of interconnected sub process/ operation in process will enhance the process productivity by minimizing construction bottlenecks*".

As shown in Figure 1, the methodology involved developing solution framework and testing of the enunciated hypothesis developed using case study approach. Multiple techniques were used to collect the data from two sites of an ongoing project over a period of one month duration and Extend Sim was used as DES (i.e discrete event simulation) tool to identify the bottlenecks along with preparation of material/ crew flow. Although the study was carefully designed to minimize the chances of misrepresentation, there are limitations on generalizing findings from a single case study (Stake 1995).

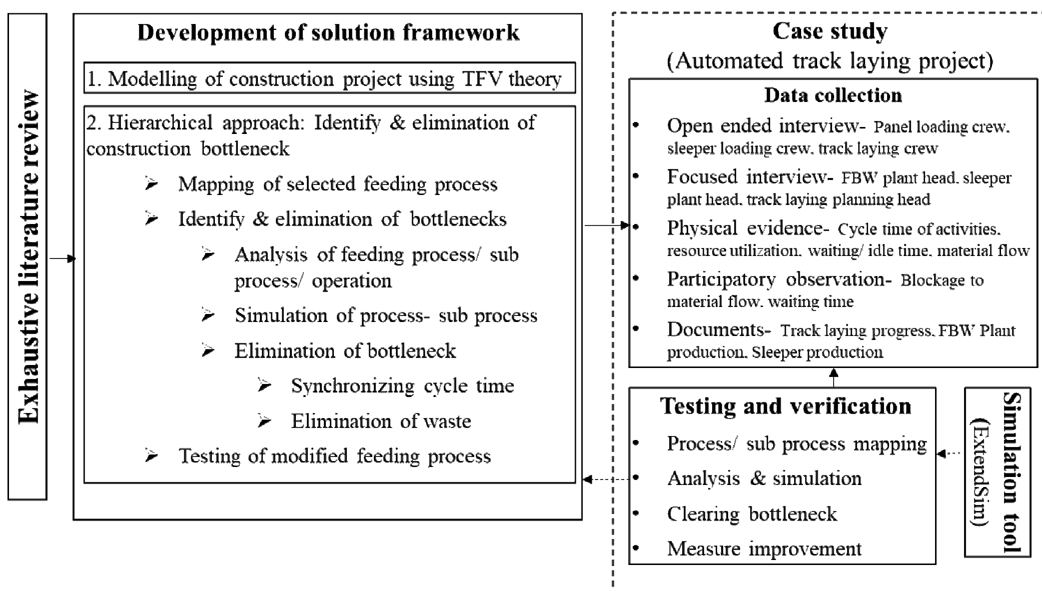


Figure 1: Research Methodology

SOLUTION FRAMEWORK

A construction project can be modelled as combination of main activity network and feeding processes (Bertelsen et al. 2006) as shown in Figure 2. These feeding processes consist of linearly connected (i.e., end to start relation) sub processes/ operations. In the present study 'operation' is considered asset of tasks performed by a crew (i.e combination of man and machine) which cannot be broken further and a sub process is a combination of more than one operation with identifiable input and output.

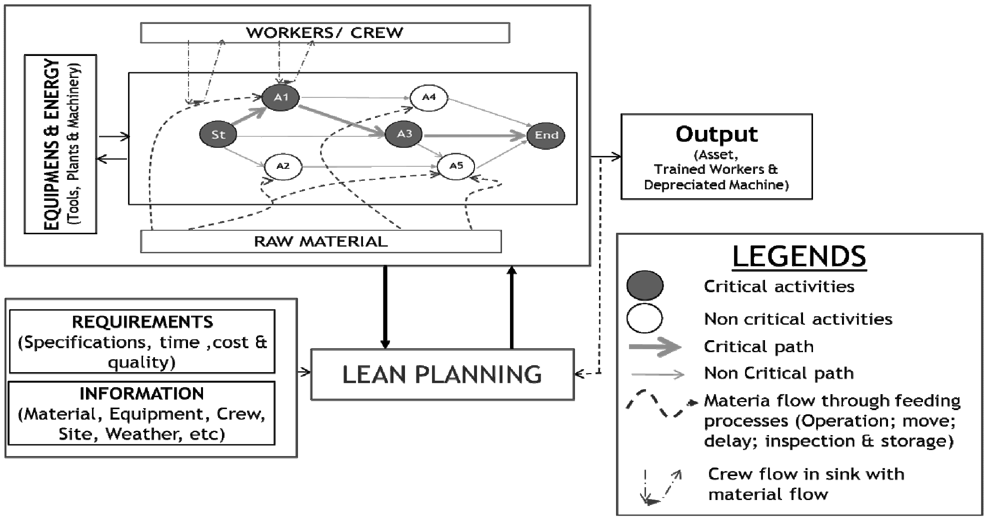


Figure 1: Model of Construction Project (Koskela 2000; Bertelsen et al. 2006).

Ideally material should flow continuously through each of its sub-processes and operation (Ballard and Tommelien 1999) which means each sub-process/ operation should process same quantity of material in a unit of time (i.e hour, shift, day, etc). The variation in C/T creates bottlenecks as some sub process/ operation would not be able to match the material processing rate of their predecessors and/or successors. A flow diagram for optimization of flow process is shownas Figure 3.

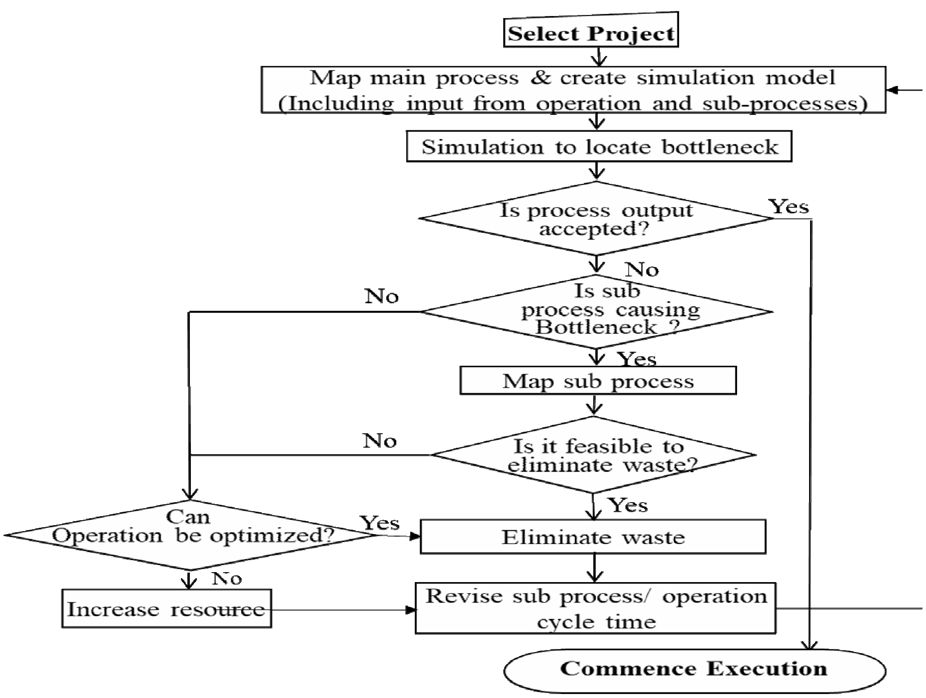


Figure 3: Flowchart to Clear Bottlenecks

The sub process/operation with little or nil idle time (i.e crew waiting for input material from downstream) located just before sub-process or operation with high idle time is the place where bottleneck is being formed. Since construction projects are complex involving multiple feeding processes with several sub processes and operations, complete synchronization of C/T is not feasible. Hence, it will be appropriate to select key feeding process, map all sub processes/ operations and keep on optimizing hierarchically till desired productivity is achieved through synchronization of C/T. The C/T can be modified either by additional allocation of resource and/ or elimination of waste using lean principles. The process involves data collection, process mapping, identification and elimination of bottlenecks progressively from feeding process to sub process and then to operations levels.

CASE STUDY

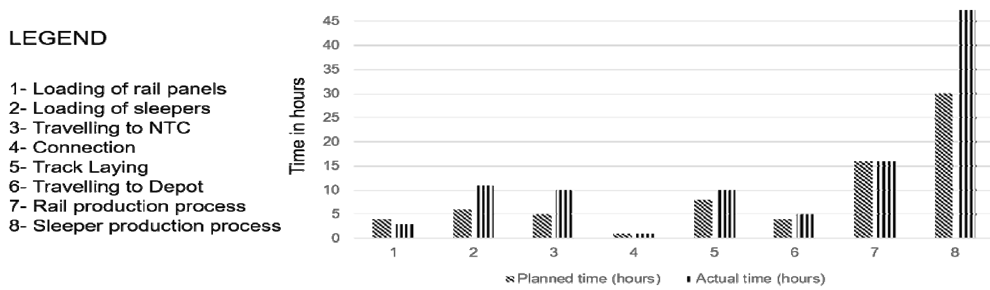
PROJECT DESCRIPTION

The proposed study was performed to identify the cause behind low productivity of NTC (i.e 1.15 km / day instead of 1.5 km /day) employed in a green field railway track laying project in India. The scope of work involved 626 km track laying which was divided into two sectors; 1) from 0 to 340 Km; 2) 340 to 626 km. Base depot of Sector I was located at 107 km and Sector II base depot was located at 436 km. The track laying process involves welding of 25 m long rails in flash butt welding (FBW) plant to form 250 m long rail panels which are then loaded in the rake (i.e group of rail cars) using a gantry set-up. The concrete sleepers are mass produced using semi-automated system. After loading rail panels, rakeis moved to sleeper plan wherein sleepers are loaded using gantry setup. This loaded rake is hauled from the Depot to the NTC location by a locomotive. The loaded rake is attached to the rear of NTC machine and the NTC machine starts placing the sleepers at predetermined spacing and the rail panels on top of it. After the sleepers, rail panels, clips etc. are exhausted, the empty rake is hauled back to the depot by the locomotive and the cycle is repeated. The NTC typically starts laying track from the depot and as it moves away from the depot, the distance between the depot and NTC location keeps on increasing. This increases overall C/T of track laying and reduces rate of progress.

DATA COLLECTION AND ANALYSIS

Mapping of Track Construction Process

The NTC machine has capacity to lay 1.5 km track of approximately 10 hours. However, productivity of NTC was 30 km against planned progress of 40.5 km (assuming 31 days in a month). Since, there was no breakdown of NTC machine, lower productivity is attributed to some other sub process or operation. The railway track construction can be modelled as one pull activity (i.e track laying using NTC) and supply of input material to the NTC as feeding process (Figure 2). The sub processes and operations involved in this feeding process with their planned and actual C/T is illustrated through graph in Figure 4. As seen in the graph, sleeper production, sleeper loading and travellingof rake to NTC have C/T higher than planned C/T. Hence, these selected sub processes would require detailed analysis.



	1	2	3	4	5	6	7	8
Planned Time (hrs	4	6	5	1	8	4	16	30
Actual Time (hrs)	3	11	10	1	10	5	16	47.3

Figure 4: Railway Track Construction Process

Flow Process Analysis

The summary of the entire process with typicaltravelling time of rake is shownasFigure 5. In addition material flow chart was made to identify interdependence between various sub process/ operations in addition to identification and elimination of waste. The analysis revealed that rail production (B sub process) is fairly efficient. The loading of sleepers in the rake (A2 operation) was inefficient and affected by frequent breakdown of gantry. The hauling of rake to NTC took long time due to variable hauling distance (Figure 5) which required accurate identification NTC position and coordination between NTC crew loco-operators.

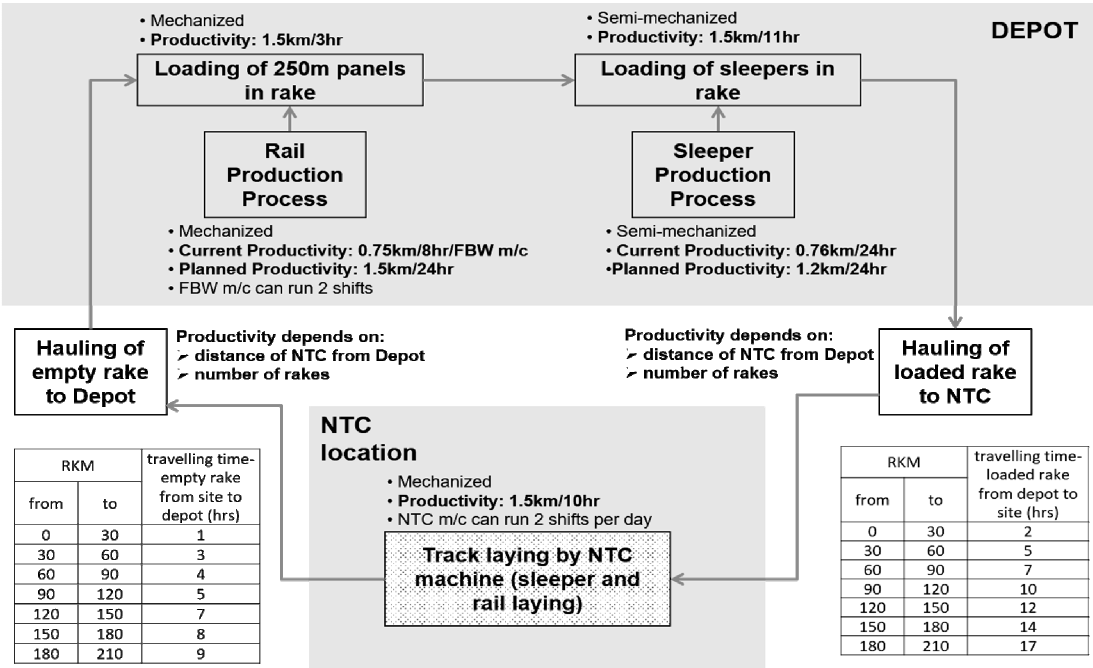


Figure 5: Flow of Railway Track Construction Process

Thus, use of GPS based tracking system was recommended. As seen in Figure 4, sleeper production sub process is the slowest which took almost 2 days to produce 2500 sleepers required for 1.5 km.

The study revealed that use of 2 gantrycan reduce loading time from 11 hrs to 5 hrs (i.e. one gantry loads 20 sleepers in 5 min; 2500 sleepers will require 10 hrs 25 min). In case of breakdown one gantry will also work as reserve for the other. The use two FBW crew can reduce the C/T from 16 hrs to 8 hrs. The use of GPS based system and better communication system can save approximately 2 hours in hauling of rake to NTC. However, sleeper production system would require deeper analysis as there are multiple sub processes/ operations are involved.

Mapping of Sleeper Production Sub-Process

The sleepers are produced by the long-line method of sleeper production where each bed has 400 moulds for casting the sleepers. The number of beds is a variable and depends on the resources available and the production of sleepers needed. The sequence of activities in sleeper production process and resource required are; 1) Cleaning the beds and insert fixing- one crew with cleaning tools; 2) HTS Wire Pulling-one crew with baffle machine; 3) HTS Wire Tensioning- one crew with tension gun; 4) Concreting and Baffle removing- one crew for concreting and baffle machine crew; 5) Steam Curing- nil; 6) Wire Cutting and De-moulding- one crew each for cutting and de-moulding. In addition tractor mounted buckets are required for transporting concrete from batching plant. Since, sleeper production is done in parallel on multiple beds, managing flow of construction teams, machinery and material becomes crucial.

As seen in Table 1, the C/T for three operations (i.e Cleaning and insert fixing; HTS wire pulling; and Initial tensioning) are in excess of planned C/T. Also the waiting time is to the tune of around 5 hours which needs to be eliminated by managing the flow of crew and machinery. The material flow is also getting constricted during the shifting of sleepers to curing tank.

Table 1: Sleeper Production Process Analysis

SN	Activities	Men Nos	Planned (hh:mm)	Average (hh:mm) W-1	W-2	W-3	W-4	W-5	Month
1	Cleaning & Insert Fixing	8	1:30	4:43	6:35	5:06	5:00	5:03	5:17
2	HTS Wire Pulling	8	2:00	4:19	5:01	4:53	4:28	4:50	4:42
3	Initial Tensioning	4	1:30	3:48	3:39	4:10	3:30	3:52	3:48
4	Final Tensioning	1	0.30	0:20	0:30	0:22	0:46	0:24	0:28
5	Concreting & Baffle Removing	14	3:30	4:08	5:45	4:00	3:59	3:52	4:21
6	Steam Curing	2	11:30	11:30	11:30	11:30	11:30	11:30	11:30
7	HTS Wire Cutting &Demoulding	8	3:25	3:25	3:48	3:36	3:52	3:46	3:45
	Total	45	23:55	32:38	36:38	33:54	33:01	33:17	33:54
8	Gap Time		00:00	5:25	2:22	4:35	6:03	5:38	4:49
9	**Total Time with Gaps**		**23:55**	**38:03**	**39:01**	**38:28**	**39:04**	**38:55**	**38:42**

Simulation to Identify Bottlenecks

Since sub process is complex, discrete event simulation was attempted for three-bed sleeper production process using ExtendSim software. The results of simulation is illustrated in Figure 6. Initially one unit of each resourcewas considered. The timing of activities on the different beds was varied and checked for minimum waiting time. It was found that for 1 nos. each of all the resources, HTS wire pulling on bed-2 had a waiting time of 3hr45min, HTS wire pulling on bed-3 had a waiting time of 1hr45min and Concreting on bed-3 had a waiting time of 2hr15min. The total time was 37 hr 15min. From the utilization of resources data, it was observed that the baffle machine has the highest utilization rate of 73.5%.

The second simulation with 2 nos. of baffle machine and 1 nos. of all other resources completely eliminated idle time. The sleeper production C/T reduced to 33hrs15min from 37hr15min. However, baffle machine utilization was 38% with slight increase in utilization of other machines. The operations were optimization through method study which resulted into 3 hrs reduction in C/T of cleaning and insert fixing operation and 2.5 hours saving in HTS wire pulling operation. Thus, C/T for sleeper laying sub-process reduced to 27hr45min (33hr15min - 3hr - 2.5hr) producing 1200 sleepers 1037 sleepers in 24 hours cycle using 3 bed system and additional baffle machine. Since,9 beds system can produce 3113 beds in 24 hours cycle, C/T for 2500 sleeper production will be in 19 hrs.

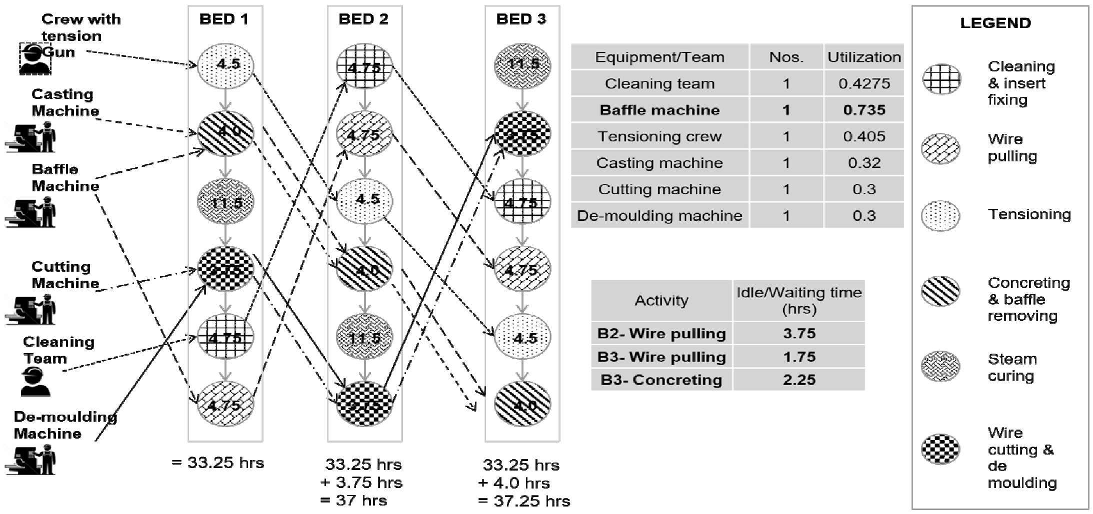


Figure 6: Simulation Trial 1

RESULTS AND DISCUSSION

As seen before, C/T of sub processes/ operations can be reduced by additional allocation of resource or elimination of waste/flow activities. The initially planned C/T for various sub processes/ operations along with revised C/T has been summarized in the Table 2.

Track laying with Single rake system

As per revised C/T, rail panel loading commenced at 0800 hrs and ends at 1100 hrs. The sleeper loading commenced at 1100 hrs and ends at 1600 hrs. Loaded rake starts at 1600 hrs and reach NTC location at 0200 hrs next day. The NTC starts track laying at 0300hrs and empty rake returns for panel loading at 1800 hrs day. Thus, despite higher rate of sleeper production, the C/T for track laying remains 32 hrs. To overcome the problem two rake system can be used.

Track laying with Two Rake system

The two rakes system will reduce C/T to 21 hrs because 11 hrs spent on connecting with NTC and track laying will happen in staggered manner as shown in Table 2. Considering maintenance period, NTC can work at the most 20 hrs in 24 hrs cycle. As shown in Table 2, each operation/ sub-process will have two shifts in 24 hrs. The sleeper production system will have to work continuously and will require 14.5 sleeper beds to produce 5000 sleepers in 24 hrs cycle or approximately 23hr with 15 beds (i.e 5x 3 beds). This type of arrangement will ensure 3 km track laying in 24 hours or 72 kms in a month (i.e.26 days, less Sundays) against actual progress of 30 kms per month.

Table 2: Process C/T with Single and Two Rake System

Sub process/	Process C/T (Hrs)	Remarks

Operation	Planed	Actual	Revised C/T One Rake	Revised C/T Two Rake	
A Track laying	28	40	32	21@	@ Timing staggered
A1:Load rail panel	4	3	3	3	As per actual
A2: Load sleepers	6	11	5	5	2 Gantry used
A3: Move rake to NTC	5	10	8	8	GPS system for tracking
A4: Connect to NTC	1	1	1	Nil @	
A5: NTC operation	8	10	10	Nil @	NTC lays 3.0 km in 24 cycle
A6: Rake returns	4	5	5	5	As per actual
B- Rail Panel production	16	16	16	16*	*Two shifts of 16 hrs each
C-Sleeper production	30	47.3	19$	21#	$ 9 sleeper beds required # 15 sleeper beds required

In the present study focus was on synchronization of C/T, thus waste reduction was limited to identification of issues causing inefficiencies and assessing approximate reduction in C/T. More improvement in C/T may be feasible using lean tools and techniques (i.e VSM, Bigroom, etc). As seen in Table 1, all sub processes and operations finally have balanced over C/T of 24 hrs by having two shifts except sleeper production process which progresses continuously. The use of simulation was restricted to sleeper production sub process which was complex critical for process optimization. The impact of starting of sleeper production with a lead time, leapfrogging of depots and variable hauling time were not considered in the present study. These aspects may be explored in future works.

SUMMARY AND CONCLUSIONS

The problem associated with the part mechanization in construction industry was explained with the help of a case study wherein full benefit could not be achieved in the absence of synchronization among various sub processes and operations. A hierarchical framework was presented to analyze the flow process including supporting sub-processes and operations. Construction bottlenecks are eliminated by reducing C/T of selected sub processes/ operations followed by synchronization of C/T through allocation of additional resources and/ or elimination of waste using lean principles.

The solution framework was tested using data collected from ongoing automated railway track laying project. Initially the progress was 1.15 km per day against planned progress of 1.5 km per day. The sleeper production sub process emerged as the key sub process after analysis. The process was synchronised over 24 hrs cycle by increased sleeper beds from 5 to 15 along with 5 additional baffle machines. Other resources were doubled by employing them in two shifts. These actions enhanced NTC productivity to 3 km per day or 72 km against actual progress of 30 km per month (i.e., 24 working days).

The study revealed that lack of synchronization in a feeding process create construction bottlenecks and restrict continuous flow of input material to the pull activities. Adding resources or waste reduction does reduce the C/T but may not enhance the overall rate of progress if the flow is not balanced, rather shift the location of bottlenecks. The proposed framework, offers systematic approach needed to identify and progressively synchronize the C/T till required rate of progress is achieved.

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CHARACTERIZATION OF WASTE IN ETHIOPIAN BUILDING CONSTRUCTION PROJECTS

Tadesse Ayalew[1], **Zakaria Dakhli**[2], **Zoubeir Lafhaj**[3]

ABSTRACT

According to the February 2017 Mckinsey Global Institute report, construction industry is one of the largest sectors in the world economy with $10 trillion spending, 13% of GDP contribution and 7% employment opportunity annually. However, the sector labor-productivity for the past two decades couldn't exceed 1% a year while the total world economy and the manufacturing sector has been grown by 2.8 and 3.6 % respectively**.** As a result of this, the industry loss a value of $1.6 trillion a year that would meet about half of the world's annual infrastructure needs or boost global GDP by 2 %.

According to this report, Ethiopia is the last in the list of countries with poor productivity. Considering the above fact, this study assess building construction projects in Ethiopia with respect to the common types of waste in order to identify the most important waste in Ethiopian building construction projects.

Accordingly the study confirmed that close to 40% of the project time is wasted in performing non value adding activities due to over production, over processing, Transport, motion and waiting related wastes.

KEYWORDS

Ethiopia, building projects, lean construction, process, waste

INTRODUCTION

Construction industry is one of the largest sectors in the world economy with $10 trillion spending, 13% of GDP contribution and 7% employee annually (Barbosa et al., 2017),However, the industry has been criticized for its underperformance for many years**.** For example, the sector labor-productivity for the past two decades couldn't exceed 1% a year while the total world economy and the manufacturing sector has been grown 2.8 and 3.6 % respectively(Barbosa et al., 2017)**.** As a result, the industry is facing a value loss of

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$1.6 trillion a year, which would meet about half of the world's annual infrastructure, needs or boost global GDP by 2 %.

An assessment on 25 countries including Ethiopia in this regard indicates that only 25 % of construction firms matched the productivity growth achieved by the overall economies of their respective countries. The report also pointed out that, Ethiopia is the most poorly performing country in this regard(See Fig 1, below). The result confirms the finding of Ethiopian economics association, that reported construction output per employee in Ethiopia is only US $994.9, which is far behind corresponding low income countries average of US $8507 (On & Ethiopian, 2005).

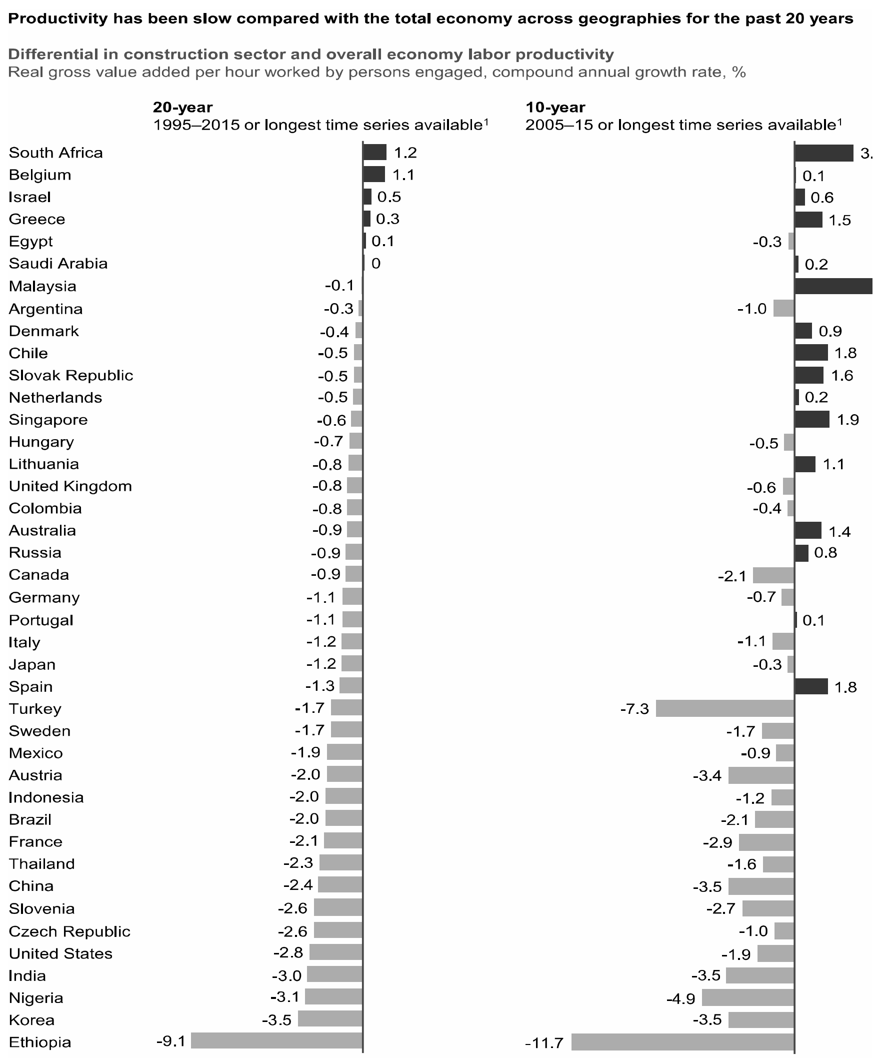


Figure 1: Differential Construction Sector and Overall Economy Labor Productivity (Figure 10, in Barbosa et al., 2017)

It is therefore imperative to identify the characteristics of this waste that causes such poor performance. However there is no previous study on waste in Ethiopian construction industry except an assessment on professional awareness on lean construction and related concepts by (Ayalew, Dakhli, & Lafhaj, 2016). According to this study 48% of professionals are aware of the lean concept but lean is not yet practiced in Ethiopian construction industry.

This study therefore tries to characterize the seven common types of wastes in Ethiopian construction industry using a local survey in order to buy professionals concern on the subject of lean construction in general and that of waste in particular.

WASTE IN CONSTRUCTION PROJECT

Construction industry is a diverse sector of the national economy, which involves a wide range of scarce resources for a given country; therefore productivity of construction industry concerns not only the industry itself, but also other industries, which depends on its performance. This is particularly important for developing countries like Ethiopia which involves massive construction activities with these days(Ofori, 2006). Due to this, productivity and waste are considered to be central issues for improvements(Forsberg & Saukkoriipi, 2007). This section therefore will explore different literatures to identify various categories of wastes as a base for assessment.

DEFINITION OF WASTE

Construction professionals tend to conceptualize "waste" as physical construction waste rather than a more generic conception of the term that include both the incidence of material losses as well as the execution of unnecessary work(Ramaswamy & Kalidindi, 2008). This misunderstanding is more significant in developing courtiers like Ethiopia with very little knowledge on the concept of lean construction (Ayalew, Dakhli, & Lafhaj, 2016). It is therefore essential to understand a broader view of waste that includes not only material waste, but also waste related to resources such as labor and equipment. With this understanding (L. Koskela, 1992) defines waste as any inefficiency that results in the use of equipment, materials, labor, or capital in larger quantities than those considered as necessary in the production processes. In this context value can be understood as the fulfillment of customer requirements. Similarly, in the lean production paradigm, the concept of waste is directly associated with the use of resources that do not add value to the final product(Ramaswamy & Kalidindi, 2008)(Howell & Ballard, 1994)(Alarcón, Diethelm, Rojo, & Calderón, 2008)

Therefore, waste should be defined as any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the customer (client).

CLASSIFICATION OF WASTE

Waste can be classified as *unavoidable waste* (or natural waste), in which the investment needed to its reduction is higher than the economy produced, and *avoidable waste*, when the cost of waste is significantly higher than the cost to prevent it(Formoso & Hirota, 1999). Similarly(Serpell, Venturi, & Contreras, 1995)categorized wastes as *controllable* and *non-controllable* where controllable wastes are wastes related to flow, conversion and management activities where as non-controllable waste include waste due to failure in external flow and environmental causes. Fig. 2 below illustrates categories of wastes by(Serpell et al., 1995).

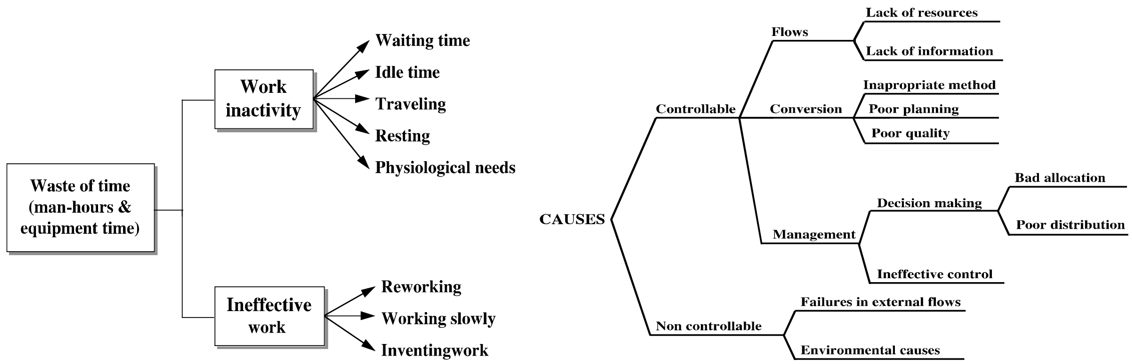


Figure 2: Category of Waste and Their Causes *(* Figure 3, in*Serpell et al., 1995)*

(Ramaswamy & Kalidindi, 2008) on the other hand classified waste into the following four groups. These include materials, quality, labor and equipment.

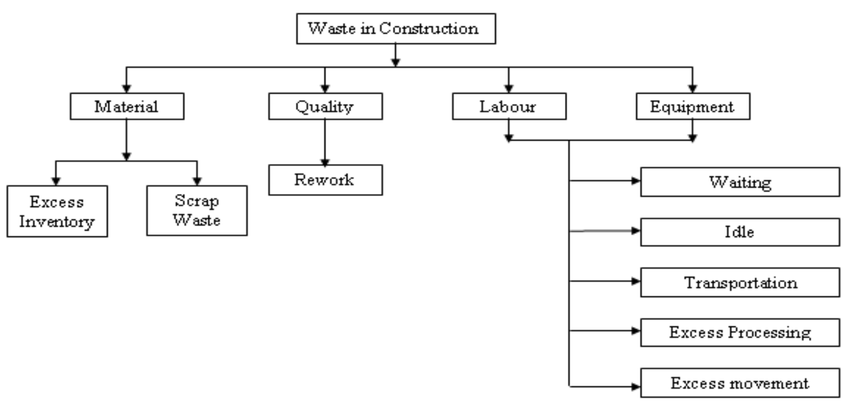


Figure 3: Classification of Waste (Figure…inRamaswamy & Kalidindi, 2008)

Waste can also be classified according to its origin, i.e. the stage that the main root cause is related to. Classifying construction waste according to its origin enables managers to understand the different forms of waste, why they occur and how to act in order to avoid them. In this regard (Formoso & Hirota, 1999) customized the seven types of waste identified in the Toyota production system from construction perspective. This research also basis its assessment on this base. Table1 below summarizes the seven wastes from (Formoso & Hirota, 1999) and their description;

Table 1: Types of Waste and their description

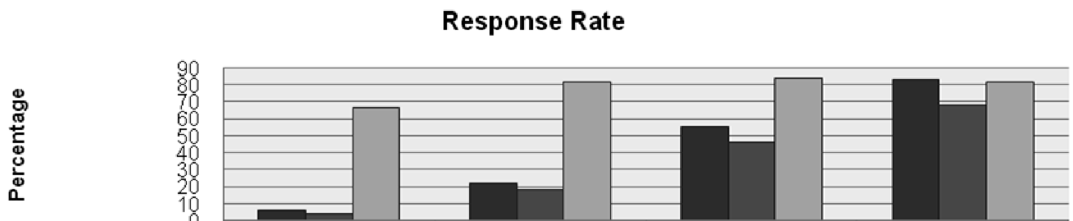
Categoryof Waste	Description
Overproduction	Production of a quantity greater than required or earlier than necessary, which may cause waste of materials, man-hours or equipment usage.
Waiting time:	This kind of waste related to idle time caused by lack of synchronization and leveling of material flows, and pace of work by different crew or equipment.
Transportation:	Concerned with the internal movement of materials on site. It is usually related to poor layout, and the lack of planning of material flows. Its main consequences are: waste of man hours, waste of energy and the possibility of material waste during transportation.
Processing:	This one is related to the nature of the processing (conversion) activity, which could only be avoided by changing the construction technology.
Inventories:	This is due to excessive or unnecessary inventories, which lead to material waste (by deterioration, losses due to inadequate stock conditions on site, robbery, vandalism), and monetary losses due to capital tied up. It might be a result of lack of resource planning or uncertainty on the estimation of quantities.
Movement:	Concerned with unnecessary or inefficient movements made by workers during their job. This might be caused by inadequate equipment, ineffective work methods, or poor arrangement of the working place.
Production of defective products:	It occurs when the final or intermediate product does not fit the quality specifications. It can be caused by a wide range of reasons: poor design and specification, lack of planning and control, poor qualification of the team work, lack of integration between design and production, etc.

In addition to the above waste category identified earlier, (Lauri Koskela, 2004) and (Macomber & Howell, 2004) recently identified “Making do” and “Underutilization of human potential” as a common types of wastes in construction. Although they are not included in the survey since the researcher were not well aware of these category of wastes during data collection, these category of wastes are also a major concern for construction industry in developing countries in general and that of Ethiopian construction industry in particular.

METHODOLOGY

The study approach involves both literature search and the use of structured questionnaire, which was considered to be more appropriate tool to reach the population of the study with limited time and from a distance at a time. The literature review was conducted to extract variables for the assessment and to have a conceptual bases on the subject.

According to Ministry of housing and construction, currently there are 138 Category I and 44 Category I Consultants in the capital. Out of which 55 Contractors and 22 Consulting firms were considered as a representative sample for this study. Accordingly the designed questionnaire were distributed to 83 professionals selected through stratified random sampling from 55 construction companies, 22 consulting firms and 6 clients which are actively involved on building construction projects in the capital. Out of the 83 questionnaires distributed, 68 were received completed and found suitable for analysis, representing a responses rate of 81.93%.



	Client	Consultant	Contractors	Total
Distributed	6	22	55	83
Returned	4	18	46	68
Response rate (%)	66.67	81.82	83.64	81.93

Figure 4: Respondent Response Rate

The data obtained from the survey was analyzed using mean score in order to rank the major types of waste in Ethiopian building construction projects. The output is then presented using tables and graphs for further interpretation and discussion.

RESULT AND DISCUSSION

As shown in Fig. 5 below, 9 % of the respondents were General & Deputy General mangers, 12% Project Coordinators, 18% Project Managers, 19% Site Engineers, 10% Office Engineers, 7% Resident Engineers, 10% Supervisors and 6% others.

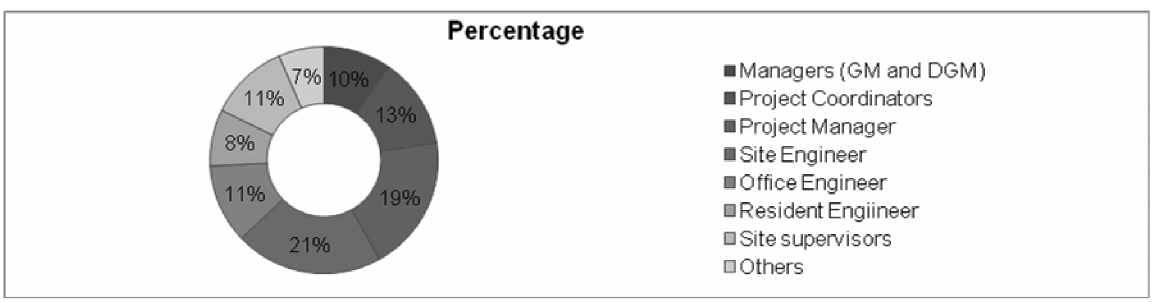


Figure 5: Respondent Profile Based on Their Position

This indicates that the respondent are raging from the top management who is responsible for strategic and tactical planning to site engineers who are mainly responsible to the day to day operational activities on construction site. In terms of experience, about 65% of the respondent has more than 6years' professional experiences, which is sufficient to understand the construction processes and related wastes.

EXTENT OF TIMEWASTE

Following their profile identification, respondent were requested their opinion on the existence and extent of waste in Ethiopian construction industry. In this regard 100% of the respondent agreed that waste is one of major problem that challenges Ethiopian construction industry. Regarding its extent, more than (60%) of the respondent believes that the extent of wasted time in Ethiopian context is about 30-40%. The finding from site observation on randomly selected work item show ever confirmed that more than 50% of the working hour is wasted in performing non-value adding activities *(See table 2 and 3, below).*

Table 2: Site Observation on Time Waste for Concrete Work

Item No	Category	Productive time out of the 8 working hours in a day							
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average	Productive Time (%)
1	Mason	3,16	3,56	3,41	2,16	2,46	3,24	3,00	37,48
2	Loader Operator	3,42	0	4,52	0	3,42	0	3,79	47,33
3	Crane Operator	4,23	4,43	3,53	4,07	4,03	3,47	3,96	49,50
4	Mixer Operator	5,01	4,51	4,05	4,19	4,51	3,19	4,24	53,04
5	Daily laborer	4,19	4,39	4,09	4,07	3,40	3,42	3,93	49,08
					Average				**47,29**

Table 3: Site Observation on Time Waste for Hollow Concrete Block Work

Item No	Category	Productive time out of the 8 working hours in a day							
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Average	Productive Time (%)
1	Mason	3,34	3,27	2,57	3,57	3,25	3,42	3,24	40,46
2	Winch Operator	3,47	4,47	4,3	2,2	3,3	4,55	3,72	46,44
3	Daily laborer	3,55	4,3	4,47	4,12	3,45	4,25	4,02	50,29
					Average				**45,73**

The finding some how agreed with the finding of other researchers in this regard. For example (Serpell et al., 1995) analyzing 17 building projects in Chile reported that a minimum and maximum value of 35% and 55%. In Sweden the amount of waste was reported around 30-35% (Forsberg & Saukkoriipi, 2007), (Lauri Koskela, 2000) on his part reported that the average distribution of working time used in value-adding activities are in the range of 30% to 40%. This means about 60-70% of the time is lost in performing non-value adding activities.

THE MOST INFLUENTIAL TYPE OF WASTE IN ETHIOPIAN CONTEXT

In order to rank the seven types of waste identified from literatures, professionals working in the sector were requested to rate each type of wastes based on their frequency of occurrence using a 4-point scale. The study identify that over production waste (3.08), over processing waste (3;03) and Transport waste (3.03) are the most dominating type of wastes in Ethiopian building construction projects.

According to (Formoso & Hirota, 1999), over production waste occurs due to production of quantity greater than required or earlier than necessary, which leads to waste of materials, man-hours or equipment usage. This kind of waste is common in most building construction projects in Ethiopia. As an example over production of hollow concrete blocks, which is usually left over on construction site after project completion or damaged during transpiration to another sites. Similarly ordering greater quantities of materials such reinforcement and floor, pipes, electrical cables& tiles are also a major problem in Ethiopian context. Overproduction of mortar that cannot be used on time is also significant problem on many construction sites.

This type of waste also contributes for "Making do" and "Underutilization of human potential" related wastes which are identified by (Lauri Koskela, 2004) and (Macomber & Howell, 2004) respectively.

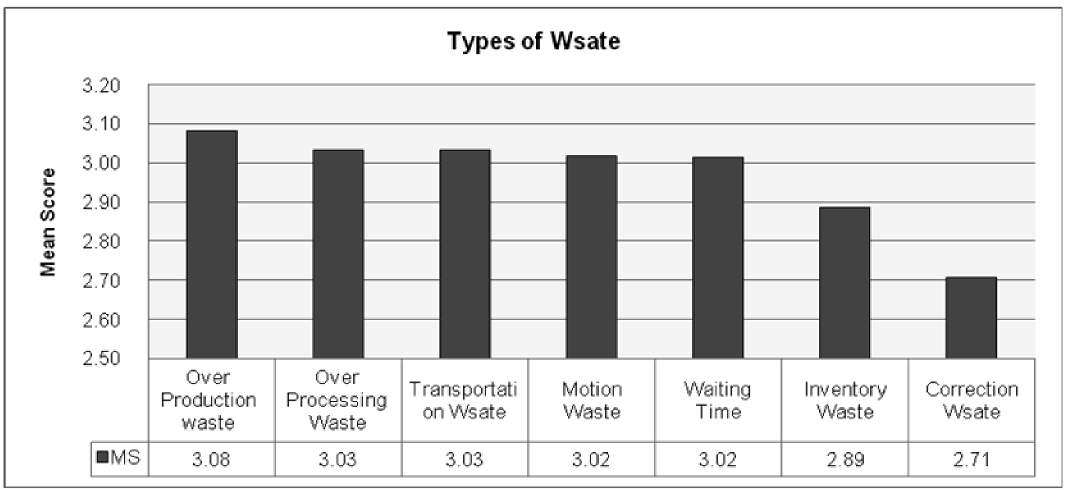


Figure 6: Types of Waste and their Order Priority

Internal movement of materials within construction sites, which is usually related to poor site layout, and lack of planning of material flow is also another common problem in Ethiopian context. As pointed out by(Formoso & Hirota, 1999) the consequences of such type of waste are waste of man hours, waste of energy and the possibility of material waste during transportation. Developing a site layout plan for construction projects is not a common practice in most construction sites in Ethiopia, as result moving materials repeatedly from one place to other (which is considered as non value adding activity) is also significant problem.

Over processing waste is a waste that could be avoided by changing the construction technology. This kind of waste is obvious to be one of the critical types of waste in developing countries, which are still using traditional construction technology in their business. Some examples of waste related to over processing in the Ethiopian context include, concrete production on construction sites during batching, mixing and transporting of concrete, which is common almost in all construction projects. A percentage of mortar wasted while plastering of ceiling is also another common problem related to lack of advanced methods. In the same fashion a percentage of concert blocks cut to close small size of openings and stone wasted during dressing are some examples in construction sites. As one of the developing country in Africa, over processing is typical problem in the day-to-day practice of construction within Ethiopian construction industry.

As shown in Fig 6 above motion waste and waiting time are also significant types of waste with equal level of importance (3.02). The first one is mainly caused by lack of synchronization and leveling of material flows, and piece of work by different crew or equipment where as the second one concerned with unnecessary or inefficient movements made by workers during their job which may be caused due to inadequate equipment, ineffective work methods, or poor arrangement of the working place.

CONCLUSION

The study identifies seven types of wastes from literatures and conducted a survey on the extent of waste and their frequency of occurrence in Ethiopian building construction projects. Accordingly over production waste (3.08), over processing waste (3;03), Transport waste (3.03), waiting time (3.02)and motion wastes (3.02)are found to be the most dominating wastes in Ethiopian building construction projects.

Considering this study as a base, the research will further identify the root causes of these wastes and their consequence in Ethiopian building construction projects to bring academics and practitioners concern on waste in particular and lean construction in general as an intervention for overall improvement of Ethiopian construction industry.

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CONSTRAINT REMOVAL AND WORK PLAN RELIABILITY: A BRIDGE PROJECT CASE STUDY

Ashtad Javanmardi[1], S. Alireza Abbasian-Hosseini[2], Simon M. Hsiang[3], and Min Liu[4]

ABSTRACT

Effective removal of constraints is critical in the Last Planner System (LPS®)to improve work plan reliability. While removing constraints is important, it remains unclear to project managers about which types of constraint have the highest level of uncertainty and to what extent the constraint removal discussions are efficient for improving work plan reliability. This research uses a bridge project as an example to answer these research questions. The authors collected planning meeting minutes, look ahead plans, and production dataof11 weeks to analyze constraint removal discussions in weekly plan meetings and the associated Percent Plan Complete (PPC).Information theory method was used to calculate the amount of information gain and the information transmission efficiency for PPC improvement.

Results show that "Prerequisite Readiness" is the most important constraint to discuss and contributes to 24% of the total information gain for PPC improvement. This constraint also has the highest information transmission efficiency of 36%, almost twice the average information transmission efficiency of the other constraints. The method proposed in this paper can be used repetitively on other projects and will help project managers to improve their meeting effectiveness in order to achieve higher work plan reliability.

KEYWORDS

Meeting, information theory, plan reliability, constraint analysis, lean construction

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INTRODUCTION

Last Planner System (LPS®) is a pull-driven production scheduling method developed to improve plan reliability and productivity for construction projects (Ballard 2000). Instead of emphasizing on deadlines, LPS®emphasizes on constraint removal in the make-ready process to produce high reliable short-term work plans (Hamzeh et al. 2015). According to Koskela (1999)there are seven constraints that shouldbe removed for having sound assignments. These constraints are: 1) external conditions (i.e. weather), 2) equipment availability, 3) labor availability, 4) material availability, 5) prerequisite work readiness, 6) space availability, and 7) design and working method clarification.

Project managers hold planning meetings to identify constraints, discuss ways to remove constraints, and provide updates on the status of constraint removal. Several studies addressed this process (Jang and Kim 2008; Lind hard and Wandahl 2012; Hamzehet al. 2015; Wang et al. 2016). According to the authors' knowledge, limited research wasfound to quantify the information gain and transmission of constraint removal and how it affects work plan reliability.

To fill in this gap of knowledge, this research aims to 1) quantify the information gain for each constraint removal, 2) measure the information transmission efficiency of constraint removal discussion in planning meetings, and 3) propose a guideline to improve the meeting effectiveness in order to increase plan reliability. This research collected planning and production data from a bridge project and used the information theory framework to analyze the data. The results are useful for project managers by providing a better understanding the impacts of constraint removal on planning reliability.

LITERATURE REVIEW

LPS® AND CONSTRAINT REMOVAL

LPS® is a production planning and control system based on lean production principles that aims to improve the reliability of work plans (Ballard 2000).LPS® uses Percent Plan Complete (PPC) as an indicator forplan reliability. PPC is calculated by dividing the number oftasks completed 100% at the end of a plan period(i.e. a week) relative to those tasks planned at the beginning of that plan period.(Liu et al. 2010; Hamzeh et al. 2015).LPS® improves PPC by ensuring only sound activities are selected for execution in the short-term period (Lindhard and Wandahl2012). Sound activities refer to the activities which their constraints are completely removed (Koskela 1999).

Koskela (1999) specified seven internal and external constraints that can interrupt smooth execution of activities. By focusing on three residential and educational case studies and analyzing about 1280 reasons for task non-completion, Lindhard and Wandahl (2012) found the seven Koskela's constraints (Koskela 1999) plus two additional constraints namely unsafe working conditions and unknown working conditions were underlying reasons for non-completed tasks. Jang and Kim (2008) showed that there is a significant positive relationship between Percentage of Constraint Removal (PCR) and PPC by collecting data from two bridge construction projects. In a more recent study, through computer simulation and using Tasks Made Ready (TMR) measurement, Hamzehet al. (2015) showed identifying and eliminating constraints during make-ready process influence the reliability of construction lookahead plans and impact project duration. Previous research emphasized the importance of constraint removal. But they did not investigate the information gain and transmission of constraint removal information during weekly planning meetings and how it impacts PPC.

INFORMATION THEORY

In construction, information can be communicated in different formats using different verbal and non-verbal methods. Scholars in Civil Engineering have used information theory to find best schemes for optimal communication of information. Jalayer et al. (2012) compared several alternative Intensity Measures (IMs) in terms of the expected difference in the information provided about a predicted structural drift response and the most informative of those IMs identified. To identify the important factors affecting the constructability, Chang et al. (2017) utilized information theory to quantify the amount of information needed to construct truss structural systems with different assembly.

Although there has been limited use of information theory in Civil Engineering, to the best of the authors' knowledge, none of the researchers utilized information theory in analyzing construction meetings.Information theory has some distinctive abilities to 1)measure the amount of information;2) estimate the amount of information gain;and 3)quantify the efficiency of information transmission.

To measure the amount of information a variable generates, this research calculates entropy, *H(X)*, introduced by Shannon (1948), using the following equation:

$$H(X) = \sum_{i=1}^{m} p(x_i) \log_2 \frac{1}{p(x_i)} bits \tag{1}$$

In Eq. 1, X is a discrete random variable which can take m possible outcomes of x_i, where $p(x_i)$ is the probability for the random variable X to have the outcome x_i, $x_i \in \{x_1, x_2, \ldots, x_m\}$.The unit of information in Eq. 1is bit. One bit represents the amount of information required for one of two equally probable alternatives to be specified(Stone, 2015).Entropy is the amount of information that can be conveyed by the random variable(Stone, 2015).

To estimate the amount of information gained about one variable giving another, this research calculates mutual information, *I(X,Y)*,using following equation (Shannon 1948):

$$I(X,Y) = \sum_{i=1}^{m_x} \sum_{j=1}^{m_y} p(x_i, y_j) \log_2 \frac{p(x_i, y_j)}{p(x_i) p(y_j)} bits \tag{2}$$

In Eq. 2. X and Y are two discrete random variables that can take m_x and m_y possible different values respectively. $p(y_j)$ is the probability for the random variable Y to have the outcome y_j and $p(x_i, y_i)$ is the joint probability for X and Y. Mutual information can be calculated by Eq. 3.

$$I(X,Y) = H(X) + H(Y) - H(X,Y) \ bits \tag{3}$$

where

$$H(X,Y) = \sum_{i=1}^{m_x} \sum_{j=1}^{m_y} p(x_i, y_j) \log_2 \frac{1}{p(x_i, y_j)} \ bits \tag{4}$$

is the joint entropy between *X* and *Y*. Mutual information is a general measure of association between two variables and measures how much knowing one of these variables reduces uncertainty about the other(Stone, 2015).

To quantify the efficiency of information transmission between variables, information transmission efficiency can be calculated using the following equation:

$$\text{Information Transmission Efficiency} = \frac{I(X,Y)}{H(X)} \tag{5}$$

Where *H(X)* is the amount of information about uncertainty that variable *X* generates, and *I(X,Y)* is the amount of information gained about *Y* given *X*.

METHOD

Figure 1 shows research design for this paper. First two sets of data, weekly planning meeting minutes and weekly lookahead plan, were collected from the case study project. Meeting minutes were studied and categorized to identify the frequency of discussion regarding each of the constraint removals during meetings. Lookahead plan and consequence were used to calculate PPC. Once PPC values were calculated, they were divided into three groups low, medium, and high using *k*-means clustering algorithm. Next, information gain and information transmission efficiency were calculated for every constraint category. Finally, the paper proposed a plan for improvement of meeting effectiveness to achieve higher PPC.

CASE DESCRIPTION

A bridge construction project was selected for this study because it contained linear and repetitive activities which are comparable in terms of work complexity across the project. The project was a Design-Build project with an estimated cost of $200 million. The project started in March 2016 and it was scheduled to get completed in September 2019. The project was over 90% self-performed by the General Contractor (GC) who had highly-trained and experienced labors in addition to specialized equipment required for this project. Therefore, GC team was directly responsible for planning, and managing labor, materials and equipment throughout the duration of the studied phase.

The scope of this study is the pile installation activity of three bents lasted for 11 weeks. Bents are the supporting structures for the bridge’s girders and decks and are consisted of two main substructure, piles and caps. Each bent had three 140 ft cylinder concrete piles needed to be driven approximately 110 ft into the ground. The pile installation activity was performed by a crew of six people, including one foreman, four workers, and one crane operator who were managed by GC's personnel.

The project did not use LPS ® as the method of scheduling and control system, but they practiced some elements of LPS ® unintentionally. For example, the project had three weeks lookahead plans which were updated weekly after weekly planning meetings. Plans in this project were created and updated by the project control team after receiving feedback from superintendents and field engineers and there was no systematic procedure for removal of constraints before adding tasks to weekly work plans.

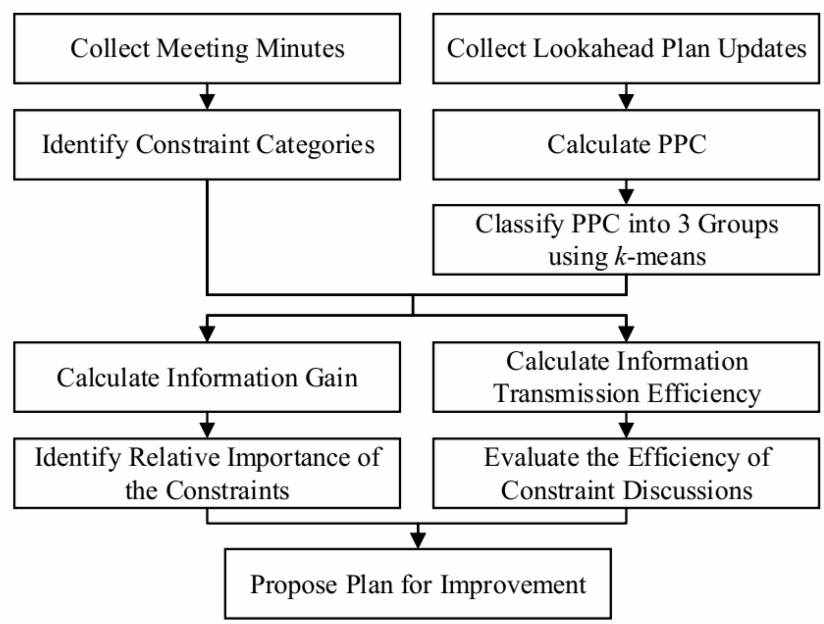

Figure 1: Flowchart for Research Method

WEEKLY PLANNING MEETINGS

In this project meetings were held every Wednesday at 4PM. The average meeting duration was 108 minutes with a minimum of 86 minutes and a maximum of 135 minutes. The number of meeting participants ranges from 7 to 15, with an average of 11. Participants include one to three construction and project managers, one project control manager, one to two general superintendents, one to three crew superintendents, one to three project engineers, and three to five field engineers. Meetings were facilitated/chaired by the project manager. In these meetings, participants discussed pile installation activity as well as other major activities, such as trestle installation, cap installation, girder installation, deck installation. There were also discussions regarding project general condition and other matters (i.e. safety, contract documents, site layout, etc.). For this study, the authors consider only the portion of the meetings that is relevant to pile installation activities.

Meeting minutes were descriptive and contained what transpired during the meetings. All the 11 minutes were taken by the same project engineer who had7 years of construction experience and had participated in all the meetings on the project from the first day. After carefully reviewing the meeting minutes, the authors classified the discussion items for pile installation activity into the seven constraint categories mentioned by Koskela (1999).It should be noted that the validity of identifying constraint categories based on the minute notes was checked by the GC's pile installation field engineer who participated in all the 11 meetings and was fully aware of the context behind the minutes.

PPC CALCULATION AND CLASSIFICATION

Lookahead plans in this project were updated every Friday, demonstrating the actual start times and actual finish times of pile installation activities in the current week and the week before. In addition, lookahead plans contained the planned start times and the planned finish times of pile installation activities of the future three weeks.

This study uses PPC as the measure of plan reliability and can be calculated as follow (Liu et al. 2010):

$$\mathbf{PPC} = \frac{\textbf{Number of completed tasks out of the planned tasks}}{\textbf{Total number of planned tasks}} \tag{6}$$

To differentiate between plan reliabilities, *K*-means clustering algorithm (Ibbs and Liu 2011) and SAS Enterprise Miner (SAS EM) 14.2 were used to classify PPC. SAS EM provides user friendly interface where building models require simple clicks and drag and drop *nodes* into the diagram area. *K*-means tries to classify PPCs into *K* clusters (*K* is defined by the user) in which each PPC belongs to the cluster with the nearest mean. The reason for selecting *K*-means for clustering was that its algorithm is a non-overlapping algorithm and PPCs will not be classified to more than one cluster.

INFORMATION GAIN AND INFORMATION TRANSMISSION EFFICIENCY

This study took the following steps to calculate entropy and information gain for constraint discussion:

1. Categorize meetings based on the seven constraints and record the frequency of constraint removal discussions into variables X_1 to $X_7$where X_1= External Conditions, X_2= Equipment Availability, X_3= Labor Availability, X_4= Material Availability, X_5= Prerequisite Work Readiness, X_6= Space Availability, and X_7= Design and Working Method Clarification. (Table 1, columns 2-8). Also, classify PPCs into L, M or H and record data into a discrete variable Y (Table 1, column 9-10).
2. Generate a Cross-tab between every X and Y.Every cross-tab displays the distribution of the X variable against the Y variable in the 2-dimensional matrix format. The rows in cross-tabs are the frequencies of constraint removal discussion in meetings (i.e.once, twice, three times, etc.) and the columns are PPC levels (i.e. L, M or H).
3. Add a row and a column to the created cross-tabs in theprevious stepand insert the sum of rows and columns of the cross-tabs generated in step 2.
4. Calculate joint and marginal probabilities by dividing every cell of cross-tabs in step 3 by the total sum.
5. Take the logarithms to the base 2 of the inverse probabilities in step 4.

6. Calculate joint and marginal entropies using Eq. 4.
7. Calculate every X and Y entropies using Eq. 1. and summing marginal entropies calculated in step 6.
8. Calculate the mutual information using Eq. 3 based on the results of steps 6 and 7.
9. Calculate information transmission efficiency using Eq.5 based on the results in steps 7 and 8.

Table 1: Constraint Removal Discussion and PPC Categorization

Week (1)	External Conditions (2)	Equipment Availability (3)	Labor Availability (4)	Material Availability (5)	Prerequisite Readiness (6)	Space Adequacy (7)	Design and Method (8)	PPC (9)	PPC Categories (10)
1	0	0	2	0	0	0	1	0%	L
2	0	0	2	0	0	0	0	0%	L
3	0	1	0	0	0	0	3	0%	L
4	0	0	1	0	0	0	1	13%	L
5	0	1	1	0	0	0	1	43%	M
6	1	1	1	2	0	1	2	5%	L
7	0	0	1	2	2	0	3	45%	M
8	0	0	2	2	0	0	2	22%	M
9	0	0	1	0	2	0	3	0%	L
10	0	1	0	2	2	0	3	67%	H
11	1	1	2	0	2	0	2	67%	H

RESULT AND DISCUSSION

In Table 2, *H(X)* represents the amount of information generated by constraint categories. *H(Y*) represents the uncertainty in PPC or the amount of information needed to eliminate uncertainty in PPC. Uncertainty arisesfrom the unpredictability of next week's PPC, whether it is going to be L, M, or H. *I(X,Y)* is the amount of information gained about PPC given the constraint information. *I(X,Y)/H(X)* is the information transmission efficiency between constraints and PPC. For example, the amount of information "Design and Working Method Clarification X_7 "generated is 1.87 bits, almost twice the information that "Prerequisite Work Readiness X_5 "generated, which is 0.95 bits. Comparing between the two aforementioned constraint categories, information gained from the latter one is 0.34/0.21=1.62 times more than the information gained from the former one. The information transmission efficiency for X_5 is almost three times more than information transmission efficiency for X_7 (0.36 vs. 0.11).

Table 2: Information Gained and Transmission Efficiency in Weekly Meetings

Constraints	H(X)	H(Y)	I(X,Y)	I(X,Y)/H(X)
X_1	0.68	1.44	0.15	0.22
X_2	0.99	1.44	0.24	0.24

X_3	1.49	1.44	0.27	0.18
X_4	0.95	1.44	0.16	0.17
X_5	0.95	1.44	0.34	0.36
X_6	0.44	1.44	0.08	0.19
X_7	1.87	1.44	0.21	0.11

In Table 2 all numbers are in the units of a bitexcept the last column. Table 2 shows there are 1.44 bits of uncertainty in the PPC. As a result, 1.44 bits of information should be gained to eliminate the uncertainty. The total information that can be gained from the constraint removal discussions is $\sum I(X,Y) = \mathbf{1.45\ bits}$ which is almost equal to the amount of uncertainty in PPC.

Figure 2 shows the risk of missing constraint removalinformation calculated by dividing the information gain from each constraint by the total information gained. The top three categories that highly contribute to the total information gain for PPC improvement are “Prerequisite Work Readiness”. “Labor Availability”, and “Equipment Availability.”

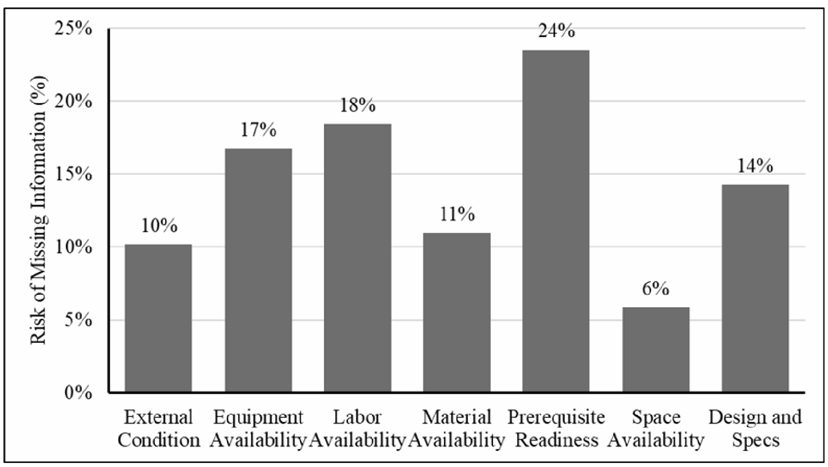

Figure 2: Risk of missing constraint removal category information

In Figure 3,the X-axis is information gain and theY-axis is information transmission efficiency. The chart is divided further into four areas based on the average information gain and average information transmission efficiency of all constraints. Figure 3 shows that “Design and Working Method Clarification (X_5)” discussion not only result in high information gain, but also the information is transmitted in high efficiency of 36%.

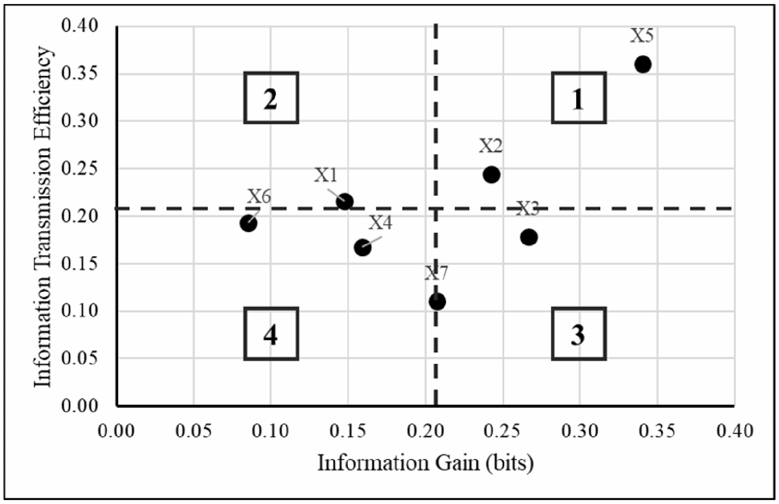

Figure 3: Information Gained vs. Information Transmission Efficiency

Figure 3 provides a basis for prioritizing constraint removal discussion in weekly meetings. In the 1st area of Figure 3, constraints are both important for PPC improvement and were efficiently discussed. Therefore, constraints in this area (X_5 and X_2) have the highest priority for discussion at meetings. In the 2nd area of Figure 3, constraints were less important for PPC improvement, but they were efficiently discussed. Therefore, constraints in this area (X_1) were addressed concisely with less effort and have second priority for discussion at meetings. In the 3rd area of Figure 3, constraints were important for PPC improvement, but they were not efficiently discussed. Therefore, constraints in this area (X_3 and X_7) took more effort to be addressed and have third priority for discussion. Finally, in the 4th area of Figure 3, constraints were less important for PPC improvement and were not discussed efficiently. Therefore, constraints in this area (X_4 and X_6) have the lowest priority for discussion at meetings. Prioritizing constraint discussion in this way will assure that more information for PPC improvement is gained in a limited time (meeting duration).

CONCLUSIONS

Using information theory and based on a case study, this paper showed how project managers can improve their effectiveness of weekly meetings by prioritizing the list of meeting agenda and ensuring that the most important constraints get removed. The findings of this paper showed weekly planning meetings work best to solve issues related to sequencing, whereas other types of meetings are maybe required for more technical matters.Results in Figure 2 can be translated to expected PPC improvements by multiplying the numbers in Figure 2 by 64%(64% is the PPC improvement from the L category with the average PPC of 3%, to the H category with the average PPC of 67% in Table 1). For example, the expected PPC improvement by gaining information about “Prerequisite Work Readiness (X_5)” will be 0.24 × 0.64 = 15%.

Figure 3 implied that the quality and effectiveness of communications on a subject were not necessarily derived from the volume of information generated on it. For instance, results showed that "Prerequisite Work Readiness (X_5)" information was communicated almost 3 times more efficiently than information regarding "Design and Working Method Clarification (X_7)". Since the pile installation tasks were performed in a sequence and removing any prerequisite work-related constraints was a high priority for the project team. Also, the communications addressing this constraint in weekly meetings usually had a quick and direct impact on the PPC of the following week. In contrast, communications over "Design and Working Method Clarification (X_7)" were not fully effective because its impacts were not fully reflected in the PPC measured in the following week. For instance, at the beginning of the project, the construction method was to jet the piles to a certain elevation before driving them to the final tip elevation to keep the driving stresses low by lowering the driving length. After installation of a few piles and measuring pile stresses during driving, project team realized there was no need to jet the pile prior driving and they could remove the costly and time-consuming jetting operation from the work plan. The communication over this issue was done over several weeks and in a several meetings (including the weekly progress meeting) and the impact of these communications and decisions is not measurable by the PPC of a particular week and was reflected in a longer period.

The analysis in this paper can be repeated during a project to improve its future meeting effectiveness after enough data has been collected from its past meetings. The authors believe communication about constraints, and the subsequent follow up of these, would be much more effective if constraints were addressed and categorized directly in the work plan during the planning meetings. It should be noted that this paper considered the Koskela's seven constraint categories (Koskela 1999). However, there were some constraints that did not fit into the Koskela's constraints (i.e. unsafe working conditions). Future research can consider a broader range of constraints and include their impacts on schedule performance. In this paper every discussion was fitted into only one constraint base on the content behind the discussion. Future research, however, can fit discussions to multiple constraints and consider information sharing among them and propose more advanced methods for prioritizing constraint removal discussions.

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BUFFER MANAGEMENT IN CONSTRUCTION - A NEW ZEALAND STUDY

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ABSTRACT

Buffers in the form of extra capacity, time, or inventory can help stabilizingconstruction workflow. From a lean construction perspective, however, buffers are recognized as waste. It presents a dichotomy in the use of buffers that calls for the establishment of a balance between the theoretical goals and the practical norms. This paper presents a study on the practical norms of buffer management in construction projects in New Zealand. Twelve semi-structured face-to-face interviews were conducted with the construction planning and management experts across the country. Thematic analysis of the responses indicated nine conceptual themes related to managing buffers in construction projects. The indicated themes give an overall picture of the prevailing features of ongoing buffer management processes in the industry. The results of the study pave the road for designing the next development steps to accommodate shifting from the standard buffer management practices to the lean ideal.

KEYWORDS

Lean construction, buffer management, prevailing features, scheduling

INTRODUCTION

Lean construction ventures three key strategies to enhance the construction performance being stabilization of workflow, reduction of inflow variation, and improvement of downstream performance. (Ballard and Howell 1994; Howell and Ballard 1994; Ballard and Howell 1997). The performance of the systems is profoundly bonded to their ability to cope with variations (Hopp and Spearman 2008). Variations are known to be an inherent component of the production systems (Shewhart 1939; Garvin 1988; Koskela 2000). They can be disseminated from one production unit to another. As a result, a production unit with a variable performance can destabilize the performance of the whole system (Thomas et al. 2002). Buffers in the form of extra capacity, time, or inventory can

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protect the production unit against variations in its environment while preventing dissemination of variation to the environment (Hopp and Spearman 2008). Buffers compensate for the uncertainty in the actual rates of consumption and supply to each production unit, compensate for the variable average rates of consumption and supply between the units, and capacitate the project of a re-arrangement of work sequences within supplier and succeeding production units (Ballard and Howell 1994). The absence of buffers induces inefficiencies, deteriorates productivity, increases cycle times and inflates project cost (Howell and Ballard 1994; Tommelein et al. 1999; Poshdar et al. 2016; Poshdar et al. 2018). Thus, from a practical standpoint, without the use of buffers, a production system can hardly have efficient throughput (Hall 1983; Ballard 2000; Womack and Jones 2003; González et al. 2009; Erdmann et al. 2012). Despite the benefits of using buffers, they represent non-value-adding components of systems. Accordingly, lean ideal suggests avoiding the use of buffers to the maximum possible extent (Hopp and Spearman 2008). Therefore, projects are obliged to adopt a definite buffer management strategy that can simultaneously address the practical requirements and the lean ideal.

Despite all the advancement in developing buffer management techniques, the construction industry acknowledges the use of informal and intuitive approaches for buffer management (González and Alarcón 2010; González et al. 2013; Poshdar et al. 2015).In order to find a balance between theoretical goals and the practical norms regarding buffer management, this research was formulated to answer the three following main questions within the New Zealand construction industry: 1. what are the approaches used for buffer management? 2. What are the main challenges? And 3. How to promote tools that support buffer management?

THE DEVELOPMENTS IN BUFFER MANAGEMENT

Some of the prominent methods involved the use of buffers in projects over the past half century are as follows (Poshdar et al. 2016):

Program Evaluation and Review Technique (PERT) by Malcolm et al. (1959); it was one of the first scheduling methods that proposed a stochastic approach to calculate time contingencies.

Critical Chain Project Management (CCPM) by Goldratt (1997), which shifted the concern in the use of buffers from task protection to the protection of the project completion time.

The risk aggregation technique using the*Root Square Error* (RSE) proposed by Newbold (1998), which presented a technique to calculate the size of buffers by aggregating the risks along different chains on a network of activities.

Normality assumption for the *project completion time* based on the Central Limit Theorem (CLT) suggested by Demeulemeester and Herroelen (2002), which uses statistical theory to estimate a proper size of buffers. It states that given a sufficiently large sample of a population, the mean of all samples from the same population will be approximately equal to the mean of the population. This mean value can be used to calculate the required size of buffers

The *reliability and stability buffering approach* by Lee et al. (2006), which is developed based on the overlapping principle of activities, and the dynamic planning and control methodology (DPM).

The *adaptive methods* by Tukel et al. (2006) that consider the effects of resource tightness and number of precedence activities on the buffer allocation.

Computer-based methods such as in Koh (2006), Srisuwanrat and Ioannou (2007), and González and Alarcón (2010), which typically utilizea Monte Carlo approach.

RESEARCH METHOD

A systematizing expert interview was undertaken to obtain complete information from the participants by using spontaneous communications. This type of interviews focuses on knowledge of action and experience derived from practice (Bogner et al. 2009). Accordingly, twelve semi-structured face-to-face interviews were conducted with the industry professionals, which collected qualitative data on the active state of buffer management in construction sector across the country. The responses from the interviewees were transcribed and developed into coherent essays suitable for thematic analysis. The analysis results provide an insight into the operational condition of buffer management in construction projects, which is of particular importance for designing further steps to advance from the conventional management practices to the lean construction concept.

DATA COLLECTION

The semi-structured interviews that were adopted by this study represent a subjective data collection method. It solicits the interviewees with a series of pre-determined open-ended questions. This approach enables the research participants to elaborate on self-selected aspects of the questions (Lewis et al. 2007).

SAMPLING

A purposive sampling approach was carried out. The purposive sampling represents a non-probability technique, which enabled shifting the aim of sampling from generalizations to assessing particular features of the population. A specific type of sampling approach was undertaken that is known as expert sampling. Accordingly, the original population frame of the study was defined as the individuals who possess particular expertise in the field of buffer management in construction. The information contributed by the experts is representative of their full understanding of the area of expertise. Accordingly, qualified answers were providedto the study questions (Teddlie and Yu 2007; Tongco 2007; Magrath 2012). The information collected by interviewing experts can serve as a robust source for the analysts independent of the sampling size (Tongco 2007; Magrath 2012).

In order toensure that the interviewees would possess the expected expertise and full understanding of the area under investigation, the suggestion of Walton (2010)was adopted to outline the following sample selection criteria:

Criterion 1: Having broad knowledge and understanding of construction management practices

Criterion 2: Having recent/on-going and direct involvement in construction planning

Criterion 3: Having the experience of allocating buffers to construction projects.

Twelve experts were selected (Table 1), whoprovided a strong diversity in their positions in relation to implementing the buffer management.

Table 1: Interviewees – Brief Description

#	Years of Experience	Position Held	#	Years of Experience	Position Held
Interviewee 1	12	Planner/Delay Analyst	Interviewee 7	5	Project Manager
Interviewee 2	25	Site Manager	Interviewee 8	10	**Site Manager**
Interviewee 3	15	Construction Manager	Interviewee 9	9	**Managing Director**
Interviewee 4	30	Managing Director	Interviewee 10	23	**Senior Planner**
Interviewee 5	40	CEO	Interviewee 11	7	**VDC/BIM Manager**
Interviewee 6	15	Project Manager	Interviewee 12	13	**Project Manager**

INTERVIEW SESSION

The data collection process proceeded with conducting face-to-face interviews. Meeting the interviewee in person created an opportunity to have an in-depth understanding of perspectives of the participants. It also provided the opportunity to clarify the responses instantaneously. Each session was designed to take place in approximately one hour. The responses were recorded, given that the interviewees were permitted to stop the recording whenever amid the session. The discussions during the interview involved the necessity of using buffers in projects and the potential buffer management methods that couldbe obtained. The audio recordings of the interviews were transcribed carefully. The interviewee was given the opportunity to review the transcribed statements and request for excluding any part.

INTERVIEW QUESTIONS

The interview protocol included three questions as follows, which conform to the main research questions.

1. What considerations are typical on variations in the performance of construction activities? 2. What are the methods used for the buffer management purposes?3. What are the main challenges in the current buffer management tools and process?

Three subject matter experts reviewed the questions to make sure the interviewees would have no problem in understanding the questions.

THE THEMATIC ANALYSIS

The steps of a thematic analysis proposed by Braun and Clarke (2006) were employed to decode and clarify the information provided by the interviewees. The analysis involved seven stages including transcription and review; generating initial codes; searching for the recurring pattern across the dataset; joining the found patterns against each other as well as against the original data; defining and naming themes, and producing the final report. Accordingly, nine following themes were identified and included inthe final report.

PROJECTS REALIZE THE USE OF BUFFERS AS AN INEVITABLE COMPONENT

Buffers are being used as an auxiliary component of the projects that keeps the job up and running. Figure reports the main reasons expressed by the twelve interviewees for using buffers.

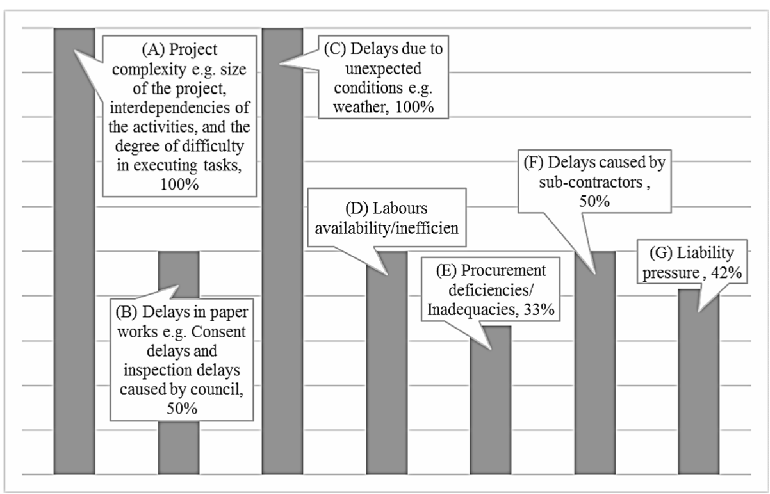

Figure 1: Main Reasons for using buffers as an inevitable component in projects. The percentage is based on the frequency of the reason being stated. no buffer management method with a holistic view is pursued

Eleven interviewees out of twelve (1-4 & 6-12) were using the Critical Path Method (CPM) as their main scheduling technique. Critical path refers to a sequence of networked operations that dictates the project completion time (Kelley Jr and Walker 1959). This method, however, is known for being unable to provide a holistic view of the operational situation of the project network. During the execution, the critical path may change frequently having some prolonged operations on the non-critical paths (Adlakha and Kulkarni 1989). It will restrain the applicability of the original project analysis results. Therefore, even though a considerable time is spent in the developing schedules, significant time overruns might be reported.

NO SYSTEMATIC STRATEGY IS EMPLOYED TO ALLOCATE BUFFERS

As a common approach, buffers are being incorporated to the projects' schedule by adding a fixed percentage of the expected duration to every operation on the project network (Interviewees 4, 5, 7, 8, 10 and 12). The percentage to be added to the duration is typically decided based on the personal judgment and experience of the project decision makers (Interviewees 4 and 10).

THE CURRENT BUFFER MANAGEMENT METHODS ARE NOT EFFECTIVE

Despite recognizing the use of buffers as an inevitable component, the interviews reinforced the fact that the projects are still plagued with delays. Particularly, the time allocation process to the sub-contractors and the materials suppliers is an arduous practice due to the large uncertainty (Interviewees 5, 7, 8 and 12). The buffer management methods in used by the projects can mitigate the time overruns only to a limited extent. The residual time overruns result in substantially inflated costs (Interviewees 4, 5, 7 and 12). These extra costs arise from involving labors and machinery in excess to compensate for the time deviations. Such ineffectiveness also extends over other projects by restraining the availability of the workforce (Interviewees 4).

THE FINANCIAL PENALTIES ARE THE REAL DRIVERS

In case of delays, the construction firms will end up with paying significant penalties (Interviewees 5, 7, 8 and 12). Any change of the program at the project execution phase will involve a full update of the scheduled resources. Construction projects are resource intensive. Therefore, the rescheduling of the resources is associated with substantial extra costs (Interviewees 5, 8 and 12). The avoidance of such cost surcharges pressurizes the contractors to complete the tasks even at the cost of a deteriorated quality (Interviewees 5, 7, 8 and 12). This finding sits well with the observations of Goldratt et al. (1992)who associated the ultimate goal of every enterprise with making money.

THE CONTRACTUAL ISSUES MAY CURTAIL THE USE OF BUFFER

In line with the previous finding, the analysis of the responses indicated another aspect of the moneymaking mindset of the construction enterprises that affects the use of buffer management strategies. In the common types of contractual agreements such as the fixed-price contracts, the contractors are prevented from being benefited by the potential savings incurred due to improvements in their production performance. It has abstained the use of efficient buffer management strategies (Interviewee 7).

NEW BUFFER MANAGEMENT TECHNOLOGIES ARE RESISTED

Disbelief in alleviating the construction scheduling problems by using new technologies was observed. Twenty-five percent of the respondents expressed their reluctance towards implementing new technology for the buffer management purposes (Interviewees 2, 8 and 12). They placed less credence in the benefits to be gained from adopting new technology. As a result, they stated a preference towards non-computerized methods. Interviewee 12 demonstrated a tendency towards spending the extra money to hire more experienced professionals instead of employing new technology.

CURRENT BUFFER MANAGEMENT TOOLS AND TECHNIQUES ARE CHALLENGING

The challenges that were identified in utilizing the buffer management tools and techniques can be divided into the following three broad categories:

Challenges at the organizational level:Lack of the experienced construction planner/programmer (Interviewees 2, 9 and 10); Lack of training among the professionals to use a particular method (Interviewees 9 and 10); Organizational structure (Interviewees 7, 10 and 11); Lack of collaboration between the stakeholders at the planning phase (Interviewees 3, 9 and 10); Partial/late implementation of buffering strategy (Interviewees 3, 9 and 10).

*Challenges at the individual level:*A lack of understanding of the new complex methodologies (Interviewees 1 and 2); Lack of knowledge about the benefits of using optimum buffers in project schedules (Interviewees 2 and 8); Lack of commitment (Interviewees 1, 2 and 12); Being inexperienced with the buffering strategies (Interviewees 2, 3, 8 and 12)

Challenges in using the available tools:Lengthy procedure to allocate the buffers (Interviewees 4, 8 and 12); Complexity of the tools, which typically need to be operated by trained and specialized personnel; A prolonged learning process that has been found to be a key discouraging feature (Interviewee 2, 3, 5 and 8); The restricted information provided by the typical software packages, which remain limited to the activity schedules, resource and assignment lists. For robust decision-making, however, they should be able to involve multiple other facets of the project. It means the users would be urged to combine several software packages to track and control the project activities (Interviewee 2, 4 and 6); the typical software packages such as MS Project allow only limited number of baseline schedules, which make the scheduling process extremely onerous in the event of more changes to the project (Interviewee 10).

THE MAIN FEATURES THAT CAN PROMOTE THE USE OF A BUFFER MANAGEMENT TOOL

As discussed, the popular tools that could support buffer management have been found to be far from gaining wide acceptance in construction projects. Three main feature were indicated by the interviewee, which could promote the application of a certain buffer management tool. *Automation in the application:*A computerized tool with a simple, user-friendly interface that facilitates generating construction program by personnel with minimum computer knowledge was recognized as a key enabler of buffer management in construction projects (Interviewee 2, 3, 5, 8, 9 and 12). It was suggested that the human interactions should be reduced to the greatest possible extent in an ideal tool (Interviewee 4). *Customizing ability:* Having a mechanism involved in interacting with the users and enabling them to exchange information with the tool wasfound crucial to the acceptance of the tool (Interviewee 4, 6 and 12). *Visual presentation:* The visualizations can be used as a communication means during the planning processes. For instance, showing cost variations by the project duration helps to enhance the robustness of decisions (Interviewee 4, 10 and 11).

Table 2 summarizes the contributions of the interviewees to the detected themes.

Table 2: Summary of contributions

Theme	Interviewees whose opinion contributed to the theme	Theme	Interviewees whose opinion contributed to the theme
1	1 to 12	6	7
2	1 to 4, and 6 to 12	7	2, 8 and 12
3	4, 5, 7, 8, 10 and 12	8	1 to 6, 8 to 10 and 12
4	4, 5, 7, 8 and 12	9	2 to 6, 8 to 11 and 12
5	5, 7, 8 and 12		

CONCLUSIONS

While buffers are known as the non-value-adding components of the projects in lean construction, their absence can make the construction program vulnerable to disruptions. Such paradoxical situation calls for the implementation of a cohesive buffer management strategy in projects that enable optimum use of buffers. This paper provided an insight into the operational conditions of buffer management strategies in construction projects by conducting an interview-based study in New Zealand. Twelve industry experts were chosen systematically and invited for a face-to-face interview. The thematic analysis of the responses indicated nine main themes representative of the experts' opinion about the status of buffer management methods in construction projects, the challenges, and opportunities to implement an enhanced buffer management approach.

Even though therespondents recognized the use of buffer as an inevitable component of their projects, it was found that buffers were being incorporatedinto the project program as a fixed percentage added to the expected duration of each operation. The majority of the respondents were relying on CPM as their main scheduling method. However, this method has proven to be unable in providing a holistic view of the potential operational status of the project network. The lack of a method that could provide this holistic view of the project network was one of the main challenges identified by the experts in dealing with buffer management. As a result, the projects still deal with time overruns that could cause substantial financial penalties for the construction firms. The firms may try to minimize these financial penalties by reducing the quality of work. Additional issues, such as the fixed-price agreements, which are typical to construction projects has been found discouraging the adoption of an enhanced buffer management strategy. Despite the resistance from the construction professionals in changing their buffer management routines, the experts indicated that automation, customizingability and involvement of visual presentation could be the three fundamental features to promote the use of a new buffer management approach. These findings suggest that in order to establish a balance between the lean theoretical goals and the practical norms in buffer management domain, a method must be established that could indicate the theoretical optimum allocation of buffer, while supports a holistic view of the project. The method should be included by customizing features to incorporate the specific requirements of any particular project. The implementation of this method in an automated tool with the ability to provide a visual presentation of the buffering solution can promote its function in the construction projects. The studymainly focused on New Zealand construction environment, where the majority of firms are of a small to medium sizes with the number of employees fewer than 50. Further studies are required to elucidate the applicability of the results to the projects undertaken by firms with larger sizes.

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ENHANCING LABOUR PRODUCTIVITY IN PETROCHEMICAL CONSTRUCTION AND MAINTENANCE PROJECTS

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ABSTRACT

Construction labour is a significant cost factor for petrochemical plant owners and their contractors. Enhancing labour productivity is therefore indispensable for the petrochemical industry in order to achieve sustainable development. Considering the variety of projects undertaken by this industry (i.e. construction and more particularly, maintenance and shutdowns/turnarounds), there is a lack of standard methods for assessing labour productivity. This generates a need for developing productivity assessment practices suitable for all project types. This paper presents solutions for labour productivity improvement based on a study conducted at various petrochemical plants. The study developed and implemented a modified Activity Analysis method suitable for the site conditions, with a focus on maintenance activities and shutdown/turnaround projects, which were rarely considered on previous productivity assessment approaches. Conducted over two cycles, this study assessed the current labour productivity, identified barriers, and analysed the efficacy of solutions implemented to mitigate these barriers. The aggregate direct work percentage was found to have increased in the second cycle. The analysis of labour productivity through Activity Analysis in maintenance and shutdown/turnaround projects is a key contribution of this study. The findings provide a basis for assessing and benchmarking labour productivity in the petrochemical industry.

KEYWORDS

Labour, Productivity, Activity Analysis, Continuous improvement, Benchmarking

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INTRODUCTION

Low cost of labour has been a key driver of economic growth in several nations(Auyong 2014). Yet, growing concerns over societal issues like ageing(Fish 2015)and tightening immigration(Auyong 2014)have forced governments to reorient towards productivity-driven economic growth. For instance, Singapore has set a bold target of 2% to 3% annual productivity growth for the decade leading up to 2020 (ESC 2010). To achieve this, it is essential to focus on the energy and chemicals industry, which accounts for nearly 34% of the total manufacturing output. Singapore's Jurong Island hosts several major energy and chemical companies and has attracted investments exceeding 35 billion Singapore Dollars (S$) (EDB 2014). Moreover, the labour cost in the manufacturing sector accounted for the largest share of total business costs. Unit labour cost (manufacturing and service sector) increased by 2.8% for 2015 due to a slight decrease in productivity and increased remuneration(MTI 2015).In view of this and tightening foreign labour policy(Ministry of Manpower (MOM) 2017),the Process Construction and Maintenance Management Committee (PCMMC) was formed in 2013, by Singapore government agencies along with plant owners, contractors, the Singapore Chemical Industry Council, and Association of Process Industry (ASPRI) to improve craft worker and project productivity(ASPRI 2015).

BACKGROUND

PRODUCTIVITY MEASUREMENT AND IMPROVEMENT

There has been an increasing focus on the application of lean principles to construction since the 1990s(Ballard and Howell 1994). Lean construction categorises production activities as either a value-adding or non-value adding activity (of no value to the consumer) (Koskela 2000). Specifically, the reduction of non-value adding activities (waste) has been identified by Koskela (1992) as a fundamental driver for enhanced productivity. However, to attain enhanced productivity, an understanding of current labour productivity is necessary. Yet, there is no unanimous definition for productivity that fits all situations and suitable productivity measurements(Yi and Chan 2014). Various researchers agreethat productivity is a ratio of output and input(Bernolak 1997; CII 2010). Productivity can be measured in two ways based on measurement aims and data availability namely: (1) total factor productivity (TFP), which examines outputs and all inputs; and (2) partial factor productivity (PFP), in which outputs and one or few chosen inputs are studied(Rakhra 1991). Labour productivity becomes a crucial PFP index due to the concentration manpower required to accomplish a task (Yi and Chan 2014). Continuous productivity measurement and comparison of data from different projects has been highlighted as key to improving construction productivity (Liou and Borcherding 1986).There fore, there is a critical need for a common productivity measurement method fit for all projects, companies and countries(Ingvaldsen et al. 2004). Singapore uses the value-added per employed person as the labour productivity index (SPRING Singapore 2011). This has limitations in international comparison and is inconsistent due to varying factors. Hence, there is a definite need for research in measuring on-site labour productivity in construction, maintenance and shutdown/turnaround projects in the energy and chemical sector. Furthermore, benchmarking is seldom used by contractor firms in Singapore (Hwang et al. 2013f).The Productivity Council of Singapore has hence collaborated with the Construction Industry Institute (CII), the University of Texas at Austin (UT), and National University of Singapore (NUS) to introduce best practices, metrics, and benchmarking for the Process, Construction and Maintenance (PCM) industry. As a first step, this research aimed to (1) assess labour efficiency in Singapore's petrochemical projects in terms of craft worker time distribution; (2) investigate reasons for non-value-added work hours; and (3) recommend best practices and guidelines to reduce non-productive activities and delays, and therefore improve labour productivity. The Activity Analysis method was chosen as it enables plant owners and contractors, to jointly measure project-level productivity and benchmark craft workers' efficiency in terms of worker time distribution(ASPRI 2015).

ACTIVITY ANALYSIS - THEORETICAL BACKGROUND

Productivity can be measured either be at the macro-level or micro-level. Macro-level productivity concerns contracting arrangements, labour laws, and organization; while micro-level productivity is measured based on-site management, execution, and operation, mainly at the job site (Dozzi and AbouRizk 1993).Activity Analysis is an indirect measurement method of labour performance at the micro-level. It is a continuous productivity improvement process that measures the time expended by workers on-site and determines hurdles to productivity which should be mitigated or eliminated to improve the direct-work rates (CII 2010; Gouett et al. 2011). It is an advanced form of the work sampling method. Work or occurrence sampling is an easy and inexpensive method used to measure the time individuals spend in various categories of activities(Josephson and Björkman 2013). In this method, an unbiased observer shadows one or more individuals and records their activities at specific times. Activity samples observed by this method at random from a big group of craftwork activities on a project tend to reflect the distribution pattern as the group itself(AACE International 2004).Work sampling has been used since the 1930s for monitoring knitting mills(Tippett 1935). Work sampling was then defined as the observation of labourers at fixed or random, infrequent intervals through the day (Buchholz et al. 1996)which provides the estimated time spent by a craft labour on various activities. Snap-reading, an important technique in the work-sampling method, refers to capturing the exact moment when the sample is taken without any information on the events prior to or after the moment (Gouett et al. 2011). When numerous samples are collecting using this technique, the sample mean was found to tend to the mean of the unknown population (Tippett 1935). Five-minute rating and occurrence sampling were used to measure labour utilization(Gong et al. 2011) and the average direct work percentage was found to be around 45.9%. Work sampling is also used to benchmark direct-work rates in few large construction companies(Gouett et al. 2011). However, work sampling method has drawbacks such as difficulties to implement, identify root causes and provide recommendations for improvement. Activity Analysis, however, includes observation and categorization of labour activities at a plant or construction site, planning and implementing improvement strategies, thereby improving productivity. Activity Analysis shares similar objectives with Value Stream Mapping (VSM), a powerful tool for lean implementation. VSM aims to reduce waste from production activities (value-streams) by mapping their current state to a future-state (ideal, waste-free) (Arbulu and Tommelein 2002). The gap between these states provides a roadmap for improvement. Hence, Activity Analysis may be construed as a VSM tool that facilitates the implementation of lean construction. It provides quick and actionable feedback to the management onworkers' performance. Activity Analysis not only diagnoses workforce issues but also identifies root causes and recommends best practices for continuous improvement.(CII 2010)

Activity Categories and Sample Size

Koskela (1992)emphasized that identification and elimination of non-value adding activities could facilitate enhanced construction productivity. Several non-value adding activities including poor planning, delays, travel, lack of tools, materials and job instructions have been identified by lean scholars (Ballard and Howell 1998; Josephson and Björkman 2013; Koskela 2000). Hence, extensive background research with NUS, The University of Texas (UT) at Austin, CII, and Singapore petrochemical industry representatives was performed to determine the appropriate categories for labour-time utilisation. Activity categories and subcategories were modified to suit Singapore site conditions. Worker time was classified into direct work and non-direct work. The non-direct work consisted of supportive work (semi-productive work), such as preparatory work, material handling, and idle (non-productive work) such as waiting for material and tools(Gong et al. 2011). Existing activity categories (CII 2010; Dozzi and AbouRizk 1993; Gouett et al. 2011) were analysed and the following categories were adopted:

- *Direct work*: Exerting physical effort in carrying out an activity or assisting an activity. Involves installation of materials and/or equipment by workers as well as the physical effort of support groups. This could be observed either during installation or demolition. For e.g., installing forms, pipes, casting concrete
- *Waiting for Permits*: Periods of waiting for authorisation to proceed, even if workers are attentive to ongoing work by other craft workers. For instance, waiting for permits, or for task completion sign-off, or to obtain entry to the work area.
- *Waiting for Instruction*: Waiting for instruction from foreman or for a job allotment
- *Waiting for Material:* Examples include waiting in line at a storage warehouse, material/parts storage area, or waiting for the return of a concrete bucket.
- *Waiting for Equipment:* For instance, waiting for a crane to hook to return for the next lift or waiting for another craft worker to finish utilizing tools or equipment.
- *Waiting for Quality Assurance/Quality Control (QA/QC):*Labour waiting for the QA/QC assessment to be completed
- *Waiting for Unknown:* Crew waiting at the workplacefor unknown reasons

- *Preparatory work:* Supporting works such as obtaining assignments and defining requirements prior to commencing tasks including stretching activities, safety/toolbox talks, start-card processes and planning of the work at the workface.
- *Material handling:* Actions directed towards obtaining, adjusting and transporting material inside the plant, excluding transport of beams, pipe spools, permanent plant equipment, rebar etc. into final position or in the general task area.
- *Tools and Equipment:* Activities related to obtaining, transporting, adjusting tools or equipment to facilitate performance of direct work activities
- *Travel:* Workers walking or riding sans tools, materials or technical information.
- *Personal:* Idleness or time-taken away from work during normal work-hours excluding normally scheduled breaks and lunch periods.

Activity Analysis follows a multinomial distribution rather than a binomial distribution, as several activity categories are considered (CII 2010). The sample size for simultaneously estimating population parameters within a distance of the true values at different significant levels can be determined (Thompson 1987). In the proposed method, for a confidence level of 95%, the sample size is 510. However, if the worker population is below 510, the minimum observation required can be calculated by the number of craft workers (N) and minimum observations (n_o) in Eq. (1). The observations per hour may be staggered over few days thereby mitigating the limitations in achieving the required sample size in a single hour. For instance, for 150 workers, the sample size would be 116per hour as per Eq.(1). The116 samples may be collected over many days in the same one hour duration as the purpose is to observe workers' behaviour at a specified time.

$$n = \frac{1}{\frac{1}{n_0} + \frac{1}{N}} \qquad (1)$$

RESEARCH METHOD AND DATA PRESENTATION

Activity Analysis was conducted in a five-step process including plan study, sample, analyse, plan and implement improvements (Caldas et al. 2016; CII 2010; Gouett et al. 2011) and was modified substantially toreflect the site conditions and maintenance activities, shutdowns, and turnarounds. A second round of Activity Analysis was conducted to verify continuous productivity improvement.

Plan Study: This step included developing the goals of the study, defining the activity categories and minimum sample size, training the researchers, obtaining craft information, and determining sampling routes and times (Gouett et al. 2011). Training sessions on the Activity Analysis method, data-collection device usage and site-training were conducted to enhance the knowledge of the data collection team. The session enabled companies to select appropriate projects. A pre-information sheet requesting project details, contractors involved, and the scope of work was circulated to the plant owners for understanding the site conditions. The first cycle of 10 pilot projects were selected from five facility owners.

Sample: The researchers accompanied by the owner company stafftread randomly-selected predefined routes for observation, focusing purely on the sampling of craft workers. The snap-reading technique was employed to observe the worker and categorize the activity accurately. The information including company, work type (e.g.: equipment, concrete, piping), and number of workers observed at that time under each activity category (e.g. installation, waiting for a permit, material handling) was recorded on an Activity Analysis software. The software, custom-made by CII for this study, could automatically provide timestamps, the cumulative number of observations in each category and save all the information. The company staff also provided key site-specific inputs which benefitted researchers in identifying causes for non-direct work hours and planning improvements.

Analyse: Data analysis was targeted at quantifying the productive (direct work) and non-productive work times. An automatic report generation tool was also developed on the Microsoft Excel platform. Workers' time distribution was analysed with respect to (1) work categories, like direct work, waiting, and preparatory work; (2) work types, such as concrete, painting and instrumentation; (3) time of the day; and (4) contractor.

Plan for Improvements: Each participant company was provided with a report of the analysis results, observations, barriers to productivity and areas for planning and implementing improvements. Several post-survey meetings with each plant owner were held to discuss the results and their interpretation to the top management and contractors. The plant owner decided on the adoption of the improvement strategies based on feasibility, logistics, available human resources, implementation cost and schedule.

Implement Improvements: The selected improvement strategies were implemented and their effect on productivity improvement was measured by conducting another round of Activity Analysis. Prior to the second round, individual meetings were held with each participant plant owner to discuss the adopted solutions and the implementation progress.

Activity data were collected at five different Singapore petrochemical plants. Two cycles of data collection in 18 projects were conducted to measure existing labour efficiency and the improvement after implementing solutions. Samples from each project were collected over two to three days depending on the average number of craft working, logistics and schedule, and the weather. In the first cycle, activity data was collected from ten pilot projects covering the three project types(i.e.3 maintenance, 3construction, and 4 shutdown/turnaround projects). Due to time and site constraints, only eight of the ten pilot projects (i.e.3 maintenance, 2 construction, and 2 shutdown/turnaround projects) were selected for the second cycle data collection. Upon analysis, the data of one project in the second cycle was found unsuitable for comparison due to large work scope variation between cycles. Thus, seven projects from the second cycle were analysed.

RESULTS AND DISCUSSION

Aggregate Direct Work Percentage in the first cycle is presented in Table 1. The overall aggregate direct work percentage was 29.5%. However, the 70.5% non-direct work time consisted of supporting activities such as preparatory work, material handling, and tools and equipment. The craft workers were noted to spend significant time on travel (23.8%), material handling (15.7%), preparatory work (13.0%), and waiting for instruction (7.0%). The overall direct work time was governed by “Equipment” trade (accounting for 34.36%), characteristic of the process industry. Direct Work Percentage varied across project types due to the difference in work scopes. The aggregate direct work percentage for construction was 33.73% and 27.00% for the maintenance and shutdown/turnaround projects. The results for maintenance and shutdown/turnaround projects have been integrated for confidentiality. Rationally, higher aggregate direct work percentage for construction projects was expected. In comparison with other studies, direct work percentage in Singapore (33.73%) was lower than in Alberta, Canada (50.7%) (Hewage and Ruwanpura 2006) and industrial construction projects in the USA (50.4%) (Gong et al. 2011). Evidently, the Singapore methodology categorised most of the direct work categories from the original method as preparatory work and material handling. Hence, cautious comparison must be made between the results. Table 2 reflects the variation of activity throughout the day. As expected, direct work percentage fluctuated over a typical work day and peaked during periods away from the day start (36.9% from 10 am to 11 am), lunch break and towards day end (42.1% from 2 pm to 3 pm). In some shutdown/turnaround projects, the direct work percentage reached 41.0% at the day-end as data collection ended at 5 PM while the work shift was 24 hours. Craft workers spent significant time waiting (45.0%) for permits, instruction and travelling (29.4%) during the first hour of a workday and around lunch break (47.2% & 37.3%). Significant material handling was prevalent all day.

Table 1: Summary of aggregate results for all pilot projects in the first cycle

Work Type		Work Category	Within Category	Across Category	Overall
All	Direct Work	Installation	95.9%	28.3%	29.5%
		Demolition	4.1%	1.2%	
	Waiting	Permits	15.0%	1.8%	12.0%
		Instruction	58.3%	7.0%	
		Material	14.2%	1.7%	
		Equipment	3.0%	0.4%	
		QA/QC	3.3%	0.4%	
		Unknown	6.2%	0.7%	
	Other	Preparatory Work	22.2%	13.0%	13.0%
		Material Handling	26.9%	15.7%	15.7%
		Tools and Equipment	1.3%	0.7%	0.7%
		Travel	40.7%	23.8%	23.8%
		Personal	9.0%	5.2%	5.2%

Table 2: Summary of worker time distribution by work hours in the first cycle

Hour / Work Type	8:00 9:00	9:00 10:00	10:00 11:00	11:00 12:00	13:00 14:00	14:00 15:00	15:00 16:00	16:00 17:00
Direct Work	5.2%	31.2%	36.9%	21.9%	23.9%	42.1%	36.4%	41.0%

Preparatory	8.5%	15.4%	**17.4%**	8.2%	13.1%	14.5%	13.1%	14.7%
Material Handling	10.6%	**18.2%**	**19.1%**	10.9%	14.6%	**17.3%**	**17.8%**	**19.4%**
Tools and Equipment	1.2%	0.8%	0.9%	1.0%	0.5%	0.5%	0.6%	0.4%
Waiting	**45.0%**	17.2%	8.2%	5.2%	9.2%	7.2%	5.5%	4.2%
Travel	**29.4%**	14.2%	9.5%	**47.2%**	**37.3%**	11.9%	14.0%	16.4%
Personal	0.1%	3.0%	7.9%	5.6%	1.5%	6.3%	12.6%	3.9%
Total	100%	100%	100%	100%	100%	100%	100%	100%

BEST PRACTICES AND IMPROVEMENT STRATEGIES

This study further identified the following key areas with scope for improvement. *Permitting:* High waiting time for permits observed at the day-start could be reduced by issuing permits fifteen minutes before the scheduled start time and before the end of each toolbox meeting every day. Moreover, tools and material mobilization and preparatory works were recommended to start within fifteen minutes from the scheduled start time which would reduce the wait for instruction or materials. *Lunch Break and Work Stoppage due to Bad Weather:* Contractors were instructed on the time to travel for lunch and when to return to restart the tasks. The lunch schedule was monitored by alarms in certain projects. Other recommended strategies were to improve the transportation to the work site and proximal placement of cafeteria, portable toilets, and shelters. In addition, area planners were recommended to log and identify rain patterns so as to plan the work effectively and avoid the delay observed in this study. Another recommendation was to use the time during work stoppages due to bad weather for tool inspection, material/fabrication in workshop, skill assessments, and toolbox meetings. *Material Transportation:* Introducing innovative and intrinsically safe systems to transport material around the site locations and between floors could mitigate material handling time. For instance, a battery-operated scaffold puller may reduce workers involved in material handling and travel. Moreover, effective planning and management of project materials and equipment, was recommended.

VALIDATION OF CONTINUOUS PRODUCTIVITY IMPROVEMENT

Second round data collection was done in seven (of ten) projects with similar work scope to measure productivity improvement. As shown in Figure 1, the aggregate direct work increased from 31.7% to 35.6%, while waiting, transport, travel, and personal time decreased between the two cycles. The 'Transport' category includes material handling and tools and equipment (MTE). Preparatory work time increased sharply. There was a redistribution of time in different work categories after implementing interventions. The direct work increased from 32.7% to 37.9% in construction projects and from 30.4% to 30.8% in maintenance projects. The slight improvement in maintenance projects was attributed to the long-established management pattern between operation and maintenance teams. Comparison of direct work by work hour in Figure 2 revealed that the first hour of a day-start and the hour after lunch benefited from the implemented solutions.

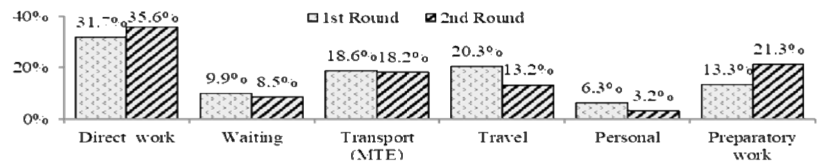

Figure 1: Comparison of aggregate worker time distribution between cycles

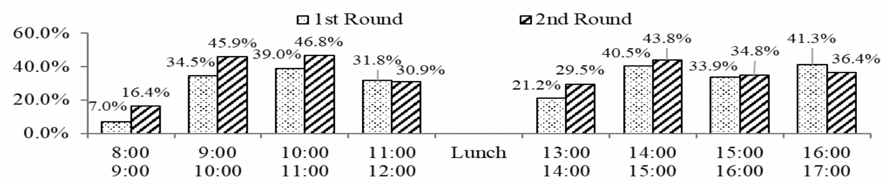

Figure 2: Comparison of direct work percentage by work hour between cycles

CONCLUSIONS AND RECOMMENDATIONS

This study developed and implemented a novel method for assessing productivity in maintenance activities, shutdowns, and turnarounds. The labour efficiency in various projects at petrochemical plants was assessed, the causes for non-value-added work hours were identified, and practices for improving productivity were recommended. Using a modified novel Activity Analysis method developed to reflect petrochemical plant conditions, two cycles of on-site assessments were conducted on pilot projects in Singapore's petrochemical plants. In the first cycle, comprising 10 projects, overall aggregate direct work percentage was 29.5%. Workers were found to spend significant time on non-direct work namely travel (23.8%), material handling (15.7%), preparatory work (13%) and waiting during the first hour of a workday. Hence this study recommended mitigation strategies such as advance issue of permits, utilisation of weather delays and implementation of efficient material transport systems. In the second cycle, the aggregate direct work percentage increased from 31.7% to 35.6%, indicating an improvement after implementing the solutions. Notably, twelve projects in this study involved maintenance activities, shutdown, and /turnaround, which are seldom addressed in productivity studies, and hence an important contribution of this study. Although the objectives were achieved, there are some limitations. First, the limited number of projects since this was designed as a pilot study. Moreover, due to time and site constraints, only seven pilot projects were analysed in the second cycle. Therefore, the results of this study must be interpreted and generalized carefully. Nevertheless, the proposed method enables the petrochemical industry to assess and benchmark craft productivity during the construction and maintenance of these facilities. With further studies, a deeper understanding of the non-direct work categories and their specific correlation with productivity could be obtained.

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LAST PLANNER IMPLEMENTATION IN BUILDING PROJECTS

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ABSTRACT

Lean Construction method is considered the core principle behind the Identification and Elimination of various wastes in construction. While there are many Conventional Lean Tools like work standardization, doing it right first time, Audits, Just in Time etc., Lean construction identifies and deals with seven forms of waste which is nothing but non-value adding items in construction and also suggests ways and means to eliminate them. As such material wastage can be easily quantified, labour wastage and non-value-added activities by labour was much higher compared to material wastage generated in the construction sites. While, Lean production attempts to integrate the concept of transformation, flow and value, a method such as Last planner when implemented for various finishing activities in building projects, there really exists a sense of deep involvement and a great achievement of the project goal. We discuss in this paper the methodology adopted to implement the Last Planner tool of Lean construction and the improvement thereafter.

KEYWORDS

Lean construction, Lean Principles, Last Planner, Labour activities, target works

INTRODUCTION

As such when we talk of construction, the immediate characteristics that go in our mind are uniqueness, complexity and end result orientation. In order to execute an activity, the first and foremost step is the thought of answering "how", "when" and most importantly "by whom". Though modern constructions have started to improvise the construction methodology by means of mechanization, a large part of any activity is dependent on the construction workers, whom we will hereinafter refer to as "Labours" throughout this paper. Lack of skilled labour and low productivity may seem to be the immediate cause of wastage of labour resource. This is significant mainly in the finishing activities of any building project, since the aesthetics and a feeling of good appearance is mind oriented which can be well organized only with the help of labours. Hence the most important phase of the project, which is the planning stage was taken into account and the Lean

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principle of Last planner was induced into some of the finishing activities of a multistoried building project in the outskirts of Chennai, Tamilnadu state, South India. This Last planner system of Lean principle was adopted in a systematic manner in few of the finishing activities and the improvement in the project performance and decrease in the labour wastage was noted on a day-to-day basis.

LAST PLANNER SYSTEM

Last Planner System is a technique that modulates the system workflow of a project and addresses the variance in the construction. As the name suggests, the Last Planner is the person or the group, which is responsible and accountable for the planning operations at the root level through which the production unit is controlled and individual assignments are clearly specified. In the Last Planner System, the work flow of the planning system moves from the bottom level of constraint and variance analysis to the Master Schedule. The middle stages of planning such as the percent plan complete, weekly work plan, reverse phase schedules are altered in accordance with the root level planning. Hence, this system develops and creates an efficient schedule of planning framework with a pull technique, which regulates the workflow and sequence of activities and the rate of activity completion. Last planner system also correlates the process flow and capacity. It also creates new methods for execution of activities and sustains communication between trades. As stated by Ballard in his works on Lean construction, the Last planner system integrates the key words such as “Should” which indicates works to be executed according to the planned schedule, “Can” indicating activities which can be accomplished in spite of various constraints and “Will” indicating a definite commitment of the last planner.

The main role of the Last Planner tool is to bring about a realistic planning from the optimistic planning approach and this is made by scrutinizing the performance of workers not only based on their productivity but also their ability to achieve their goal in a realistic and a committed manner. The ultimate aim of the Last planner is to pull the activities by reverse phase scheduling method and integrated planning. The procedure of implementing Last planner system is as follows:

- Specifying what tasks should be done when and by whom, from the phases to the mid-phases of the milestones, from the mid-operations of the phases to the end phase, and the process within various operations.
- Developing all the tasks and keeping it in a ready to be performed mode.
- Re-planning to accomplish the overall project objectives.
- Choosing the daily tasks based on weekly work schedules to decide the next immediate work to be performed.
- Making release of work between specialists reliable.
- Making visible the current and future state of the project.
- Measuring planning system performance.
- Learning from plan failures.

Here is where the Pull Planning technique that is used as a part of Last Planner System to develop a plan for doing work at any level of task breakdown is brought in to the phase schedule. Pull planning can be used to plan work in any time horizon, or to sequence activities as a part of a production plan. The most important feature of pull planning is that it should involve all who are responsible for delivering the work and with authority to make decisions, plus others who can provide needed information. Hence, the Last planner refers to the individual (front line supervisor) or the group, which is committed to measurable near-term tasks. The Last planner typically is responsible and accountable for the unit’s ability to produce and for the output, they produce. The Last planner may self-perform some of the work.

METHODOLOGY OF IMPLEMENTING LAST PLANNER SYSTEM

To start with, initially the Engineers had started observing and noting down the time taken only on the execution of the various activities and the consumption of labours on a day-to-day basis for that particular activity. This was more of a supervisory work. The next stage was the initiation of the last planner system wherein the gypsum plaster works was monitored on an hourly basis, starting the day with noting down the number of labours (Masons plus Helpers) involved and the materials organized to execute a particular stretch of gypsum plastering. This data collected on an hourly basis was then summarized on a daily basis. While implementing the last planner system, the main components of the lean construction techniques analyzed and noted down were the actual timings of works being executed by individual labour, the time spent on unproductive works by these labours. As such, the time wasted for various factors, which were analyzed, were listed down in minutes and tabulated as given in the table 1 below. The activities bore the effect of timings wasted which were recorded on hourly basis by each of the labour executing a particular common activity in a common place, for example, a floor of a multi-storied building.

During the initial stages of works, only the observation was made on the activities being executed by the labours. The next stage was the noting down of the wastages being incurred by the labour resources on an hourly basis such as usage of mobile phone, taking rest in between for no reason, arriving late after a bio-break or lunch, waiting for enabling resources such as water for mixing the mortar, builder’s hoist for shifting the materials etc., The datas were tabulated in a excel sheet as given below in Table 1 and Table 2 for the various non-compliances and non-value adding activities. As such these activities may not be completely overcome and a proper planning done to match with the hourly productivity, but to a greater extent a realization and a proper correction of these non-value added activities will definitely enhance the quality of time spent by the labours and improve upon the work involvement and provide a sense of satisfaction of achieved what is being planned by the Last Planner.

HOUSING PROJECT

Table 1: Wastage of time of the Labours – Pre-Lunch (time in minutes)

No.	Category	In Time	8 am-9 am	9 am - 10 am	10 am -11 am	11am-12pm	12 pm - 1 pm	1 pm - 2 pm	Total time wasted
1	Mason1	8 am	5	14	0	7	5	lunch	31
2	Helper 1	8 am	10	5	7	5	0	lunch	27
3	Mason 2	8 am	10	0	10	5	10	lunch	35
4	Helper 2	8 am	20	10	5	0	7	lunch	42

Table 2: Wastage of time of the Labours – Post-Lunch (time in minutes)

No.	Category	2 pm-3 pm	3 pm-4 pm	4 pm-5 pm	5 pm-6 pm	Total time wasted
1	Mason1	10	5	15	5	35
2	Helper 1	20	5	10	7	42
3	Mason 2	15	10	5	5	35
4	Helper 2	25	5	5	10	45

Item of work done:Gypsum Plastering
Total No. of gypsum bags issued: 25
Total No. of gypsum bags used: 24
Area to have been completed: 44.5 sqm
Actual area completed: 35.67 sqm

ANALYSIS OF THE LAST PLANNER SYSTEM

While studying this non-value added activities, many of the systems were found to add value and achieve what has been planned by implementing the Lean system through the Last planner.

Before Lean implementation, though a proper provision of temporary mobile toilet was kept for the labours in every fourth floor of the multi-storey building, there was no provision of drinking water. Hence, labours had to walk down for more than twenty floors to have drinking water. After the implementation of Lean system, the workers were advised to carry water bottles while coming for the day's work and were taught of how this could help them to avoid wasting time by not accomplishing their day-to-day task by theoretically counting the minutes they spent on transit for drinking water.

Before Lean implementation, the main contractor who had engaged masons and helpers had no idea of how to allocate and level his resources of labours containing masons and helpers. Hence for a smaller area of gypsum plastering work to be done in a day, four masons and one helper were engaged, but for a larger area, 2 masons and one helper was engaged. The contractor who was paid on measurement basis had not been able to get his payment. After Lean implementation, the resource leveling was done according to the area of work to be accomplished for the day and hence the contractor was able to achieve more with the same number of labours.

While the targets were set with the weekly plan on an area basis for the gypsum plastering works, the uneducated labours were not able to realize their target for the day before implementation of Lean. This resulted in a high level of mismatch of the quantum of work done with the rates fixed for carrying out the activities and hence the labours were not able to get their payment due in relation with the quantity of work done. However, these labours were educated by correlating their quantum of work target with the easily identifiable count of the target they have to achieve as a part of Lean implementation. At times, when the payment was made on measurement basis to the main labour contractors, who had arranged for the labours, the rate system of payment based on the quantity of work done was falling short heavily when correlated with the lump sum payment on daily basis made to the labours by the contractors. Hence, the daily targets were clearly understood and achieved by the labours which helped not only in realizing the payment by the contractors, with respect to the quantum of work done by the labours, but also a sufficient amount of profit was also earned by the labour contractors. In addition, there was a sense of commitment and a balance between the works done and the payment realized by the quantum of the works done.

Preparatory works plays a major role in the completion of the main activities. As such, these preparatory works do not find a place in any of the schedule. For example, of the button marks to achieve even thickness of the gypsum plaster is definitely a time consuming preparatory work, but when it is not given prior importance and is done just before the start of the plastering work, the daily planned target could not be achieved. Here is where the Lean system of the last planner came as a solution that the mason executing the main activity stayed back the previous day and completed the button marks to make sure that the main activities started on time the following day to achieve the day’s target as planned by the last planner.

The related works for the activity taken for the last planner i.e., the coordination of MEP works was a hindrance for the smooth flow of the activities planned. For example in the multi storeyed building, while the gypsum plastering works were getting completed in the 21st floor, the wall concealed electrical works were incomplete in the next floor i.e., 22nd floor wherein the gypsum works were to be taken off. This resulted in the stoppage of civil works by the mason, sometimes even for days together. This would be resulting in a major overall delay in not only in a particular building, but also in the delay in the project. Hence, last planning system was jointly made by both the labours of the civil and electrical discipline. The integrated system of planning was also made possible in this system. The integrated system brings about a direct and a straight relation and a good flow of activities with respect to the various disciplines such as civil, electrical, mechanical and plumbing works. When this particular activity of gypsum works connected with the masons of the civil discipline had to be planned by the last planner who is the mason in this case, the involvement of the electrical conduiting works which had to be concealed, the plumbing lines which had to be concealed in the walls before the application of the gypsum plaster by the mason of the civil discipline, and also the overhead piping works for the fire fighting system and the air conditioning system which has to be carried out by the mechanical discipline labours. Hence, there had to be coordinated meeting which had to be conducted by the engineer in charge who is implementing the last planner system through the mason who is carrying out the gypsum plaster works and the engineers of the electrical, mechanical and plumbing disciplines. This meeting not only brought out the particular activity completion of a particular building, but also the overall completion of the activities connected with the various disciplines and the overall completion of the project.

In the system of arranging the materials for the labour who was directly involved in the last planning system, a proper understanding was not held between the labour who did the activity and the lift operator who had to lift and shift the material for the labour to the higher floors. This was mainly due to the fact that the lift operator was working only to the assigned official timings but in order to get the next day's work started on time by the mason, the helper had to work overtime after the end of the day's work and shift the materials. The same was the work hindrance during the resumption of the work after the lunch timings. A coordinated meeting as a part of the lean system implementation helped to successfully gain the benefits of the last planner system since the materials required for the shift of a particular day was supplied to the labour without any stoppage and wastage of waiting or idle time.

A compulsion and a better sense of understanding to achieve the day's target was unable to maintain by the last planner, the labour who had to waste time of climbing down and up the 22^{nd} floor for his lunch. While the labourwho was being paid on the measurement of works done was induced with the quantum of time being wasted for his lunch, the last planner was able to get packed lunch to the work spot, thereby reducing the time taken by him for having his lunch.

There were unnecessary gap of time being wasted while shifting the activity from one work spot to other, though sometimes when both the work spots that is two walls in the same room were nearer for carrying out the gypsum plaster activity. This was due to the time taken for shifting the materials and consumables to the next work spot. As a part of lean system implementation, the helpers who were idle during the time when the masons were carrying out the plastering works arranged for the materials and consumables for the succeeding work spot and hence the idle time was considerably reduced which was caused due to shifting from one work spot to another.

The master plan had the exact sequencing of activities. Hence, in the implementation of the last planner system, proper care was taken to ensure good quality of preceding works were carried out so that there exists a smooth transition and flow of activities as existed in the master plan.

The work methodology also plays a major role in achieving the target of the last planner system. Initial setbacks were seen while doing the plastering since the sequencing was done both from top to bottom and vice versa. A large amount of wastage of materials was created because of this system. Hence, while implementing the last planner system itself, the labour was educated about the time and the material wastage and then a proper work methodology of doing the gypsum plaster from top to bottom was followed.

There were also many hurdles, which were faced during the implementation of the last planner system. It was found that plastering was done from bottom to top of any wall and during this process, a lot of spillover of the plaster occurred while doing the top portion of the wall. Hence the time consumed to finish a wall was more since the spilled over plaster had to be cleaned and the finishing of the bottom portion of the wall was a rework. As a part of the lean construction principle implementation, the masons were instructed to correct their work methodology and then start their gypsum plastering works from top portion of the wall and then go down to the bottom portion of the wall.

Next, the technology plays a vital role in the last planner system in the sense that it helps to speed up the review process and the planning process of the last planner system implementation for the monitoring of the system. But when last planner principles were adopted in the activities of the building project, it was found that these labours were often using the mobile phones in between their activities and then the works got disrupted in between and the productivity of these labours were decreasing. The helpers when they were idle during the process of the activities being done by their masons were also using the mobile phones and this was even sometimes becoming a safety issue apart from the work interruption. These mobile phones could not be totally made to be avoided since for personal use this was the only way of communication since these labours had travelled from far places in order to earn for their living.

Next, in any construction project, among the four factors of Quality, Safety, Economy and Time, Safety is the most primary factor to be considered and given more weightage since the other three factors could be achieved only if the safety of the workers were taken care of. While the labours were working in the higher floors, particularly in the outer portion of the building, the safety tools and appliances, which have to be adopted, has to be very much on the higher side. The safety equipments, the safety tools and the safety tackles, starting from the helmet, to the safety belt and hooking the belt on to the firm support were taking more time in starting of the activity itself. More over since, these labours are mostly uneducated, the adoption of these safety measures was minimal since they were more concentrating on the target achievement for the day. Hence as a part of the last planner system principle implementation, the safety personal protective equipments were given at the ground level itself, which consumed a lot of time before the start of the day’s work.

Next, in the gypsum plastering works, it was observed that there was a mismatch in the number of helpers being allocated for the number of masons. While at the start of the activity, one mason would require one helper, but during the course of the execution of the activity these helpers become idle and again the number of helpers would be fluctuating between one for one mason and two for one mason in order to feed continuously the materials for the masons to do the gypsum plastering without any interruption and also to achieve the target planned as a part of the last planner system. But inspite of this, there were more masons than helpers of the ratio of 3:1 in some places, and hence as a part of the lean implementation, the resource levelling had to be done continuously throughout the day for the number of helpers allocated to the number of masons.

CONCLUSION

The modern construction projects are complex in nature and demand to produce the structure in a very short duration is the need of the hour by the client. Though the conventional projects deal with individual activities and control their schedule and cost through various techniques, the overall project delivery is to be achieved keeping the process flow smooth and without any hindrance and this is achieved by adopting one of the Lean Construction methods as explained in this paper. The category of time wasted by the labours were identified, noted and then shown to the Labours who were then able to get a clear understanding of controlling the time wasted which were in their preview and were able to achieve a better nearby target of the work plan. Lean construction tools such as the Last planner systems, though seem to be complex tools theoretically, application of such tools has definitely improved the overall performance of the project by means of work involvement by the last planner, creating a sense of satisfaction of achieving the target by the labour, promises adhered to etc.,, This was possible only by way of measuring the end result on a daily basis. Lean principle suggests that "overall potential" will never be achieved, as pursuit of the ideal performance overtakes all previous performance benchmarks.

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COMBINING TAKT PLANNING WITH PRE-FABRICATION FOR INDUSTRIALIZED CONSTRUCTION

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ABSTRACT

Prefabrication and takt planning and control have been discussed a lot among lean construction researchers and practitioners. However, prefabrication and takt planning together as a way to promote industrialization in construction have been under explored in earlier research. Based on a literature review and two case analysis, this study explored the synergies between prefabrication and takt to promote the industrialization in construction. First case applied prefabrication and takt planning together and the second case applied takt planning, without prefabrication. Our results demonstrate that the two concepts together lead to better results and just implementing takt without prefabrication eventually moves the bottleneck of the project to drying times that could be solved with prefabrication. Therefore, both prefabrication and takt planning benefit from the combination and we argue that industrialization in construction requires both concepts.

KEYWORDS

Lean construction, Prefabrication, Takt planning, Industrial construction

INTRODUCTION

Industrial construction is a concept which aims at upgrading traditional site-based construction practices towards industrializedproduction systems(Gibb, 2001;Mao *et al.*, 2015).Implementation of industrializationwould give several benefits to the construction industry, such as reduction of cost, minimization of waste, speeds of the project time and reduction in number of needed workers (Zhang, *et al.*, 2014). Literature has proposed different approaches and methods to industrialize construction, including lean

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construction (Gann, 1996), prefabrication (Gibb 2001), re-engineering processes(Winch 2003), and new practices for planning and scheduling (Austin et al. 2000).

Prefabrication of building and its parts off-site and assembling them on site has been one of the major practices to enhance industrialization of the construction. Pre-fabrication is an umbrella term that denotes different types of practices, such as pre-assembly and off-site production. Prefabrication can cover production of volumetric rooms or structural components including beams, panels, walls, and accessories. Technically, any building that has been divided into sub-sections or sub-products which are produced in factoryenvironment and combined on site, can be considered prefabricated buildings. Numerous benefits have been mentioned regarding the utilization of prefabrication technology in construction(e.g. (Paudel et al. 2016)). Prefabrication is essential for completion of project on time, on budget and with intended quality. According to Poudel *et al*., (2016) use of pre-fabrication has increased by 86 % in the last two decades.

Despite the increasing role of prefabrication to foster industrialization of construction, in practice, productivity development of construction has still been lagging behind other industries. It can be argued that moving assembly work to factories has not improved productivity in remaining assembly activities on site. Koskela (2003) suggests, that eliminating non-value adding onsite activities is another way of promotion of industrialization concept in construction. In addition, Lessing, (2006) has defined eight areas of continuous improvement for the promotion of industrialization in construction, including not only prefabrication but also the use of takt principles in production planning. Therefore, we argue that the missing link in fostering industrial construction through prefabrication may be in inappropriate planning and control methods in on site activities. On the other hand, taktprinciples are becoming more popular in construction projects to increase productivity and reduce waste and costs(Frandson, et al., 2013). We argue that the use of prefabrication in material and component delivery would help to achieve the benefits of takt in projects. However, existing research is lacking to address the role of prefabrication and takt principles together to promote industrialization in construction.

The purpose of this research is to analyse the potential synergies of combining prefabrication and takt planning for more industrialized construction. To address this purpose, the research aims at answering the following research question: *What are the synergies of combining prefabrication and takt planning for industrialized construction on project level rather than utilizing them as separated strategies?* By synergies, we mean how the adoption of these two practices together lowers or removes the barriers or hindrances associated with adopting these practices in stand-alone implementations.

THEORETICAL BACKGROUND

INDUSTRIALIZATION IN CONSTRUCTION

Industrialization in construction has been discussed by many industrial researchers and academics and it is defined in different ways, however it is lacking a widely accepted definition (Lessing, 2006). Traditionally, industrialization in construction was mainly focused on the utilization of machinery and automated systems that replace labor doing manual work. Over the years, industrialization concept started to get broader as it was understood as offsite prefabrication of building and its parts which involves the design and manufacturing of more complex parts of the building. Today, industrialization in construction is not just limited to off-site prefabrication and factory production; it is more focused with the process than just a project which includes the systematic, controlled and standardized production in well-defined building systems (Andersson and Lessing 2017). This understanding of industrialization has been confirmed to increase the performance of construction process. A clear example can be seen in the results of Hooley et al (2002); utilization of industrialization in construction process led to savings of 16% in labour and material costs, reduction of material utilization by 26 %, and reduction of building time by 37% in North America and in Europe.

Industrialization is often understood as a gradual outcome of continuous improvements in construction processes. In other words, it is a process for finding opportunities for streamlining work and reducing waste. To define the areas for continuous improvement, Lessing (2006) focuses on eight different areas to be implemented for achieving the industrialization in the construction industry:

Planning and control of the processes; project must be pre-planned before implementation paying special attention to design activities.

Developed technical system; the suitable technical product solutions will be developed and upgraded and implemented into the systems.

Prefabrication of the building parts; this is one of the most important areas of construction industrialization. Off-site manufacturing is better suited for efficiency because working conditions have less variability and sophisticated equipment can be utilized.

Long-term relations; stakeholders and participants such as project planner, architecture, and structural engineer are engaged in the long-term relations.

Integrated logistics; The material and information flow in the construction sites and factory plants are combined with the design, production and construction process.

Use of ICT; Utilization of ICT tools such as BIM helps to enable industrialization in construction also management information system supports managing the information through all process and technical systems

Re use of experience and measurements; Performance measurement provides situational awareness about the process and enables learning.

Customer and market focus; getting knowledge of customer expectations and needs..

Continuous improvement of all these eight areas defines the current description of industrialized construction. All of these eight strategies will have different role for the implementation of industrialization. Offsite prefabrication of building and its parts has been treated as a major part of the industrialization in construction history. Hence, in this research, prefabrication as a factor of the industrialized construction will be focused.

PREFABRICATION IN CONSTRUCTION

Prefabricated construction is an alternative solution to the traditional site-based construction, which helps to increase productivity, reduce waste, increase predictability and environmental performance over life cycle, and has benefits for all the stakeholders involved in the construction process (Pan, *et al*, 2012).Elimination of waste is an important part of lean philosophy. The goal of the Flow view in Koskela's(1992) TFV-model is to increase the value-adding time by decreasing waste related to flows. The focus is on providing more value added solution to the customer (Aziz and Hafez, 2013). Currently, implementation of lean principles and tools is becoming more popular in construction projects, and it recognizes as an essential concept to be successful in the current industry (Aziz and Hafez, 2013; Bashford, *et al.*, 2005).

In industrialized construction, implementation of new technology to decrease waste is necessary. Many researchers have suggested prefabrication technology as the best tool for the minimization of waste in construction (Lu and Yuan, 2013).Thisis exemplified in a research by (Tam et al. 2005) that shows that concrete waste could be reduced by 51% to 60%, and construction waste from the adoption of timber formwork could be decreased by 74% to 87% by using steel formwork through the utilization of prefabrication. Prefabricating MEP systems has been reported to decrease man hours related to MEP installations by 30% (Khanzode,*et al.,* 2008).

TAKT IN LEAN CONSTRUCTION

The term takt is derived from the latin term “tactus” which means a sense of touch or touch, later in the 16th century, takt was redefined in German as ‘beat’ (Haghsheno *et al.*, 2016). Takt time is understood as time span of two beats. The application of takt in a process is explained as takting. Over the years, meaning of this term defined differently by different authors. Commonly accepted definition is given by Frandson, *et al.*,, (2013) as “the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate”. Which can be expressedin simple mathematical form as:

TAKT time= Available net working time/Customer demand in that time

Adoption of lean principles in the construction project plays a significant role in productivity improvement. As exemplified by Court et al., (2009), implementation of lean and agile mechanical and electrical (M&E) construction system reduced 37% of the onsite labour work and increased productivity by 116% comparing with the traditional construction systems.Among the several lean tools and practices, takt planning (e.g. Frandson *et al.*, 2013) is one of tools related to production system design that has been claimed to help projects complete on time, within budget and with high quality. Adoption of takt time is a way to examine the speed of production to the rate of construction zones; construction zones mean an assembly of building fabric process (BFP) and Mechanical, electrical and plumbing (MEP) process (Court,2009).Takt principles originated in lean manufacturing, where production rates are set to match the demand rate (e.g. Hopp and Spearman, 2008). In construction, the objective of takt planning has been to provide a balanced work flow for trades(Frandson and Tommelein 2016), and to decrease cycle times and increase productivity (Heinonen and Seppänen 2016).Takt time planning (TTP) has been proposed as a method byFrandson et al. (2013) and Takt Planning and Takt Control is a related method introduced by Dlouhy et al. (2016). The methods have in common that the work is broken down to small areas (takt areas), repetitive processes, and each process is allocated a certain amount of time to finish each takt area (takt time). By removing buffers from between tasks, the project cycle time is decreased.

COMBINING PREFABRICATION AND TAKT FORINDUSTRIALIZATION IN CONSTRUCTION

One of the key ideas of lean is to lead the continuous improvement (Kaizen) along with the elimination of waste (muda). Continuous improvement is at the heart of lean construction, lean management and lean production. Implementation of taktwould seem to prevent overproduction, reduce lead times, reduce waiting times and finally make the process transparent so that continuous improvement required for industrialization can be realized.

Major focus of industrialized construction is to create a framework for continuous improvement of several areas defined by Lessing (2006). Incorporating prefabricated products plays a major role in achieving this goal.

Thus, both prefabrication and takt seem to be factors in enabling continuous improvement, therefore paving the way for industrialization of construction. As they both have similar goals but focus on different parts of the supply chain, we argue that by implementing both, construction industry could move towards industrialization (Figure 1).

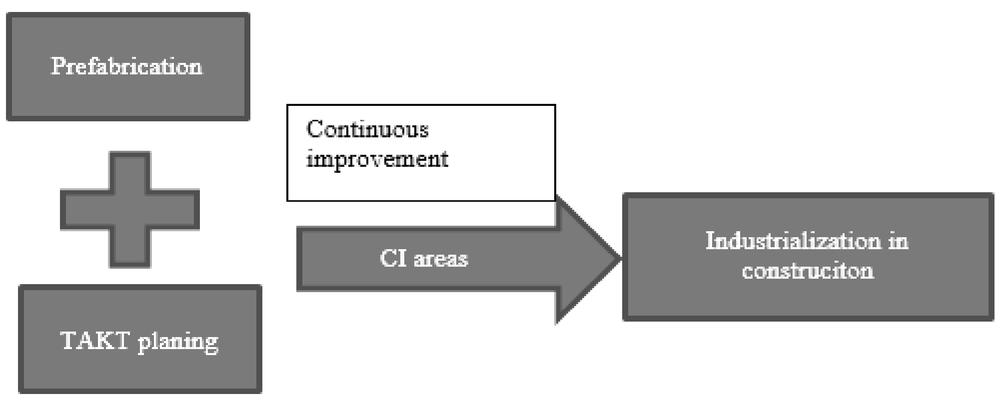

Figure 1. Prefabrication and takt role for construction industrialization

METHOD

In this paper, we first reviewed the existing literature on construction industrialization, prefabrication and takt planning in relation to the construction industry. Based on the literature, the role of prefabrication and takt planning for the promotion of industrialization in the construction industry is proposed. After that we used a case study design to empirically investigate the synergies of using takt and prefabrication for industrialized construction. We followed Yin's (2014) suggestion of analysing multiple case studies to get required variation in results by selecting two construction projects as our cases of which the first one has adopted both prefabrication and takt and the other only takt planning. This theoretical selection enabled us to investigate possible synergies of practices and to compare them to the situation in which synergies between practices were not gained. We selected one case from US and another from Finland to increase the generalization of the results. In both cases, an action-based method was followedandone author was responsible for adopting prefabrication or takt planning principles. Project documents, observations, and meeting memos were used as primary data for analysis.

RESULTS AND ANALYSIS

CASE I

The Van Ness and Geary Campus Hospital (VNGC) is a 91,974 square meter, 2.1 billion dollar construction. It is a 13-story, 274 bed acute care hospital with possible expansion to 304 bed and will be built in downtown San Francisco. It is estimated to open for patients in the first quarter of 2019. The construction site does not have any lay down area and is situated in the densest area of the city which has the second busiest traffic in the US.

Utilization of Prefabrication

At VNGC construction project prefabrication was the fundamental tool securing the completion of the project on time, on budget and with the targeted quality. The application of shared overhead utility racks for services, displacement ventilation and improved scheduling for the structural steel frame has led to significant amount of savings. Prefabrication in the factory site and site construction such as digging the base were continuedin parallel, which in turn promoted the completion of the project on time. Similarly, parts were manufactured in the factory and were assembled on site that helped minimize waste on site as well as reduce the number of onsite workers.

Overall, the utilization of prefabrication technology has greatly benefited the completion construction process on time, on budget and with quality which is a major construction industrialization area defined by Lessing (2006). Prefabrication played a significant role in the improvement of other construction industrialization areas, such as in logistics management, planning and control of the whole construction process, development of the technical system in the off-site factory as well in on-site, long-term relations with all participants and other stakeholders. Thus, prefabrication technology had the vital role for continuous improvement of construction industrialization areas (Lessing, 2006) and finally it helped to promote the industrialization of construction.

Utilization of TAKT

The project decided to apply takt planning early and built a production system around standard durations and location-based hand-offs. Once the areas were established, the entire supply chain employed those areas to batch their work accordingly. To be able to install a certain scope of work effectively in area A, the team had to detail the shop drawings, order the material, fabricate the components, kit and package the material and information, and deliver everything the area A separately. Hence, the team managed to align the supply chain to the installation schedule by clearly defining the batches of work early and globally for all stakeholder to align to.

Further, using standard durations allowed for a stable and extremely simple and visual schedule that promoted a deeper understanding of the overall flow of the project and level loaded the crews and material demands. The crews had a set duration, 1 or 3 weeks in each area and a crew worked in one area at a time, moving clockwise up the project. This structure made sure that there was a high space utilisation rate where one crew was working in each area of the floor, and limited trade stacking as only one crew were supposed to work in each area per week.

It was realized shortly afterwards that the trades that had sophisticated detailing and fabrication processes such as mechanical trades benefitted exponentially from the cyclical and batch-oriented schedule as the site became a natural expansion of their fabrication flow. The project also saw that developing a steady overall flow allowed the supply chain to align closer than ever before, reducing the inventory needs and allowed a more level headed fabrication process as well. In the past, an extremely volatile site schedule essentially forced the supply chain to overproduce and have excess inventory just to be able to cover the stop and go reactions from project sites.This case illustrates well how prefabrication enabled creating more stable material and component flow to site. On the other hand, well managed material flow was the requirement for successful takt adoption in site operations.

CASE II

Case II is a 7-story residential building project in Helsinki Finland. The building includes 42apartments. Takt planning and control is being implemented for interior finishes, starting from pouring concrete in bathrooms. Takt planning has been done in collaboration with the whole team, led by the General Contractor, Fira Oy. Prefabrication is not being extensively conducted in the project except for precast concrete structure.

The team implemented takt planning aggressively, going for a takt time of one day, and each apartment as a takt area. There are two trains, one for all other spaces within the apartment except the bathroom, which has a different work content and is considered a separate train. Takt plan of the building is shown in Figure 2, the areas outside of bathrooms are shown on the top and the bathroom areas at the bottom. This indicates that bathrooms are the bottlenecks in this residential construction project. They cannot be further accelerated because floor tiling requires concrete floor to be dry, and the floor drying cannot be further expedited.

The General Contractor has been evaluating the use of modular bathroom units in other projects but has not been able to really figure out the value proposition. Aggressive cycle time reduction of the takt plan brought the bathrooms to the critical path for the first time and further time compression is only possible with a modular solution or with product development related to concrete drying solutions. This case illustrates well that cycle time compression with takt moves the bottleneck of the project and creates a compelling business case for modular prefabrication solutions.

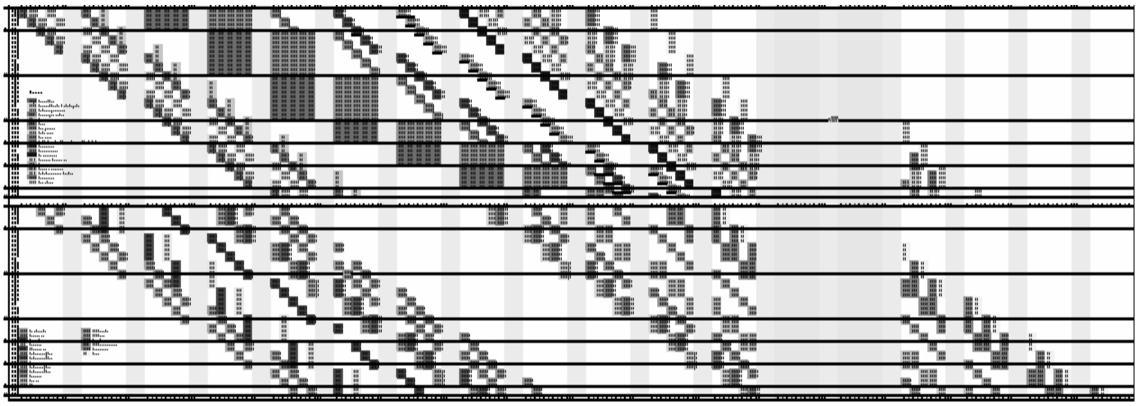

Figure 2. Takt plan of Capella project. The bathrooms are shown in the lower portion and are on the critical path. Drying time of concrete results in an empty area before floor tiling work.

DISCUSSION

This study showed that several synergies canbe identified when adopting prefabrication and takt planning together in the same project. In the first case, prefabrication and taktplaning together have significantly helped overcome several challenges such as traffic, residential neighborhood, logistics, storage and parking. By utilizing prefabrication, onsite and offsite activities were continued in parallellythat expedited the project completion. Adoption of Takt helped to manage the same speed for both on-site and off-site activities, balance their resources with the plan and production process and reduce overproduction. On the other hand, Case II showed that several bottlenecks might appear during the takt implementation if the critical path on site consists of long phases, such as drying, in which active takt crews are not needed. Prefabrication, on the other hand, would solve this problem. Thus, the analysis shows that takt planning and prefabrication are not alternatives when shortening construction time but their effects shows in different parts of the process, meaning that synergies can be achieved if they are employed together. In addition, takt planning on-site creates continuation for planning methods adopted in typical prefabrication processes. Thisindicates, that there is no need for additional material coordination between prefabrication and takt planning on site if cycle times in prefabrication and takt time on site are synchronized in the overall production planning. Prefabrication also enables less complex material packages to be delivered to the site thereby enabling more JIT based deliveries that are needed in takt planning.

CONCLUSION

Several approaches can be taken to reach the goal of the industrialisation in construction. To address the lack of earlier research on evaluating the role of prefabrication and takt time together to promote industrialization in construction, multiple case analysis was adopted in this study. Our analysis shows that takt planning and prefabrication play a significant role in industrialization areas such as in logistics by smooth material and information flow, in speeding up the project, in planning and control of the process, reuse of materials,experiences and measurements, focuses on market and customer demand and in improving the long-term relationship with project stakeholders.

In summary, our research confirms that instead of seeing different practices to enable industrial construction as separated strategies (Lessing, 2006), prefabrication and modern production planning methods, such as takt planning, would benefit when they are adopted together. Further research is needed on how these synergies are more optimally achieved and what kind of solutions are most appropriate e.g. in logistics to support the combination of prefabrication and takt planning.

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COMPLEX PRODUCTION SYSTEMS: NON-LINEAR AND NON-REPETITIVE PROJECTS

Danny Murguia[1], Alonso Urbina[2]

ABSTRACT

In most residential building construction, the production system design relies on the assumption of linearity per zone and per story, thus, takt-time schedules and flow lines are produced accordingly. However, in practice, such smoothness is difficult to achieve due to non-linear and non-repetitive projects. This research aims to identify the main challenges of the production system design when a planning team faces such projects. To achieve this objective, lean scheduling methods are analysed by a complex production system framework including: variety of tasks, task interdependence, supply chain interdependence, and work density. Two simulation case studies are presented. First, the finishing phase of a residential building presents the case of a non-linear project. Second, the structural works of an industrial project presents the challenges of a non-repetitive project. The main finding is that non-repetitive projects can be handled as multiple repetitive non-linear stages. However, the main challenges include the reciprocal interdependence between trade contractors, the work density disparity between locations and trades, the capacity buffer design, and production rates predictions for the assembly of one-off products. This research contributes to the understanding of scheduling in projects where the linearity assumption of activities is violated.

KEYWORDS

Complex production system, Flow lines, Non-linear projects, Non-repetitive projects, Production System Design

INTRODUCTION

Construction projects tend to be categorised as linear, non-linear, repetitive, and non-repetitive. On the one hand, repetitive linear projects are those in which all the operations and outputs are the same in each location (Mattila & Park 2003). On the other hand, the

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repetitive non-linear projects are characterised by repetitive operations in each location, however, outputs are not uniform in each location. By contrast, a non-repetitive project is characterised by unequal operations and outputs in almost all locations (Arditi et al. 2002). Examples of non-repetitive buildings can be found in hospitals, retail, theatres, museums, and libraries. Housing projects have also non-repetitive parts such as common areas and MEP systems in garages (Valente et al. 2014). Table 1 shows a summary of project's characteristics.

Table 1: Project's characteristics

Project	**Size of locations**	**Operations per location**	**Resources per location**	**Flow**	**Outputs per location**
Repetitive Linear	Equal	Equal	Equal	Smooth	Equal
Repetitive Non-linear	Not uniform	Equal	Not uniform	Moderate	Not uniform
Non-repetitive	Unequal	Unequal	Not uniform	Turbulent	Unequal

Contractually, these projects are managed with Critical Path Method (CPM)master schedules with multiple sectional completion dates (Olivieri et al. 2016). Moreover, in some countries, there are standards that recommend its use as good practices in time management. However, the inability of CPM to analyse the flow in the production system at the operational level is well known. The most criticised aspects are (i) not focusing on the workflow, (ii) neglecting production rates, (iii) omitting the work disparity in locations, (iv) demoting resource management, and (v) inefficient on repetitive projects (Arditi et al., 2002; Olivieri et al., 2018). Takt-Time Planning (TTP) and flowlines arose as scheduling methods to overcome some of these aspects. TTP is a method adapted from the lean manufacturing industry where the takt-time is a parameter that represents the unit of time that a product must take to be produced, in order to satisfy the demand rate (Frandson et al, 2013). The activities in the production line are aligned to the production rate of the bottleneck. Hence, a continuous workflow is defined (Seppänen, 2014). On the other hand, flowline scheduling models the project as a series of hierarchically-distributed locations which are geometrically defined by the Location Breakdown Structure (LBS). Therefore, activities flow through different locations consistently using the same amount of resources (Seppänen, 2014). LBMS integrates flowline scheduling with CPM in order to preserve the workflow on locations by delaying the start date of tasks (Frandson et al., 2015).

Non-linear and non-repetitive projects are a challenge for contractors. Production teams who apply TTP or flowlines in linear and repetitive project face problems in non-linear projects due to unequal workload between zones and discrete activities. Moreover, problems intensify in non-repetitive projects due to non-evident locations, one-off activities, complex architectural designs, a combination of structural materials, multiple services, and a variety of specialised trade contractors. Thus, the production system becomes unpredictable and the desired pull-system becomes a push-system.

There are claims of successful applications of TTP and flowline in non-repetitive projects. Linnik et al. (2013) implemented TTP in a hospital project. They found that takt-time planning is feasible and beneficial, however, it lacks the ability to define locations that have identical labour content for the bottleneck task. Valente et al. (2014) developed guidelines to implement flowlines in common areas of a residential building. However, the case study presented did not represent interactions of activities of a non-repetitive project. Tommelein (2017) implemented TTP for non-repetitive works in a small healthcare project in a collaborative environment and highlighted work density as an indicator that expresses a unit of time per unit of area. Previous studies have not attempted to use virtual models and automated software to improve the application of flowlines in non-linear and non-repetitive projects. Moreover, there are no studies linking production system design with concepts of complex systems. This research intends to advance in this aspect.

RESEARCH METHOD

The aim of this research is to (1) develop a framework for complex production systems, and (2) identify the main challenges of production system design in non-linear and non-repetitive projects. To achieve these objectives, first, a framework for complex production systems is drawn from the literature. Second, data was collected from two existing construction projects including drawings, takt-time and CPM schedules, division of locations, and trade contractors' production rates. Additionally, interviews were conducted with site engineers to identify the work sequence and challenges during the construction stage. The first case study is the finishing phase of a community-housing project which depicts a linear and a non-linear project. Meanwhile, the second case study is an industrial project which depicts a non-repetitive project. Third, projects were modelled using Revit and Tekla, and simulated in Vico Office. Fourth, results were contrasted with the complex production system framework. Finally, the findings are discussed, and directions for further empirical validation are presented.

UNDERSTANDING COMPLEX PRODUCTION SYSTEMS

Schramm et al. (2006) investigated production systems in complex projects and highlighted that a project's size, client requirements, and cost and time constraints are not parameters to define the complexity level of a production system. Gidado (1996) found that the components of complexity in the production processes of construction can be categorised as (a) complexity in components that are inherent in the operation of individual tasks, and (b) complexity when bringing together different parts to form a workflow. A similar view was shared by Williams (1999), who contended that complexity in construction projects can be regarded as (a) variety of tasks, and (b) degree of interdependencies of tasks. Moreover, the research also found that complexity is also created by the instability of assumptions upon which the tasks are based.

Miranda Filho et al. (2016) argued that a complex product is comprised of different elements that can be managed by the assumption that the whole is equal to the sum of the parts. Therefore, complex production systems are composed of a *variety of sub-systems* where the focus is upon how these sub-systems interrelate. In complex projects, some sub-systems might be one-off products or tasks which require detailed design, tools for visualisation and simulation, profound understanding, detailed collaborative planning, and strict control during the assembly process. This *variety of sub-system s*have natural processes during installation. As such, there is a *task interdependence* that cannot be violated. For instance, a mixed structure of concrete and steel often requires the erection of concrete elements first before proceeding with steel components. Thus, the division of such elements in different areas for takt-time scheduling is difficult to achieve.

Thompson (1967)identified three levels of internal interdependency in organisational structure; pooled, sequential and reciprocal. The least degree of interaction is *pooled* interdependence in which two units are not dependent on each other but share the same pool of resources. For instance, the rebar installation trade contractor requires resources from the bending and cutting rebar station. However, they allocate two independent crews for vertical and horizontal elements who work in different areas. This is an example of *pooled* tasks. The interdependence may also be serial and the order specified, with the output of one activity becoming the input of the next activity. This interdependence is *sequential* such as the main tasks in a master takt-time schedule. Finally, the greater degree of interdependence can be *reciprocal* in which tasks have a high degree of negotiation to address conflicts. The actions of one task modify the results in the other, which in turn, returns an input to the previous task. This is the case of the pull-planning process, in which *reciprocal* interdependences become evident as the tasks are unveiled at the operational level. For example, in a reinforced concrete structure, the beam formwork crew installs the horizontal forms and vertical shores. Then, the rebar crew installs the beam rebar. Finally, the beam formwork crew returns to install the lateral forms in parallel with the slab formwork. If these interdependencies are not visible in the pull-planning meetings, process clashes occur in the field.

Bertelsen (2003) contended that considering almost all construction projects are divided into parts that are subcontracted and may be executed in any sequence or even simultaneously, *supply chain interdependence* is a factor when analysing the complexity of a production system. *Supply chain interdependence* becomes critical when detailed design is to be completed during the construction stage by the trade contractor of fabricator.

A concept that helps to understand a production system design is "*work density*". It is defined as the amount of work required by one trade to do their work in a particular area based on the (1) scope of work, (2) trade's size and capabilities, and (3) trade's means and method (Frandson et al., 2015; Tommelein, 2017). Thus, keeping constant trade's methods, crew size, and capabilities, the work density in a non-linear project will be different between locations due to the varying scope of work. Moreover, the work density ina given area of a non-repetitive project will vary from trade to trade due to the variety of sub-systems and diverting methods and equipment required. This disparity is a challenge in the production system design.

SIMULATIONS AND RESULTS

CASESTUDY 1

The first case study will simulate the finishing phase of a five-story community-housing project including the following activities: (1) painting, (2) doors, (3) windows, (4) closets, (5) flooring, and (6) baseboards. The typical story consists of eight identical two-bedroom flats. For the analysis, the story will be divided as a linear project with four locations and 2 flats per location. It will also be analysed as a non-linear project assuming four locations with different sizes: 2, 3, 2, and 1 flats per location. The rationale behind this division is that most residential projects have combinations of 1-, 2-, 3-bedroom flats per story. Thus, flats have different sizes and the work density disparity and non-linearity becomes evident. Finishing tasks were broken down and sequenced at the operational level. This process should be collaborative and negotiated with trade contractors in the pull planning process. Figure 1 shows the networking of activities based on Murguia et al. (2016).

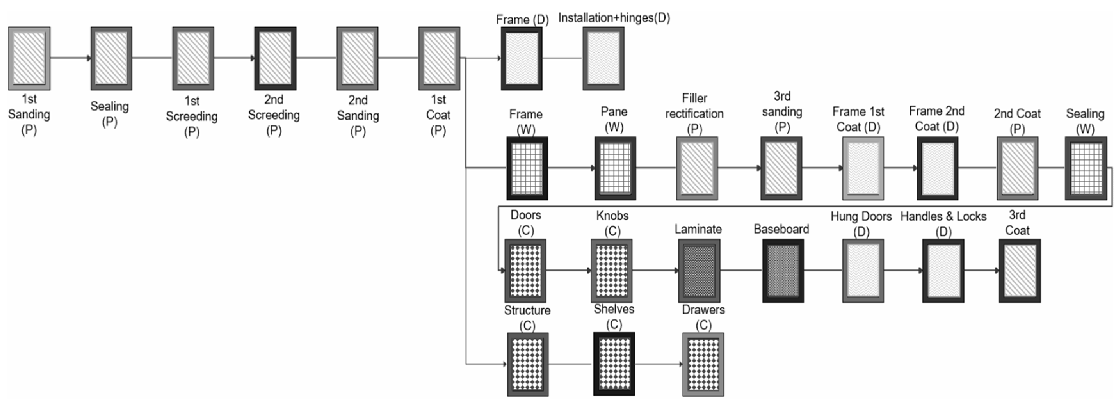

Figure 1: Network of activities (in green painting trade, in yellow doors trade, in blue windows trade, in brown closets trade, and in purple flooring trade)

The next step is to design the number of crews per task and per location in an iterative process. The crew capacity (work density/crew man hours) would help to decide how many crews to allocate in each area. According to Frandson et al. (2015), capacity buffers are preferred in TTP whilst time buffers are preferred in LBMS. To make linear and non-linear simulations comparable, the number of crews will be defined using a takt-time equal to one day in the linear project with a 10%capacity buffer. Table 2 shows an example of crew and capacity buffer calculation. None of the iterations exhibit 10% of a capacity buffer. However, it is decided to use two crews to avoid low productivity. This extra capacity could be further negotiated in practice with trade contractors by means of extra bonuses for on-time completion.

Table 2: Crew Capacity iterations for First Coat of Painting (1 crew=1.5 workers)

Item	Yield (mh/m^2)	Take-off (m^2)	Work Density (mh)	Number Crews	Number Workers	Planned (mh)	Crew Capacity (%)	Capacity Buffer (%)
1	0.07	419.87	28	1	1.5 (2)	16	175	-75
2	0.07	419.87	28	2	3	24	117	-17
3	0.07	419.87	28	3	4.5 (5)	40	70	30

Table 3 shows the crew capacity of the painting contractor per location in the linear and non-linear simulation considering a takt equal to one day. The capacity buffer ranges from -80% to 58%with critical crew capacity in location1. To deal with this design problem some solutions might be proposed. First, allocating an additional crew only for location 1, however, it is not viable in practice as trade contractors prefer constant labour in the field. Second, changing the boundaries of locations, however, the deliverables in the finishing phase are individual flats. Thus, if we restrict one-day takt in the non-linear project, there will labour instability across locations. The flowline method, which assumes constant resource use, will be used.

Table 3: Crew Capacity in linear and non-linear project for the painting trade contractor

Task	Number of Crews (Takt = 1 day)	Linear - Crew Capacity (%)				Non-linear - Crew Capacity (%)			
		L1	L2	L3	L4	L1	L2	L3	L4
1st sanding	1	120				180	120	120	60
Sealing	1	105				157	105	105	52
1st, 2nd screed	2	91				137	91	91	46
2nd sanding	2	84				126	84	84	42
1st,2nd,3rd coat	2	117				175	117	117	58

Figure 2 shows the flowlines of the non-linear project. The varying slopes of a single flowline owe to the different time that crews need to complete a task in a location. In this simulation, the flowline schedule (98 days) exceeded in 8% the takt-time schedule (91 days). Planners can decide between TTP or flowlines by comparing the schedule difference with the problems that arise with the one-day takt restriction. For example, they might choose TTP if there is workable backlog.

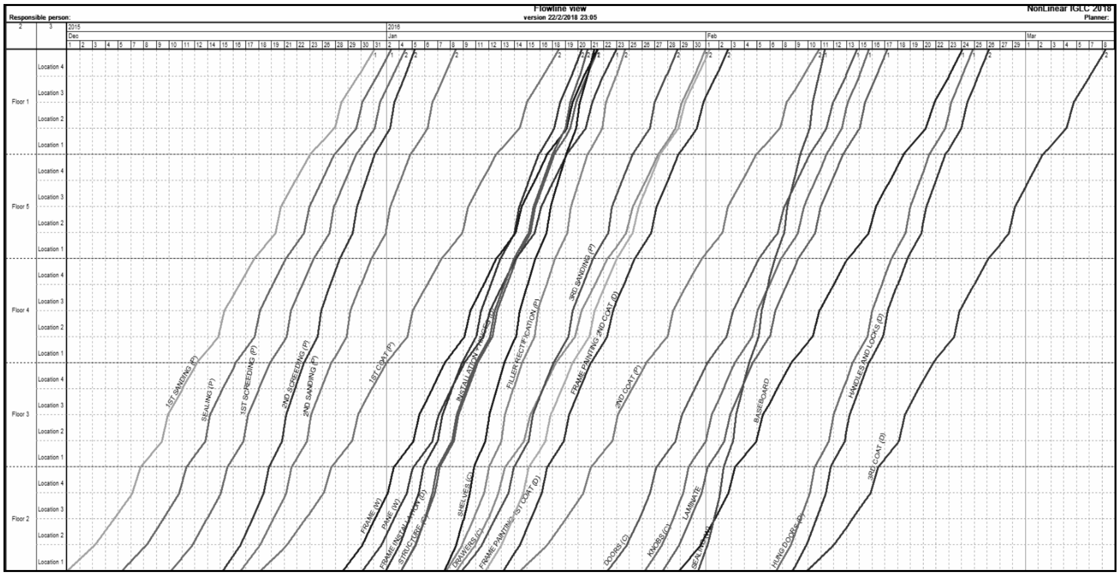

Figure 2: Flowlines of the non-linear project

CASE STUDY 2

The second case study is a small industrial project with a mixed structure of concrete and steel. The LBS will be defined by (1) foundations, (2) superstructures, and (3) steel roofing as shown in figure 3. The superstructure was divided into (2.1) one-off concrete structures and (2.2) steel structure. A second-level LBS will be established by defining three locations per division. The second case study exhibits the challenges of a non-repetitive project. This includes one-off products and high levels of supply chain interdependence such as the steel contractor finishing the detailing during construction, a variety of equipment suppliers, and off-site fabrication. The project will be modelled as a non-repetitive project (e.g. superstructure steel contractor does not start activities until all foundations are finalised) and as a repetitive project (activities running smoothly in each second-level division).

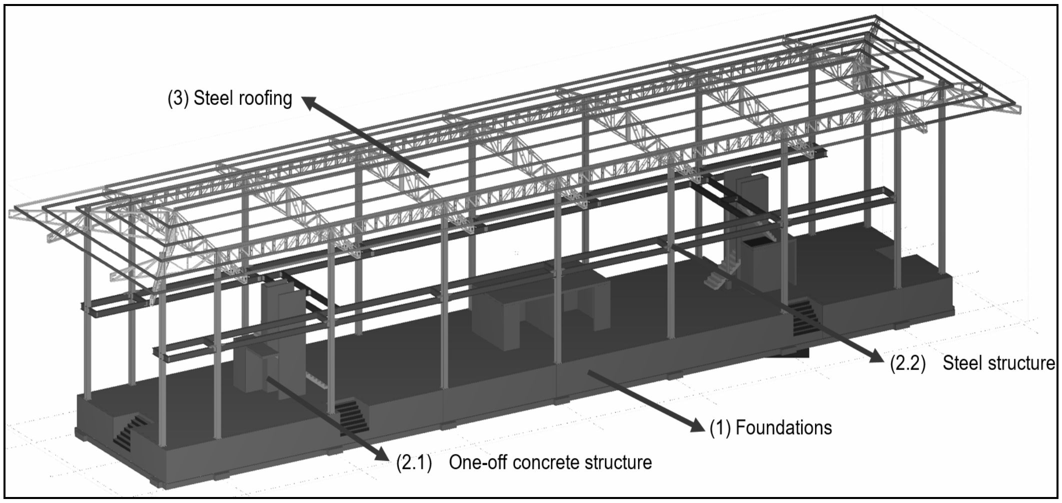

Figure 3: Scope of the non-repetitive project

CPM master schedules for non-repetitive work are produced based on contractual stipulations (e.g. individual work packages contracts) that force trade contractors to start only when their predecessors have fully finished. For example, MEP trade contractor must wait until steel roofing trade contractor concludes. Thus, the project is divided into several independent stages depending on the *variety of sub-systems* in which each trade contractor works independently from others. This becomes critical when one-off products are to be installed. As a result, the more sub-systems, the more stages in the master schedule and the project duration is extended.

Structural steel assembly could be regarded as a linear process due to the great number of similar components that follow a *sequential* interdependence. However, activities at the operational level have high levels of uncertainty, negotiation, and *supply chain interdependence*. For instance, it depends on the resource availability (fabricator), equipment usage (supplier), joints configuration (designers), the relative position of the worker and the component (method and safety), and access (site layout). Thus, productivity rates vary from projections and negatively impact the work density per location and per crew, which in turn leads to significant delays.

Crew design also becomes a challenge as it is not economical nor productive to allocate crews for each component type or unique task. As such, crews can be defined as permanent members and floating members who will assist the permanent members when it is required. Thus, multi-tasking workers could be necessary when planning a non-repetitive project. Figure 4 shows the flowline schedule with three independent major stages (1) foundations, (2) one-off concrete products, and (3) steel structure assembly, with a total project duration of 60 days.

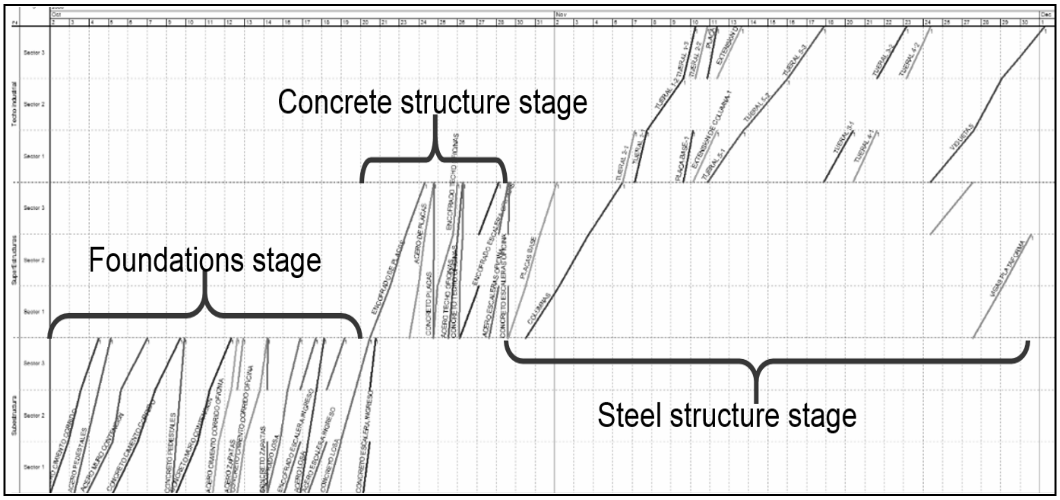

Figure 4: Flowline schedule of the non-repetitive project

A smooth workflow is also simulated by forcing steel trade contractors to start their work as soon as the general contractor finishes the foundations in the first location. As a result, the non-repetitive schedule (60 days) exceeds the repetitive non-linear schedule (50 days) by 20%. Hence, there is an opportunity to treat the non-repetitive project as a repetitive non-linear when the project size justifies the division of products (e.g. foundations) in work chunks. However, a *work density* disparity is observed between trades in the same location (828 mh for foundations, 248 mh for structural columns, and 513 mh for steel roofing).

DISCUSSION

In the first simulation, a moderate variety of tasks and trade contractors, low levels of *pooled* interdependence, and high levels of *sequential* and *reciprocal* interdependence were observed. Figure 1 shows the sequential way in which different trade contractors perform activities in a single location. Furthermore, it also shows the reciprocal interdependence between painting, closets, windows and door crews. The production system design must also consider some time buffers to address field problems such as crews damaging previous trade contractor's work. One of the main challenges of a non-linear system is the crew design due to the work density disparity between zones. In practice, it is rare that a trade contractor daily allocates a different number of crews to sustain the flow in non-linear projects. If the number of crews is fixed, there will be high productivity in the bigger locations and low productivity in the smaller locations. Crews might not be able to deal with cycles of random work shifts. Thus, LBMS seems to be a strategy for the production system design as it allows constant resources across locations. However, schedules can be extended. Finally, the supply chain interdependence could be minimised if pre-fabrication of components is allowed in the system. However, this requires standardised design and installation strategies to reduce error and improve quality.

In the second case study, pooled and sequential interdependences are observed *between stages*. However, *within stages*, reciprocal interdependence is low and sequential interdependence is high. As such, 4D modelling is advisable to detect process clashes which can alter the weak workflow. It was also observed that due to the size of the project, the general contractor must finish the foundations before the steel contractor starts the erection of structural columns. However, whenever possible is advisable to split the products into chunks if the project size is large enough to make this possible. One-off products should be collaboratively placed in the schedule as it rarely can be split into chunks. Thus, it is found that a non-repetitive project can be treated as several repetitive non-linear stages. It is also required detailed analysis and iterations to define equal or comparable locations within stages: here, collaborative BIM can be used to good effect. Nonetheless, the challenge is to predict production rates in complex products assembly.

CONCLUSIONS

This research proposes a framework for production system design for non-linear and non-repetitive projects using lean scheduling techniques. The focus is on the variety of tasks and their interdependence, the supply chain interdependence, and the work density disparity across areas and between trades. A crucial step is to identify the reciprocal interdependences between trade contractors as this interaction becomes critical in the field. The work density disparity is a key factor in the production system design as it causes high and low productivities in different locations as well as crew's periods of downtime. The simulation suggests that flowlines scheduling method is more suitable when a planning team faces a non-linear project. This is due to the ability of flowlines to deal with constant labour resources and the use of time buffers. However, takt-time planning is advisable when workable backlog is available. A non-repetitive project can be handled as a repetitive non-linear one although quantities and distribution of locations change across stages. However, each location exhibits high levels of variability due to the supply chain interdependence and the difficulty in the prediction of production rates. Therefore, the production system designer lies on how well different concepts from complex systems are put together during the planning stage. Further research would include detailed case studies in non-repetitive and non-linear projects to collect data such as(1) location division in complex architectural designs, (2) reciprocal interdependences, (3) trade contractor labour allocation, (4) crews' flow across locations, and (5) resource variability across locations.

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NEW APPROACH TO DEVELOPING INTEGRATED MILESTONES FOR PLANNING AND PRODUCTION CONTROL

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ABSTRACT

This paper examines the issue of bringing improved structure with integrated milestones into the project and production management process to handle progress and strategic coordination in complex AEC-projects. We address the phases between front-end planning and project execution. In terms of theory, we base our project on a concept of strategic milestone planning and we find inspiration in ideas from the practical world.

The design research approach is applied, and our artefact is a proposed method by which to develop a network of pull-based integrated milestones. The proposal is verified by documentation of the application in a construction project.

In this paper, we argue that the described method can be applied as an improvement of milestone planning both in Last Planner and in more traditional project management.

The present study fills a gap in project management literature, which appears to address milestones in a superficial manner; this is partly the case for Last Planner System for production control. Our study contributes to theory and practice regarding development of milestones.

KEYWORDS

Milestones, Front-end, Result-oriented, Integrated, Pull-Network

INTRODUCTION

Milestones are an important part of project planning and management, whether traditionally oriented or based on the concepts of Lean Construction (LC). Last Planner System® (LPS) for production management (Ballard, 2000) is a key component of LC and is built up of several elements of which the overarching one is the master plan. The master plan is a milestone plan. Whereas there are detailed descriptions of functionality and development method in the other elements of LPS, this is not the case with the master plan. The latter is more a "given", although its functionality is clearly described. Ballard

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and Tommele in (2016: 61), for example, list eight functions in LPS, of which the first is «*Specifying what tasks should be done when and by whom, from milestones to phases between milestones, to process within phases, to operations within processes, to steps within operations*». To our minds, these authors are missing a point in the list concerning development of milestones and their function for overall management and control.

A traditional way to establish milestones for construction is to split the building period into phases, usually with a milestone for the transition between phases. The phases may be installation, groundwork, foundation, framework superstructure, roofing, interior work, outdoor work and handover. Depending on the provisions and type of contract, the assignment may also entail pre-design and detailed design. What characterizes this approach is a breaking down of the project based on WBS logic (Work Breakdown Structure).

An alternative option that we have observed being used in practice is process-oriented milestone planning in an early phase of projects. A salient example we know well and that has been a source of inspiration for this article is the construction of a new art institute, Bergen Academy of Art & Design (Statsbygg&KHiB team, 2017). KHiB relied on guidance from Porsche Consulting when they initiated the project budgeted at approximately NOK 1 billion (start-up sitework in 2014 – handover late 2017). We have found no references to any publication pertaining to process-oriented milestone planning from Porsche Consulting, and we conclude that progress in practice has surpassed that of academia.

It is difficult to say with certainty, based on available information, but the method that Suffolk Construction, Boston, applies to handle design processes (Uusitalo, Olivieri, Seppänen, Pikas and Peltokorpi, 2017) resembles process-oriented milestone planning. The authors write that Suffolk, unlike other cases they have studied, apply a milestone-driven pull plan to manage Level of Detail (LoD) (Leite, Akcamete, Akinci, Atasoy & Kiziltas, 2011) in BiM based on milestone requirements.

What, then, is process-oriented milestone planning, and what is different from a traditional WBS approach? We shall return to the details but will here offer a few examples of what we might call core processes in construction; these include production, detail design, materials procurement and builder decisions. A building period is normally given, meaning that the dates for start-up and handover are known in advance to the contracting builder. Production can be regarded as a client's need for a basis for work and materials and components, that is, a demand or requirement for both design and procurement processes. Furthermore, the procurement process needs a basis for placing orders from the design process, which is often dependent on decisions made by the owner/client. We can break this down even further and enter more processes, but we shall return to this aspect later. The difference from a purely WBS-based milestone plan is that here, we rely on a pull-based network of sequential dependencies on the general level, whereas the traditional method consists more of isolated nodes, even though there is a basic sequential logic here as well, but no network logic.

Ballard and Tommelein's (2016: 66) update on LPS address milestones: "*Pull planning involves the identification and definition of the milestone, or key event that the team will be pulling to; e.g., releasing subsequent work activities. Identifying the* *conditions of satisfaction of the milestone is critical to a successful pull plan. To assure that shared understanding, the first step in pull planning is to co-create with the team a description of the milestone from which to pull—what's included and excluded, what work it releases, etc. The completion of one milestone sets the stage for the beginning of another one.*"

This describes the use of reverse planning to identify milestones. We are in total agreement so far. Our additional point in this paper, is that we argue for the development of a pull-based network of milestones in the early phases of core processes. Based on our own practice, we claim that reverse planning is a powerful tool for collaboration, but perhaps not equally applicable for revealing structure and dependencies between milestones. Our research question, then, is **how to identify a method for development of process-oriented milestones in an early stage of project management**. We use the term 'integrated' to describe milestones in such a network.

METHOD

Design science research is applied as the methodical framework in the article since the objective we aim for is creating and not merely describing something (Koskela, 2008; Lukka, 2003; Hevner, 2007; Kuchler & Vaishnavi, 2011; Rocha, Formoso, Tzortzopouluos, Fazenda, Koskela & Tezel, 2012). Design science is based on constructivist theory and correlates to learning by making/constructing. The artefact we want to create is an alternative method for creating process-oriented milestones for construction management, which we define as integrated milestones.

The idea for this study came out of a relatively large building project that was inspired by a consultancy (Porsche Consulting) as they developed their process-oriented milestones and initiated the project as a lean project. This project (Statsbygg & KHiB team, 2017) is the source of the data used to verify our proposal (artefact), namely a method by which to develop process-oriented milestones. Data were collected via observation and interviews with key personnel. In addition, the project team provided several descriptions (op cit.).

As part of the process to illustrate "state of the art" and to find relevant theory, we first reviewed the literature from the lean construction environment. We got seven hits for "milestones" on IGLC.net but none had a focus identical to ours beyond what is mentioned above in the introduction. Following this, we consulted several sources in what we might term 'traditional project management' or classical "PMI-oriented" literature. It is reason to ask whether milestones in the PMI-literature is comparable to milestones in LP. We will argue that the understanding of the idea of milestones is the same, but the usage is, however, very different, confer the pull planning approach in LP vs. push in the critical path method. Following the search for PMI-oriented literature we proceeded to strategic project management, where we found ideas and concepts that we worked further with to develop a proposed method that, as stated above, we verified with data. Finally, we make a short comment on our findings and results from the discussion concerning the applied theory.

LITERATURE REVIEW

In the foregoing, we have referred to lean construction literature without identifying any sources that extend beyond what has already been emphasized. Below are the findings under the categories that we term 'classic project management literature' ("PMI-oriented" literature) and thereafter, 'strategic oriented project management literature'.

CLASSICAL PROJECT MANAGEMENT LITERATURE

We found Kerzner's (2009) often cited systematic approach to planning scheduling and control to be a representative source in the classical project management literature. His approach starts with identifying the project manager as the planning agent. This responsibility is met through the provision of:

- a complete task definition
- definitions of resource requirements
- major timetable milestones
- definitions of end-item quality and reliability requirements, and
- the basis for performance measurement

Concerning Kerzner's list, we intend to focus on literature describing the inception of the planning process where the development of the milestones is embedded in the set of task definitions. Starting with Kerzner's recommendations, effective planning cannot be accomplished unless the following information requirements are met:

- The statement of work (SOW), a narrative description of the work required for the project
- The project specifications, describing the SOW in a more specific level of detail enabling overall estimates of man-hours, equipment and material estimates.
- The milestones schedule (defined by the project manager), and
- The work breakdown structure (WBS)

The two first items are of course necessary for proper planning and will not be discussed further here. Kerzner's guidance on how to develop a milestones schedule is limited in scope to a project start and stop date; furthermore, it contains "other milestones and data items such as reports etc". In stark contrast to the brief description of how to develop a milestones schedule, Kerzner has an extensive explanation on how to develop the work breakdown structure (WBS). Contrary to the idea of this paper, he emphasizes that the development of a WBS is the first major step in the planning process.

STRATEGY-ORIENTED PROJECT MANAGEMENT LITERATURE

Searching for answers with a broader perspective by using rather obvious search words such as "Milestone planning", one finds a few publications and a few papers that appear to be relevant to this pursuit. The authors of these publications seem to agree and refer to each other about milestone planning and its significance. The books by Andersen, Grude, and Haug (2009)[3]and Turner (2012)[4] present a thorough description of a collaborative

[3] First published in 1984

milestone planning as a requisite for the strategic development of the projects and comes before any form of work breakdown of the project. Turner and Cochrand (1993) argue for milestone planning as the right planning approach (as opposed to activity planning approach) for all types of projects except projects where the goals and methods are well understood. Most projects have deficiencies in either the goal or planning methodology; hence, milestone planning is the right approach to a planning process, according to Andersen (1996), who characterizes activity planning as hazardous in the early stages. He argues (op cit.: 89) that "*it is doubtful whether project planners can foresee all the activities at the beginning of the project" and further "the kind of activities that should be undertaken depend on the results, the successes and misfortunes, of earlier activities*", which is in accordance with an LPS principle (Ballard, 2000). Andersen's principal argument for a milestone-oriented start of the planning process should focus on the results that the project is intended to achieve. These results and sub-results should be arranged in the most optimal sequence in order to attain the desired project outcome. His final comment is that the most prominent plan in the project should highlight these matters and not be an activity-based plan that takes the focus away from what is to be achieved.

Based on the theory revealed above combined with findings in the KHiB-case, we present our suggested approach to developing integrated milestones and relate it to other planning tasks. Following our suggested approach (artefact), we will address the KHiB-project for verification purposes.

APPROACH TO DEVELOP INTEGRATED MILESTONES

This study's artefact based on theory and practice is how to conduct a milestone-driven planning process in collaboration with the project's key actors (e.g. the owner, designers, engineers, main contractor, subcontractors). The method is summarized below:

a. Identify all core processes (and dedicate one owner per process)
b. Identify maximum 15-20 milestones per core process
c. Find the logical sequence for the minor milestones in each core process by pull scheduling
d. Identify the network and logical sequence between the minor milestones in all core processes
e. Establish basic process information (input/activity/output/due date) for each minor milestone where the *Output information* should satisfy predefined Conditions of Satisfaction (CoS) such as acceptance, confer Table .

How to conduct a milestone-driven planning process is step two in a sequence of methodological actions. The first is to adapt to a general project management model that many large companies and organizations use. Such a model is normally structured with generic stages and gates that are described in relation to input, activity and required output.

[4] First published in 1993

Subsequent actions, in a more holistic method, will entail initiating planning sessions for the design process (cf. Figure 1) and likewise for implementation of production processes. The need for production sets the premises for deliveries from design and procurement and so on. This implies that the indicated steps must necessarily undergo one or more iterations before the milestone network is in sync with the lead times, etc.

We have conducted a verification of our proposal and present this in the next section.

VERIFICATION: THE PRACTICAL EXAMPLE FROM KHIB

At the inception of the detailed design phase of the KHiB project, the project management decided to initiate the planning process by using methods presented by Porsche Consulting (PC) (Statsbygg & KHiB team, 2017). The basis for the milestone planning session was Statsbygg's project management model with associated main milestones (gates). The project management and the design team deconstructed the project into milestones. Via several iterations, they ended up with milestones distributed over the following core processes: *1. Project management responsibilities, 2. Design., 3. Procurement., 4. End users/equipment., 5. Construction., 6. Quality.,7. Economy.*

The resulting milestone schedule identifies all significant milestones in each core process, and they were placed in their logical order indicating their necessary sequence across the core processes. All the key points were then described in detail in terms of necessary input, necessary activities, expected output and finally a due date. A responsible actor was assigned for each milestone. In Figure 1, we take the KHiB example one step further and illustrate a network of pull-oriented milestones, which is in accordance with the concept of strategic milestone planning referred to (Andersen, 1996). The example is greatly simplified, because of space constraints here, compared to KHIB's original plan, but it still holds sufficient substance to illustrate the methodology.

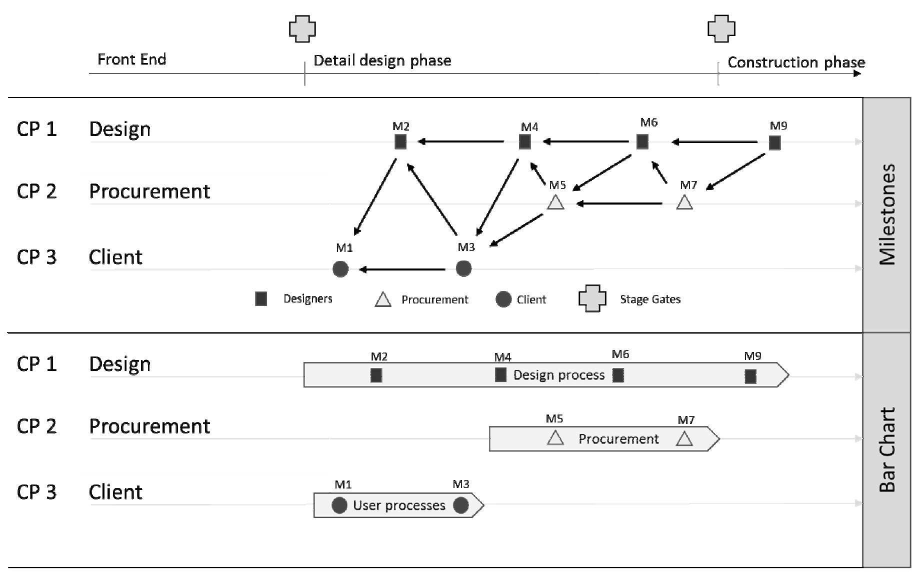

Figure 1: Illustration of a network developed process-oriented milestone plan

In Figure we have illustrated our outline of the proposed method for milestone planning inspired from Porsche takt[5] and the experience from KHiB (Statsbygg & KHiBteam, 2017). To illustrate the concept, the prerequisites for achieving milestone M9 (shop drawings finished) are that M6 (tender material) and then M7 (tender material published) have been completed, cf. the set-up in Table 1 for further details.

We regard the planning process as a societal process in which the significant milestones are identified in brainstorming sessions and by reverse-phase scheduling technique ('planning from the future'). However, some milestones are also push-based within the project context, e.g. finish date in due time before the Christmas sale for shopping malls or before the semester start for schools. Having finished the milestone plan, the slogan in the KHiB-project was "*Well, now we have the key to the project. The next task is to identify all procedures necessary to meet each milestone*". Hence, the milestone schedule is applied as the basis for more detailed WBS-oriented activity planning and scheduling.

Table 1: Milestones – an example, confer Figure

#	Milestone	Input	Activity	Output * (CoS)	Due date
M1	Floor plans approved	Floor plans, Requirements	Assessment meetings	Approved plans	[Date]
M2	Freeze Floor Plans	Approval of plans	Finalize Floor Plans	Frozen Floor Plans	[Date]
M3	Furniture & Equipment approved	Approved Floor plans, Requirements	Assessment of products	Approved furniture & equipment	[Date]
M4	Freeze BIM	All related information	The design process in general	A complete model ready for tendering	[Date]
M5	Tender announced	Approval from client	Announce the coming tender	Tender announced for contractors	[Date]
M6	Tender material	All previous information	Finalize design into tender material	All design related material for tender ready	[Date]
M7	Tender material published	All design material for tender	Establish all documents for tendering	Tender material ready for bidding	[Date]
M8	Contracts established	Contractors bids	Evaluation and selection	Contracts with contractors established	[Date]
M9	Shop drawings finished	Info from contractors	Producing drawings, Quality work	Complete and approved shop drawings	[Date]

The first time the described and illustrated method is applied (Figure and Table), the experience from KHiB indicates several iterations are needed before the desired quality of sequence and interface logic are achieved. The collaborative effort, however, resulted in a solid foundation for learning and developing detailed design, procurement plans and construction plans. Two important findings in this project occurred immediately after the planning of the milestones. The first was that the project members repeated the same pull-based approach in all further planning as a matter of course. The second was that the deconstruction of the planning activities followed a group-oriented and intuitive segmentation. The various design activities were divided into themes named after the most logical topics and assigned to the actor best suited to take responsibility for each theme. Overall, the themes defined and constituted all activities within the design process (other plans were made for the other core processes).

[5]Porsche Consulting

REFLECTIONS

The method we present here expands pull scheduling and the network concept to master-plan level in Last Planner. The pull mechanism itself is not an innovation in this setting; cf. Ballard and Tommelein's (2016) argumentation. What is new is the introduction of the network concept (Andersen, 1996) into milestone planning, and not least, the replacement of pure WBS logic in an early phase with result-oriented planning (deliveries). Of course, in practice planners have always postulated a certain form of network in this context, in that milestones must have a logical sequence; engineering generates input for procurement etc. In the concept we are emphasizing, however, there is a different systemic organization in the approach to network planning for the development of what we have called integrated milestones, and not least in large and relatively complicated projects, we anticipate that it will be able to take project management one step further.

We have used the KHiB project as a source of inspiration and for pending verification of our proposed concept. The milestone plan in the KHiB-project is represented as a large Gantt chart. Even though the project is intended to have a network of milestones, such a network is not explicitly developed. A Gantt chart having a relatively large number of milestones does not visualize structure that emerges in a network diagram. In our opinion, this visualization is important to communicate an understanding to the participants in the project to promote flow, cf. Koskela's (2000) TFV theory. Moreover, we anticipate that an explicit development of milestones in a network based on the LP principle of involvement will yield a better-quality assurance of logical connections and scope than will working in a more linear fashion.

One challenge that must be handled with crystal clarity is to communicate that there must necessarily be a hierarchy of milestones. Most large companies in the field, for example, will have a generic project model as a part of its business plan that lists milestones (gates) at the uppermost level. These kinds of project models are often formulated according to stage-gate logic. Furthermore, when we begin to approach execution, we have to transform milestones into more detailed processes. It is not our intention, however, to discuss this issue any further in the present paper.

The method for developing integrated milestones is generic, but the specific actor(s) who should develop such plans for a specified project will depend on the project delivery model. The KHiB project was a design-bid-build project for which the client's project team developed a milestone plan. This is challenging, in relation to the LP principle of involvement of the executing participants. In such cases, one might perhaps imagine that the client first develops a rough plan, which is then reworked once the executing participants are under contract. Other delivery models with early involvement of contractors provide a better basis for concurrent development of integrated milestones. For example, it may involve different types of collaboration models a team of principal contractor, technical subcontractors and a design team develop a construction project beginning from blueprint level, and not least Integrated Project Delivery (AIA, 2007; Ashcraft, 2012)

Milestones are generally more robust to manage in relation to than are activities, which may change sequence as the building project matures. Although we put most emphasis on LPS in this paper, we see nothing that would prevent more traditional project management from being able to benefit from process-oriented milestone planning.

CONCLUSION

A basic idea in this study is to apply a process approach to creating milestones at the front-end of a construction project, whereas the conventional approach starts up with WBS. The master plan in Last Planner is also based on a conventional approach to milestones, but ideas are present for development in which the pull-concept is included.

Our literature search reveals that the literature in the area of project management is quite deficient and superficial when it comes to development of milestones. However, we find the network approach in a more strategic part of the literature, and we build further on that. Moreover, we intend to think more delivery and less WBS in front-end planning. In addition, we are inspired by the practical world, which in some respects appears to have made more advances than academia in the field concerned.

We place design science research as a basic approach in the present study, and our artefact is our proposal for a new approach to develop integrated milestones for planning and production control. In this paper, we primarily discuss how to conduct a milestone-driven planning process in collaboration with the project's key actors. We place this in a framework that also encompasses an overarching generic project management model with its generic milestones and stage gates, and underlying processes of initiating design and production.

Our proposed method for developing what we define as integrated milestones is verified based on experiences from a relatively large and complicated building project. There is nevertheless a need for further verification and testing. The theory concerning use of pull-oriented network planning as a backdrop for process-oriented milestone planning appears promising.

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EMPLOYING SIMULATION TO STUDY THE ROLE OF DESIGN STRUCTURE MATRIX IN REDUCING WASTE IN DESIGN

Salam Khalife[1], Bahaa Eddine Mneymneh[2], Amena Tawbe[3], Mohamad Hilal Chatila[4], and Farook Hamzeh[5]

ABSTRACT

The design process is a complex and dynamic system owing to the interdependencies of tasks which need to be coordinated between different involved parties. As the design process continues to grow in complexity with the progress of design, and since the early stages are the most complex to manage, this paper proposes the use of the design structure matrix (DSM) to overcome the encountered challenges within the design management process. This study is based on the implementation of the DSM method to manage information flow in the preliminary design of a building project following a traditional design approach. Based on interviews with multidiscipline practitioners, tasks are identified and presented in a Base DSM. To better manage dependencies and improve performance, tasks are re-sequenced in a Partitioned DSM. Accordingly, two simulation models were developed for the Base DSM and the Partitioned DSM. Results show that the flow of tasks in traditional design leads to an increase in the design duration due to negative iterations representing rework in tasks receiving modified input from subsequent activities. Results also show the cyclic dependency between considered tasks and the effect of information change on work progress. This paper concludes by suggesting the application of an integrated design approach to manage the current planning system of the design process at early stages, where intensive coordination is required.

KEYWORDS

Design Structure Matrix, integrated design, work flow, waste, work structuring.

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INTRODUCTION

The design process is a highly complex phase in the project life cycle due to the iterative and generative nature of design (Ballard 2000). Design iterations are of two types, positive iteration (value adding) and negative iteration (non-value adding) (Ballard 2000).Negative iterations are considered as waste and need to be mitigated.Complexity in design is also due to the fact that many design decisions are made independently making the management of work flow between different involved parties highly difficult and expressly important (Ballard & Koskela 1998). This complexity is further accentuated by the interdependencies present between different disciplines within the same organization. Parraguez et al. (2016) categorized the interdependencies in the design process into three domains: the process domain (network of activities), the organization domain (a network of people), and the product domain (a network of components).These interdependencies disrupt the flow of information leading to design errors and time loss. To elaborate more on the process domain, Tuholski and Tommelein (2010) classified three types of activity dependencies: independent/parallel, dependent/sequential, and interdependent/coupled.

Several methods have been used to optimize the design process, improve work flow and reduce waste. The Last Planner System (LPS) was implemented to improve the design processes through managing its variability and improving reliability (Hamzeh et al. 2009; Wesz et al. 2013; Fosse & Ballard 2016). Other methods such as the set-based design and the target value design has been recommended by lean practitioners to support lean design management and decrease negative iterations in design (Ballard 200).Ko and Chung (2014) developed a lean design process to establish an organizational learning environment which enhances timely feedback cycles hence reducing the likelihood of errors occurring. Additionally, the Social Network Analysis (SNA) has been employed in design to study the interdependencies of the design teams and visually understand the interaction and communication between parties (Al Hattab & Hamzeh 2015). To analyse design workflow, Al Hattab and Hamzeh (2016) used an Angent Based Modelling (ABM) approach to study the workflow between design players by integrating both the social and process aspects. This helped in determining the impact of teams' structures on the status of design workflow.

Another tool was recommended by Ballard (2000) to reduce rework in design which is the Design Structure Matrix (DSM). The design structure matrix is a visual tool that represents the different levels of interactions within a system (Eppinger and Browning 2012). DSM is used to plan and improve the execution of complex projects through managing the interdependency between tasks, allowing for a smooth flow of information (Yassine 2004; Tuholski and Tommelein 2010). Browning (2016) reviewed 553 research papers on DSM across a wide range of industries. He concludes that DSM has a strong presence in engineering design and management, yet more work is needed to broaden its applicability. As such, researchers have been studying the effect of DSM in minimizing the complexity of design processes and improving workflow (e.g., Hammond et al. 2000; Yassine and Braha 2003; Hickethier et al. 2012).

However, although previous studies showed the beneficial aspects of using the mentioned tools to improve design, the current practice is still behind in implementing such tools. Our objective in this paper is to reflect on the current practices in traditional design. This paper introduces simulation to help in numerically realizing the need to enhance the design process and minimize the duration of the design phase by adopting efficient tools such as the design structure matrix. Additionally, we aim at showing the need for an integrated design process along with the necessary tools to improve the whole process. This research contributes to the body of knowledge in further proving the importance of better planning the early design phasesto work efficiently and reduce waste.

METHODOLOGY

In order to achieve the aforementioned objectives, the planning and control of the design process for a typical building project at its early stages is assessed. The study consists of four major stages: (1) Acquiring data through a survey with experts, (2) Setting up the Base DSM, (3) Creating the Partitioned DSM, and (4) Employing simulation and identifying improvements.

In the first step, following thorough consultations with practitioners fromvarious disciplines involved in the design phase, major tasks necessary for the completion of the preliminary design stage, and their dependencies, are identified. Then, these tasksare displayed on the Base DSM along with their dependencies. Following many iterations, the DSM was partitioned to identify the tasks' sequence that minimizes feedback loops, which should lead to an improvement in the flow of information and design decisions and will ultimately shorten the duration of the design process by reducing waste.

Finally, using simulation, the Base DSM and the Partitioned DSM are compared, in terms of the duration of the design process. Based on data from the survey, a Task-Based DSM simulation using "Any Logic" is executed to assess the project duration, mainly affected by negative iteration and rework, for the two design strategies. The rework risk factors are influenced by the probability of change in inputs of activities depending from each other and its effect on the project tasks' schedule (Yassine 2004).

Based on simulation results, a comparison between the current practices and the integrated approach is performed to determine the increase in the project duration due to negative iterations. The results helped understand the effect of the integrated approach on the improvement of the overall production process.

BASE DSM: TASKS IDENTIFICATION AND DEPENDENCIES

Interviews were conducted with practitioners from architecture, structure and MEP disciplines from different design consultancy firms in Lebanon. Practitioners were asked to identify the major tasks necessary for the submittal of a residential building project at the preliminary design stage. Respondents participated in the survey are shown in Table 1.

Table 1: Respondents

Disciplines of Respondents	Number of Respondents
Architecture	16
Structure	16
Mechanical	12
Electrical	8

Respondents include 16 architects, 16 structural, 12 mechanical and 8 electrical engineers involved in different types of residential, commercial and industrial projects with an experience range varying from 10 to 30 years in the design field.

First the interviewees were asked to decompose the project into a process that includes the major tasks performed during the preliminary design stage for a building project, each according to his/her own discipline. Based on the collected data, a Base DSM was developed and represented in Table 2.

Table 2: Base DSM

Primary Design Tasks			A1	A2	A3	A4	A5	A6	A7	S1	S2	S3	ME1	M2	M3	M4	E1	E2
Architectural	Plans	A1								3.00			3.00				1.90	
	Sections	A2	2.25		1.75			1.00			2.25			1.00				
	Elevations	A3	2.25	1.75														
	Finishing	A4	1.50															
	Doors & Windows Schedules	A5	2.25		3.00				1.75									
	False Ceiling layouts	A6	2.25	2.25					1.75		1.40			2.25				
	Fire Zoning layouts	A7	2.75														1.25	
Structural	Layout & Sizing of Vertical Elements	S1	3.00			2.25					3.00						2.00	
	Layout & Sizing of Slabs/Beams	S2	3.00			2.10									1.20			
	Location & Sizing of Footings	S3								3.00	3.00							
Mechanical	MEP Shafts	ME1	3.00											1.45	1.00			
	Routing & Sizing HVAC	M2	3.00	1.40							3.00							
	Plumbing	M3	3.00	1.10	1.00								2.00					
	List of Power Req. to Electrical	M4												2.50	1.30			
Elect.	Transformer Rooms	E1	2.75	1.20					1.45							1.75		
	Earth Pits location	E2	2.50									2.00						

The Base DSM shows the traditional arrangement of tasks with respect to each discipline working independently from the other. Given these points, practitioners had also to identify the required inputs and outputs for each activity in order to determine the dependencies between these tasks and to validate their cyclic dependent nature. In addition, Table 2 displays the value of the dependencies degrees of importance between different selected tasks. These values were calculated by finding the average frequency of dependencies between tasks. Three dependency values were adopted and classified in terms of importance as follows: (a) low (L) for values ranging between 1.00 and 1.50 (yellow cells), which mean that the corresponding tasks are low dependent from each other and their relation doesn't not seriously interrupt the flow of information, (b) medium (M) for values 1.50-2.00 (orange cells) representing tasks that are fairly dependent from each other and require reasonable coordination between participants, and (c) high (H) for values 2.00-3.00(red cells)indicating that the corresponding tasks are highly dependent from each other, require intensive coordination between participants, and should be treated as high priority during the design process in order to proceed forward and avoid any potential rework.

For example, activity A1 needs input from activities S1 and ME1 with high dependency and from activity E1 with medium dependency, which means that activity A1 cannot be fully completed without having S1, ME1 and E1 finished first. An empty cell means no substantial dependencies are found between corresponding tasks. The practitioners justified the low dependencies between different tasks as based on incorporating assumptions in design, acquired from what they have learned from experience. These assumptions are resolved during the work progress and the low dependent tasks are reviewed if needed.

To understand further the dependencies between the activities and the necessary outputs and inputs established in the Base DSM, a Spaghetti Graph (Yassine and Braha 2003) was developed (Figure 1).

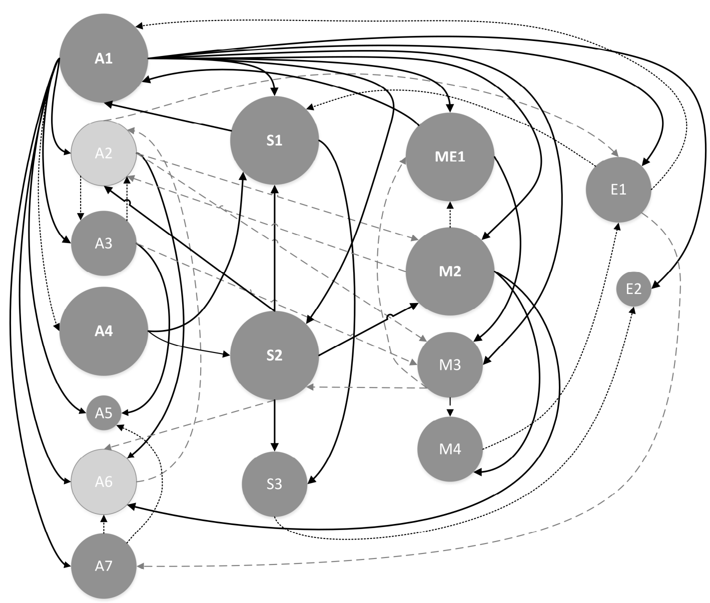

Figure 1: Spaghetti diagram

The different activities are represented as nodes. Arrows connected between nodes show the inputs and outputs for each activity. Arrows are represented according to the importance of dependency: High- continuous line, Medium- dotted line, Low- dashed line.

PARTITIONEDDSM: REMOVING/ REDUCING FEEDBACK

The Base DSM shows activities positioned in the adopted order of performing those activities within each discipline (Table 1). If a time sequence is associated with those activities, then all marks above the diagonal represent feedback loops (Yassine&Braha

2003). This indicates that these tasks are performed with incomplete information where the required inputs are not available at the needed time. Therefore, assumptions are made to complete the activity in the feedback loop. Those assumptions would be revisited as the project progresses and the needed input is available. This would lead to rework if the assumptions made were inaccurate which is considered waste in the time consumed on executing such activity and other dependent activities.

As a result, the matrix needs to be reorganized to remove or reduce feedbacks. This is done through analyzing the medium and high dependencies found above the diagonal which have a high probability in causing rework of other activities. This is known as the partitioning process (Yassine & Braha 2003). After several re-shuffling of activities, the final Partitioned DSM is represented in Table 3.

Table 3: Partitioned DSM

Preliminary Design Tasks		A1	A4	S2	S1	ME1	M2	M4	E1	A2	A3	M3	A7	A6	S3	E2	A5
Plans	A1				H	H			M								
Finishing	A4	M															
Layout & Sizing of Slabs/Beams	S2	H	H														
Layout & Sizing of Vertical Elements	S1	H	H	H					M								
MEP Shafts	ME1	H					M										
Routing & Sizing HVAC	M2	H		H													
List of Power Req. to Electrical	M4						H										
Transformer Rooms	E1	H						M									
Sections	A2	H		H							M						
Elevations	A3	H								M							
Plumbing	M3	H				H											
Fire Zoning layouts	A7	H															
False Ceiling layouts	A6	H					H			H			M				
Location & Sizing of Footings	S3			H	H												
Earth Pits location	E2	H													M		
Doors & Windows Schedules	A5	H									H		M				

Major Coupled loop

DISCUSSION

The Partitioned DSM helped in identifying the sequential, parallel, and coupled tasks. Note that the Partitioned DSM may not show the optimal sequence of tasks, but it aids the process in reducing iterations. The iterative loop(Table 3) is more confined compared to the disarranged loop covering the whole Base DSM (Table 2). Amajor coupled loop was found which includes 8 activities (A1, A4, S2, S1, ME1, M2, M4 and E1). Those activities are related to all four disciplines which indicate the need of upfront coordination across functional teams at the beginning of the design process. The loop which includes tasks with high dependencies represents a cluster where design integration between people in charge is needed. This will help in executing the necessary tasks while completing the activities with minimal time and least rework. Relating it to the Spaghetti Graph, six of the eight activities included in the loop were represented as big nodes indicating high interdependencies.

The A1 activity (plans), having highest number of outputs required for the completion of other activities (13 outputs), needs input from 3 activities (S1, ME1, & E1) from the structural, mechanical, and electrical disciplines. In return those 3 activities are also dependent on other activities; therefore, all shall be included in the same loop called the iterative loop. The iterative loop represents a loop of information flow that require people having input/output within this loop not to work independently. To that effect, empty cells represent tasks that can achieved following the traditional design approach, while filled cells require the need for collaboration between the relative involved parties. Another coupled loop includes A2 and A3 activities (sections & elevations) is found where several iterations are required between these two activities during the design process.

Therefore, what was remarkably observed while interviewing the practitioners is that architects who were not using the latest industry's technologies were more concerned and keen to identify dependencies, while others who were using BIM, Revit as an example, were more hassle-free relying on such tool to facilitate dynamic and efficient coordination. Therefore, implementing a combination of DSM and BIM during the design can be useful in organizing design activities and allowing for proper coordination.

Moreover, coupled loops may seem confusing for design teams since they cannot work independently. On the other hand, coupled loops help create value through aiding integrated teams spur innovation. Set-based design can implemented in the coupled loops where coordination and collaboration between the involved parties, within the coupled loop, facilitate building consensus for the considered alternatives. This approach consists of keeping alive multiple alternatives until the last responsible moment in order to come up with a better design decision, rather than rushing into choosing one alternative. This thus reduce rework and time wasted on distant back and forth information exchange.

The preliminary design stage involves critical decisions taken during the design process. In addition, cost for changes is the lowest in the early stages of design but builds up fast as the design progresses as per the Macleamy curves (Macleamy 2004). Failure to achieve a high level of collaboration leads to waste in both time and resources. Such waste is mainly due to the rise of design errors and the corresponding relevant rework, all affecting the quality of deliverables and clients value.

SIMULATION RESULTS

The simulation is based on the preliminary design process of a ten-story residential building project using "AnyLogic". The original durations of each activity are based on the initial estimate of design practitioners and are summarized in table 3. Accordingly, the total required duration, or value adding duration, is equal to 51 days. Two simulation models are created to assess the actual required duration of the design process, based on the sequences in the original and Partitioned DSM.

Table 4: Durations (days) of the design activities

Task ID	Duration	Task ID	Duration	Task ID	Duration	Task ID	Duration
A1	12	A5	2	S2	5	M3	2
A2	5	A6	2	S3	2	M4	1
A3	4	A7	1	ME1	3	E1	2
A4	3	S1	4	M2	2	E2	1

The simulation models are based on the assumption that a task requiring input from a preceding activity is completed based on assumptions made by the designer. If the assumption proves to be inaccurate, the task would have to be rechecked. Thus, rework occurs in tasks receiving modified input from subsequent activities. For example, activity (A1) depends on activity (S1) but is completed before it. If a change occurs in (S1), some rework for (A1) is required. In the simulation models, and according to practitioners, changes resulting from a strong dependency will induce a rework equal to 20% of the original duration of the activity, while changes resulting from a medium dependency will induce a 10% rework. As for the probability that a change occurs, this value is high for the first design iteration (80%), and low (20%) for the remaining iterations. In “AnyLogic”, the simulation models are conducted as per the layouts presented in Figures 2 and 3.

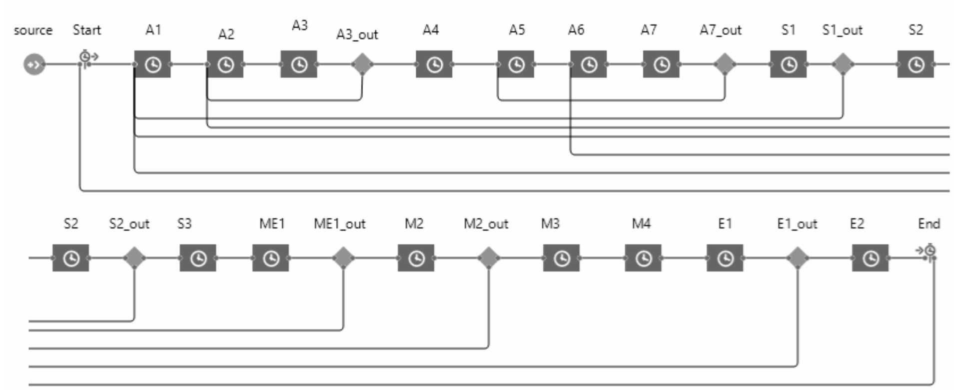

Figure 1: Simulation model for the Base DSM

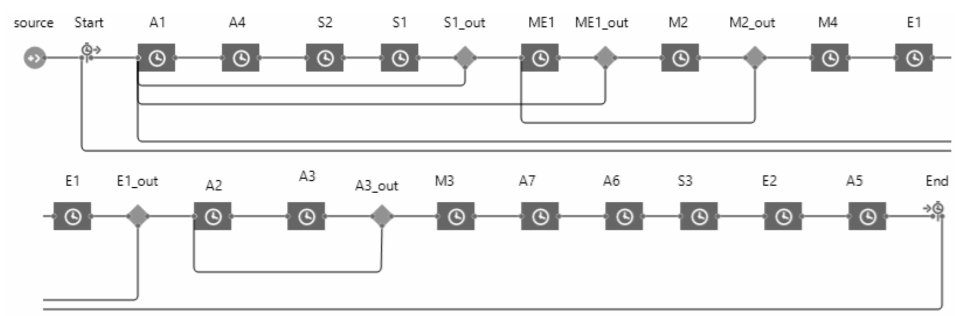

Figure 2: Simulation model for the Partitioned DSM

The interdependencies between activities are identical, while the tasks are sequenced according to the Base and Partitioned DSM. 23 variables are used to allow for the modelling of the possible changes in the durations of activities, and the probabilities of rework. For example, the duration of each activity (A1) (Figures 2 and 3) is equal to its original duration (12 days) multiplied by the variable representing the amount of required work for this activity (V_A1) which is originally set to 1. When rework is required for activity (A1), changing the value of (V_A1) allows for the determination of the actual duration of this rework. “TimeMeasureStart” and “TimeMeasureEnd” blocks are utilized to calculate the total duration of the design process.

The effect of the Partitioned DSM on the reduction of the number of feedback loops is clear in the two models. It is important to note that the simulation model is a representation of the actual amount of work required, rather than the actual duration of the design process, since some activities may overlap. However, the interest of this study is to identify waste and negative iteration in design, which are based on the actual amount of work, not the total duration of the design phase.

Based on results from 1000 runs of the two models, the average number of workdays of the preliminary design phase was equal to 93 days for the Base DSM, and 66.4 days for the Partitioned DSM (Figure 4), compared with duration of the value adding activities, equal to 51 days.

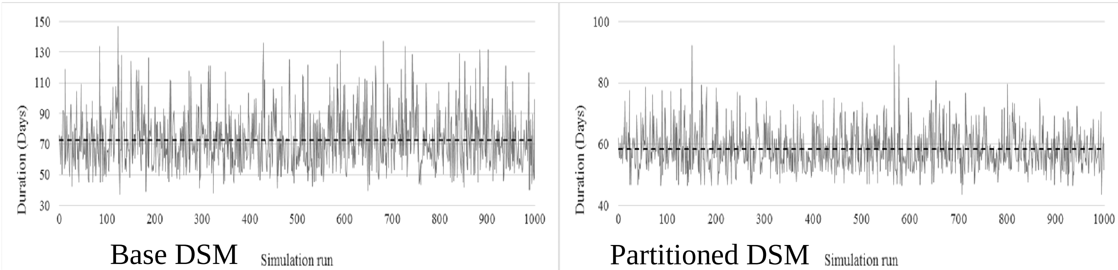

Figure3: Duration of the design phase in Base DSM vs Partitioned DSM

However, even in the model of the Partitioned DSM, a high degree of variation in the calculated duration between runs exists. This is mainly due to the iterative nature of the design process. The minimum possible duration output, equal to 51 days, occurred only once in the 1000 runs, whereas the highest calculated duration was equal to 101.1 days.

CONCLUSION

The findings of this study show that design tasks in the traditional practices are executed based on sequential pattern of dependencies ignoring the iterative nature of the design process. The study reveals the importance of planning design tasks based on the design structure matrix DSM to minimize loops and reduce negative iterations which usually cause waste in design. The main idea of this study is to depart from the practitioners' traditional practices of executing tasks without involving downstream players and to promote a restructured design management process allowing for more coordination. The simulation results highlighted a 45.2% of waste in the design phase due to rework in tasks receiving modified input from subsequent activities. This percentage can be decreased to 23.2% by adopting an improved sequencing using the DSM. However, waste in design may still occur. This creates a sense of urgency to adopt an integrated design process due to the intensive exchange level of information during the early phases of the design process. Future research will aim to develop an implementation plan and assess its effect on shortening the duration and reducing the cost of the whole project.

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USING TAKTPLANNING AND TAKTCONTROL IN PRODUCTION PROJECTS – COMPARSION OF CONSTRUCTION AND EQUIPMENT PHASES

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ABSTRACT

Takt Planning and Takt Control (TPTC) as a method for construction processes shows the potential for improving time aspects of construction sites in many practical examples. A first example of using the method of TPTC not only in construction but also in following processes such as equipment installation (production projects) indicates equal improvements. By analyzing 10 construction and seven equipment installation case studies, this paper gives an overview of similarities and differences in construction and equipment projects. Furthermore, it describes adjustments for using TPTC in the construction stage as well as in the equipment assembly stage and picturing each stage's timetable in one common Takt Plan for increased clarity. Interlinking planning phases of both stages shows not only, that further time savings in implementation phases can be realized, but also that overall project planning can benefit from considering interfaces to upstream and downstream phases.

KEYWORDS

Lean construction, lean equipment, comparison, process, work flow.

INTRODUCTION

The stages of construction projects have many interfaces to preceding and successive stages. For example, after completing a building for industrial production, assembly of

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the equipment needed for the building's end-use will begin. Thereby construction projects aim at assembling the structure of the building itself, while consecutively assembly lines and production equipment is installed in an equipment installation projects. In Dlouhy et al. (2017b) the authors use a case study project to show that the Lean Construction methods of Takt Planning and Takt Control (TPTC) (e.g. Binninger et al. 2017) are also applicable in assembly of production equipment and have similar advantages in terms of time, cost and quality compared to classical approaches (e.g. Oprach and Dlouhy 2017). In contrast to this, customers using a separate uncoupled design and execution process for the individual phases lose a large proportion of this potential. The high-level use of TPTC as an integral part of process planning and the Takt Plan as central instrument of time planning leads to an improved understanding between both stages. Experiences from planning equipment assembly projects show that using TPTC during the stage of equipment assembly is not possible without adjustments to the method and taking into account the particularities of these projects.

This paper will use data from real case study projects to show differences and particular characteristics differentiating both stages and provide a resource for preparing a common Takt Plan for both project stages.

THEORETICAL FOUNDATIONS

While TPTC is a well-known and well-established method(e.g. Frandson et al. 2013; Binninger et al. 2017; Kaiser 2013). for steadily planning and executing construction projects in the meantime, it is practically not used in equipment ventures, yet. Although a timely finish of equipment projects is crucial for the start of production and therefore decides over considerable losses of profits for principals, research rather focuses on savings through maintenance strategies instead of plannable and steady installation processes. The Takt Plan is the central scheduling tool for successful application of the Lean Construction methods of Takt Planning and Takt Control. Compared to others such as the Gantt-Chart, the Takt Plan shows more information while using less space and giving greater oversight (e.g. Oprach et al. 2018 p. 210).

Aside from information about which subcontractor executes which works at what time, the Takt Plan also shows the exact location of value creation. Figure 1 shows a typical Takt Plan, for which the additional dimension of location can also be shown in a path-time diagram.

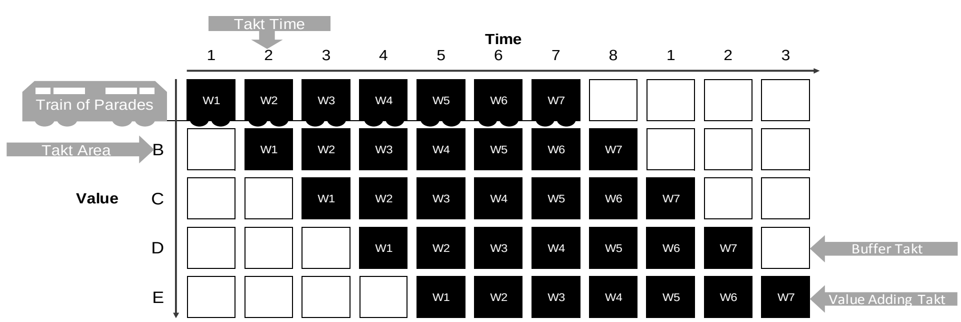

Figure 1: Example Takt Plan with typical elements (author generated image)

Using Takt Times, the x-axis shows the time dimension of the Takt Plan. Depending on the project conditions, a Takt Time can have duration from a few minutes (e.g. Dlouhy et al. 2017a) up to one week. Experience has shown that in construction projects the Takt Time generally lies between one day and one week.

The y-axis shows the spatial dimension of the Takt Plan through division of the construction site into Takt Areas (A to E in figure 1). Dividing the project into smaller entities allows more detailed planning of the works to be completed as well as simplified progress monitoring during execution. Planning of equipment assembly projects has shown that the Takt Areas are not limited by the spatial dimension, but rather other logistical factors of the construction site such as machine components or functions.

With the wagons (W1 to W7 in Figure 1) of a work train, the information about the work to be completed (who) and the applicable activities (what) are recorded in the Takt Plan. Using a legend, it is simple to show which works are part of which wagons. The associated subcontractor can either be recorded in the legend or through color-coding of the wagons.

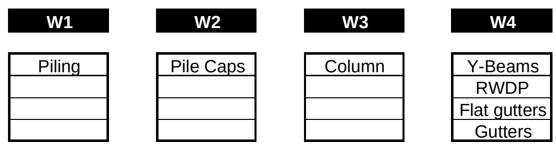

Figure 2: Legend with example of information on works to be completed in each wagon (Author generated image based onDlouhy et al. (2016))

The exact method for preparing a Takt Plan is described step by step by Binninger et al. (2017) for construction projects and by Dlouhy et al. (2017b)for equipment assembly projects. Both publications show the project planning process is different for both project stages. The exact nature of these differences will be described in this paper based on their characteristics and data from real projects.

While construction projects can usually be divided into the three phases of shell construction, fit-out and commissioning, equipment assembly projects are divided into the phases of mechanical installation, electrical installation and final phase of commissioning. For time-efficient design of a building and equipment assembly plant, seamless integration of the three phases of each project stage is necessary. In terms of the overall planning of the complete project, a uniform direction of construction and principles should be used in both sectors. A uniform direction of construction allows time to be used effectively. Using uniform principles such as fluid working groups, takt principles, needs-based supply of materials and short-cycled defects inspections creates security and understanding on both sides.

Comparison of 17 case study projects – 10 construction projects and seven equipment assembly projects – shows the differences between the two project types due to their own specific values. In some cases, equipment assembly projects are projects which followed directly after construction projects which are also part of this study. This allows comparison in terms of identical conditions in terms of surface area as well as in terms of cultural and climatic factors.

There is a large difference between the project categories in terms of costs. For example the cost of production facilities in automobile plants is many times more expensive than the cost of the building (e.g. Wiendahl et al. 2014 p. 528).

METHODICAL APPROACH

In the construction industry Takt Planning and Takt Control are established process planning methods and have been used to successfully complete many projects for varying types of customers. The potential for their use in equipment assembly has also been proven in a number of projects(e.g. Dlouhy et al. 2017b; Oprach and Dlouhy 2017).In this research, focus lies on comparing data to investigate differences in how TPTC is applied. This will show advantages of construction industry according to hard as well as soft factors which can be applied to equipment assembly projects. Apart from measurable savings in construction time while using the same materials and therefore constant costs, quality of completed works is at least equal. Moreover, using TPTC in construction projects also improves construction process by increasing stability and providing greater certainty in planning. The main reason for this is the detailed planning of works and easily understandable display of information using the Takt Plan. A basic condition for successful implementation of TPTC in equipment assembly is therefore to adapt the Takt Plan to the needs of these works.

Underlying Projects are all realized by an industrial principal in several different countries in Europe, North- and South-America, as well as Africa. While some of them were already terminated, others were in the process of construction or not yet started by the time of data acquisition. Table 1 shows a selection of TPTC-specific data gathered from the projects' Takt Plans in their latest version, respectively. By understanding the characteristics of each project stage first, commonalities and differences are being derived to find a possibility for representing both stages in one common Takt Plan.

Table 1: Comparison of selected attributes of construction and equipment assembly projects

Attribute	**Construction Projects**			**Equipment Assembly Projects**		
	Avg.	**Min.**	**Max.**	**Avg.**	**Min.**	**Max.**
Takt Time [d]	4.4	0.5	6.0	1.7	1.0	3.0
SSU [m^2]	302.4	9.0	360.0	47.9	14.0	100.0
SSU [#]	93.9	10.0	289.0	119.1	14.0	600.0
Takt Area [m^2]	1200.0	35.0	3000.0	128.1	36.0	350.0
Takt Area [#]	16.3	3.0	34.0	22.4	9.0	36.0
Wagons [#]	15.3	7.0	29.0	16.0	6.0	33.0
Trains [#]	1.5	1.0	3.0	5.9	1.0	15.0
Work Packages [#]	38.6	7.0	116.0	22.6	16.0	36.0

Function Areas [#]	2.5	1.0	5.0	1.7	1.0	5.0
Partial Handover [#]	0.9	0.0	3.0	0.0	0.0	0.0
Work Takts [#]	239.3	19.0	719.0	642.4	165.0	2092.0
Buffer Takts [#]	328.7	8.0	1253.0	1239.7	20.0	4462.0

Table 1 shows the average values of typical TPTC attributes recorded for the selected construction and equipment assembly projects. A short Takt Time as well as many Takt Areas, Wagons and Trains in both project parts mean a high level of planning and coordination effort for the construction manager. This generally requires comprehensive pre-considerations during planning to consider all dependencies. This usually leads to complicated schedules preventing potential time savings and reductions in complexity.

Through dividing the construction site into Takt Areas, and planning on this basis, dependencies must only be considered in smaller entities which can later be synchronized between the Takt Areas. When considering an entire project, synchronization between the dependencies of individual phases and between the two project stages also occurs.

As was shown in Table 1, the two project parts have different characteristics. Therefore, it is necessary to better understand the different characteristics of the two project types in greater detail:

- While the Takt Time of construction projects is 4.4 days on average, at 1.7 days it is less than half as long in equipment assembly projects.
- The smallest replicable unit (Standard Space Unit SSU see (Binninger et al. 2017)) of equipment assembly projects is many times smaller than in construction projects. This influences the dimensioning of Takt Areas.
- Equipment assembly projects therefore have more SSUs within each phase than construction projects.
- The Takt Areas of equipment assembly projects cover less space than construction projects. A phase of equipment assembly is on average made up of a higher number of Takt Areas than the equivalent phase of construction. This means that a simple construction project quickly results in a complex equipment assembly project which requires greater coordination effort. This is demonstrated in Figure 3.
- The average number of wagons is comparable in both types of project.
- An average equipment assembly project has almost four times as many trains as an average construction project.
- On average construction projects have 38.6 work packages, which is more than the average of 22.6 work packages in equipment assembly projects. Therefore, the smaller Takt Areas have less work packages per area.
- The construction projects investigated were divided into more functional areas than the equipment assembly projects.

- After completion, the equipment assembly projects were handed over in full, or no partial handovers were recorded. According to the analysis, partial handovers of parts of the project took place in the construction projects
- Equipment assembly projects are made up of many different Takts. In both types of project the number of Buffer Takts is higher than the number of Work Takts. However, the proportion of Work Takts is greater in construction projects.

The random sample used for this research is relatively small with 10 and seven projects for construction and equipment assembly projects respectively. This means it is not possible to make generalizations from the available data. Nevertheless, possible tendencies do appear. The difference in time and value dimensions is particularly noteworthy. This makes showing all works in the same Takt Plan difficult.

Time can be shown in a common Takt Plan provided that the different Takt Times are shown to scale and the spread of the Takts along the y-axis is differentiated by project stage.

Showing the Takt Areas is considerably more difficult as the Takt Areas do not necessarily align between the project types. In the analyzed projects these differ from one another. While the Takt Areas in construction projects are usually defined by building characteristics such as storeys or walls, in equipment assembly they are frequently defined by steps in the production sequence. Allocating these is less defined by spatial areas and more by steps in value creation during production. Figure 3 compares the Takt Areas of both project types according to the study by Dlouhy et al. (2017b).

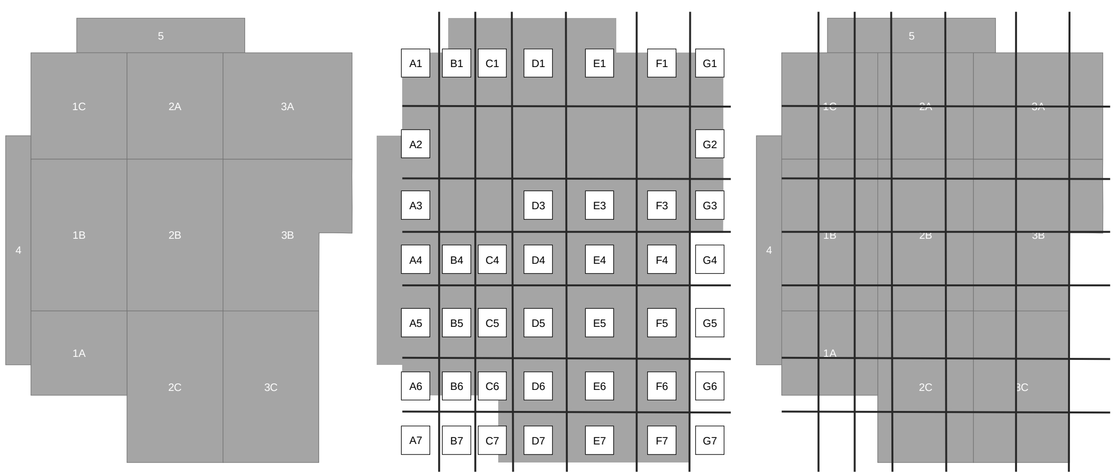

Figure 3: representation of the different Takt Areas of Lean Construction (left) and Lean Equipment (middle) and an overlay of both Takt Area boundaries (right) in the same project (author generated image)

A Takt Plan which is able to provide a common overview of the different project stages must be able to show these both in terms of time as well as in relation to value creation from different parts of the plan. Figure 4 gives an example of such a Takt Plan. Due to dependencies, the two project stages cannot work on the same parts of the project area at the same time. For this reason, it is possible to modify the time scale of the y-axis between the two project stages. However, this is not recommended as this compromises readability and simplicity. From the example in Figure 4 it is immediately recognizable that the Takt Time of equipment assembly is exactly half that of the Takt Time for construction. This connection is easily visible, but as per the data collected, it is not the norm. Other relationships to the Takt Time are more difficult to show. Using uniform horizontal sizing of Takts despite different Takt Times must be avoided, so as not to distort the time dimension of the Takt Plan.

On the x-axis, the Takt Areas of the succeeding project area is simply added as additional Takt Areas and the list is updated accordingly. In the ideal case, the Takt Areas of each project part are also uniform to give greater readability, so that the progress of works is easily visible and can be read without additional effort. However as was shown in Figure 3 and discussed above, this is seldom the case in reality.

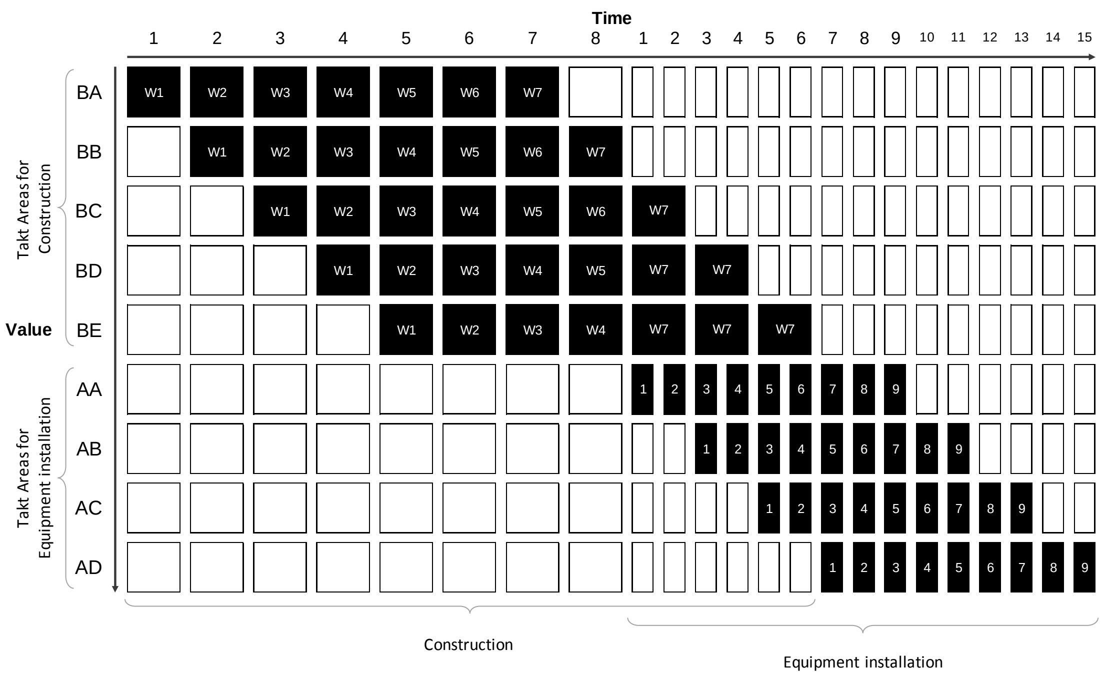

Figure 4: uniform representation of the two project stages in a higher level Takt Plan. There is a small buffer between stages due to different Takt Areas being used for each stage (author generated image)

Planning of both construction and equipment assembly projects can be completed individually for each stage. Additionally, the two Takt Plans can be joined to give an overview of the entire project and possible conflicts can be resolved.

As can be seen in Figure 5 (left image), conventional planning considers each project stage and phase in isolation. The direction of construction and principles used differ for each. Overlaying the Takt Areas, as was seen in Figure 3, supports greater understanding of the spatial layout and questions: what is the direction of construction? Which areas are handed over first? For equipment assembly, it can be determined which construction Takt

Areas can be used for early delivery and storage of tools and materials, or where the first equipment assembly works can take place. Conversely, participants in construction projects can use the equipment assembly Takt Plan to determine which areas should be prioritized, and which areas only need to be handed over for equipment assembly at a later point in time. The definition of construction direction can be standardized by overlaying the Takt Areas (see Figure 5, middle image). The Takt Plan can use the knowledge gained from the overlaid Takt Areas to form a standardized schedule. Through the complete depiction of all activities broken down according to space and time, the same principles can be applied to each project phase (right image).

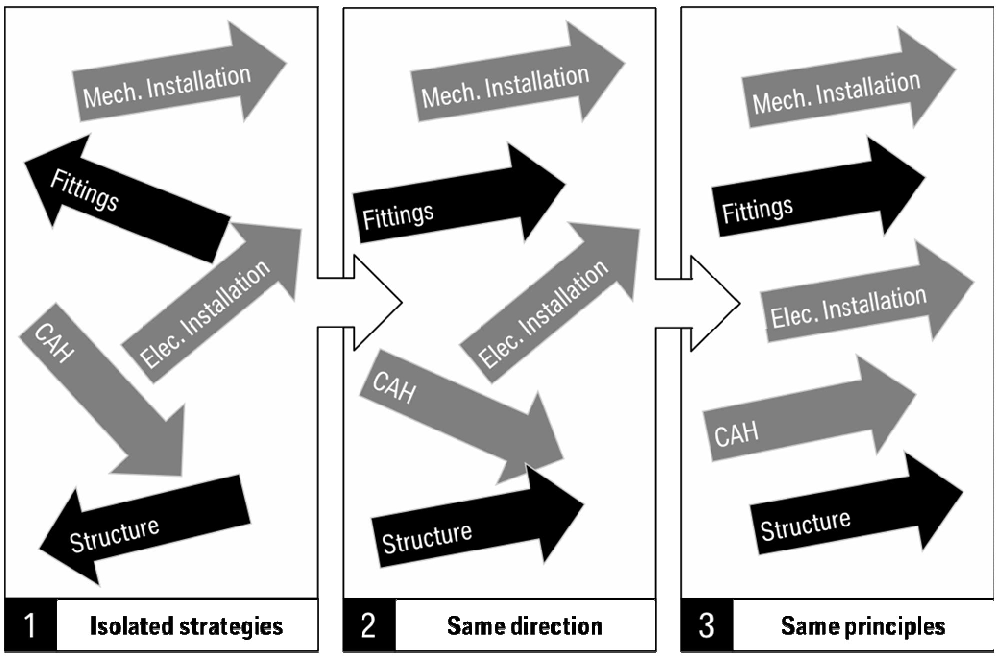

Figure 5: Advantages of a common understanding between construction and equipment assembly activities (author generated image)

DISCUSSION AND CONCLUSION

Investigation of the 10 construction projects and seven equipment assembly projects has shown the similarities and differences between the two project types. However, due to the small sample size no generalizations can be made. Despite this, the investigation shows that while joint planning of construction and equipment assembly works does not require synchronization of Takt Areas and Takt Time, it strongly simplifies planning and execution. Dialog between planners from both project stages is important to provide a common understanding of the sequence of works, and to guarantee measures with positive effects on the overall project such as earlier access to prioritized Takt Areas will occur. Apart from this, the knowledge gained could be used to prepare a new method for visualizing project information. Its use is considered a combined approach for Takt Planning and Takt Control in project planning to enable the project stages of construction and machine assembly to be shown together. As the companies involved are usually not active in both areas, this form of planning is mainly interesting for customers and their designers. With the help of a higher level Takt Plan, the construction direction as well as the use of common principles is possible. Hereby execution can be completed seamlessly with virtually no unexpected surprises. For TPTC to be applied as profitably as possible for all subcontractors involved in a project, the methodical approach must be developed which applies not only to construction phases, but also those that precede it.

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DEMONSTRATING THE VALUE OF AN EFFECTIVE COLLABORATIVE DECISION-MAKING PROCESS IN THE DESIGN PHASE

Annett Schöttle[1], Paz Arroyo[2], and Randi Christensen[3]

ABSTRACT

Decisions are the foundation for creating value in a project. Particularly in the early design phases, decisions form and restrict the value creation processes throughout the project's life cycle Therefore, project teams should pay attention to the decision-making process, and design it to secure maximum value creation and clear documentation. This paper shows and analyses the decision-making process in the design phase of four different projects based on four characteristics: (1) decision-making method, (2) structure of the decision-making process, (3) governance process, and (4) documentation process. Our findings demonstrate that all four characteristics are essential and need to be considered when designing the decision-making process. Furthermore, the results demonstrate that making decisions collaboratively will lead to value adding opportunities. Consequently, this paper explains how the decision-making process affects the value creation process and gives insights on how to design it in an effective manner.

KEYWORDS

Choosing by Advantages, collaboration, decision-making, integration, value

INTRODUCTION

“A decision is a choice made from among alternatives proposals, and the consideration of these proposals constitutes all parts of the group’s task performance” (Ellis and Fisher 1994). “It is a product of the cognitive processing of information, norms influencing the nature of social interaction, the skills, traits, and dispositions of individual group members” (Guzzo 1982). Both quotes show the complexity of group decision-making. In the Lean Construction community, many papers have been published understanding and explaining the concept of value (see Salvatierra-Garrido et al. 2012; Table 1). In comparison, searching for terms such as ‘decision’, ‘decision-making’, or ‘decision-making process’, in the title, abstract, or keywords of the last 25 years IGLC papers results in fewer findings, and the combination of those with ‘value’ leads to almost no

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results. If the term 'decision making method' was insert, it always lead to articles on 'Choosing by Advantages' (CBA).Moreover, Salvatierra-Garrido et al. 2012 analyzed IGLC papers from 1996 to 2011 and identified 52 papers to have a deeper look into the conceptualization of value. Only one of those papers were related to the design phase. A paper written by Tzortzopoulos and Formoso (1999) already pointed out the importance of the decision-making process in the design phase. Nevertheless, there is little research about the value creation through decision-making processes in the design phase.

Table 1: Hits per terms from IGLC papers 1996 to 2017 (1433 total papers)

Terms	**Hits**	**%**	**combined with 'value'**	
			Hits	**%**
value	450	31,40	-	-
decision	187	13,05	9	0,63
decision-making	47	3,27	3	0,21
decision-making method	7	0,49		
decision-making process	13	0,91		
CBA	14	0,98	**0**	**0**

We argue that how the project team decides on design alternatives is crucial for the project's success. The decision-making process makes the foundation for the creation of value for the client and sets the standard for how efficiently the supply chain will be able to deliver. To further explore this, the research consists of a literature review and a cross-case analysis to answer the following research questions: (1) What creates value in the decision-making process? (2) What is needed to make decisions effectively? (3) How should the decision-making process be designed? Based on the findings, the research questions will be discussed, and conclusions will be drawn.

LITERATURE REVIEW

EFFECTIVE GROUP DECISION-MAKING PROCESS

A group decision requires the involvement of all team members to increase the decision quality and the commitment to implement the decision (Johnson and Johnson 2009). Johnson and Johnson (2009) define five major characteristics which impact the effectiveness of a group decision: (1) the resources available to the group are fully utilized (2) time is well used, (3) the decision is correct or of high quality, (4) the decision is implemented fully by all required group members, and (5) the problem-solving ability of the group is improved, or at least not lessened. Therefore, (6) communication among the team members is essential for effective group decision to be made (Hirokawa 1990), and (7) coordination of interdependencies, goals, information, and perspectives sharing among team members is necessary (Kolb and Boos 2009). Moreover, Van Wee and Priemus (2017) state that the democratic quality of a group decision increases if the process is "based on an [(8)] adequate method and in a neutral, independent way, making clear what the impact will be of each alternative" (Van Wee and Priemus 2017). Other factors impacting the effectiveness can be clustered in (9) type and characteristic of decision task like structure, information requirements, and the evaluation demand (Hirokawa 1990), (10) characteristics of the process like available information resource, quality of the effort to come to a decision, decision logic (Hirokawa et al. 1996), conflict management, individual incentive (Johnson and Johnson 2009), (11) characteristic of the team members like personality (Ellis and Fisher 1994), relevant skills, uncritically dominant responses, egocentrism, production blocking (Johnson and Johnson 2009), thinking quality (Hirokawa et al. 1996), (12) characteristic of the group like group size, lack of group maturity, sufficient heterogeneity (Johnson and Johnson 2009), and (13) group phenomenon like social loafing, free riding, sucker effect, concurrence seeking, or cognitive dissonance (Johnson and Johnson 2009).

Based on the listed aspects it gets obvious that group decision-making requires a well-established process that considers certain social and structural factors, because they are affecting the input, process, and the output of the decision. However, the big advantage of a group decision-making process is the increased quality and acceptance of the decision (Johnson and Johnson 2009).

VALUE OF IMPLEMENTING CHOOSING BY ADVANTAGES (CBA)

Decision-making methods impact the result of the decision (Dean and Sharfman 1996; Schöttle and Arroyo 2017) and therefore it is important to implement a method which supports the process. Decision-makers often use a cost-benefit analysis to decide between alternatives. This can be problematic because "[c]ost-benefit analysis covers efficiency and effectiveness (...) but not fairness, but it was never designed to do this. (...) [This implies] that if ethical issues are at stake, a cost benefit analysis alone is not sufficient in preparing decision making" (Van Wee and Priemus 2017). CBA is a multi-criteria decision-making method that, based on an anchored judgement, compares the advantages of alternatives (Suhr 1999). Different studies have compared CBA to other decision-making methods such as weighting rating calculating (WRC), or analytical hierarchical process and presented the benefits of CBA over those methods (Arroyo et al. 2014; Schöttle and Arroyo 2017). For example, Arroyo et al. (2016) did a practical experiment and found that the teams achieved faster consensus and felt less frustration by using CBA in comparison to WRC. Based on high detailing manner, much effort is needed upfront to develop the decision and discuss intensively the advantages of the alternatives. This leads to constructive debates, a better understanding of what is wanted, less misinterpretation, and a very transparent process (Schöttle and Arroyo 2017). Some studies have already discovered those effects for design decisions (Arroyo et al. 2014; Kpamma 2016).

RESEARCH METHOD FOR CASE STUDIES

The authors used case study research and action research as strategy in dependence of the project status. The case study research was used to get a better understanding of the decision-making process in construction projects, because it allows researchers an in-depth investigation of a particular issue (Yin 2014). Action research is used when the researcher investigates an issue and takes action in the project based on the findings

(Dickens and Watkins, 1999). Table 1 shows which strategy and methods were used to collect and analyze the data. In Case 1 and 2, interviews were conducted from October to November 2014. The interviews were transcribed and analyzed using qualitative content analysis based on Mayring (2010). Case 3 and 4 are ongoing projects. The researchers used action research that involves surveys, discussions, mails, meeting evaluation, and observations to generate direct feedback to intervene in the process. In case 3 the research was collected by the Lean Manager on the project. In case 4 the data was collected by the CBA expert of the project.

Table 1: Research methods of the case studies

Case	Location	Status	Research strategy	Data collection	Data analysis
(1) UCSF Mission Hall	San Francisco	completed	Case study	documents, open-ended interviews	Qualitative content analysis
(2) UCSF Medical Centre	San Francisco	completed	Case study	documents, open-ended interviews	Qualitative content analysis
(3) Lower Thames Crossing	London	ongoing	Action research	Surveys, meeting evaluations	Grounded Theory
(4) IT Campus Project	San Francisco	ongoing	Action research	observation, documentation, interviews	Grounded Theory

CASE STUDIES

Table 3 gives an overview of the four case studies.

Table 3: Overview of the case studies

Case	UCSF Mission Hall	UCSF Medical Center	Lower Thames Crossing	IT Campus Project
Project type	Public	Public	Public	Private
Project characteristic	Office Building	Hospital	Tunnel and connecting roads	Office Building
Project completion	November 2014	February 2015	Planned 2027	Planned 2019
Construction documents	August 2012 - February 2013	January 2009 - August 2010	Preliminary design started 2017	Preliminary design started 2015
Project budget	US$ 93,8M	US$ 1,52B	US$ 6 - 8.6B	Unknown
Co-location	Yes	Yes	Yes	Virtual
BIM	Yes	Yes	Yes	Yes
LPS	Yes	Yes	Yes	Yes

CASE 1

UCSF Mission Hall is an academic office building located at the UCSF Mission Bay campus in San Francisco that opened in September 2014. The building contains mostly open and activity-based workstations, a conference center as well as classrooms at the first level and a cafe. Major design decisions were made during the tendering phase in which the DB team had to develop the design. However, during the design phase decisions had to be made very fast because of the schedule. Therefore, major actions of decisions were tracked with the LPS. Priorities in the decision-making process were quality and the project being delivered within budget. Depending on the issue, decisions were made sometimes collaboratively and sometimes from the top-down, such as a decision that resulted in a design change. The team used A3 reports to decide between alternatives in the design phase. The A3 reports summarized issues, the background, current conditions, an analysis using 5 Whys, target conditions, the proposed countermeasures, and the implementation plan showing the status of the decision with due date and contributors. Interviewees stated that CBA was used in those A3 reports, but this wasn't the case. Decisions were made based on defined advantages and disadvantages of alternatives. The cost of every alternative was displayed. Other decisions were made in meetings through discussion about the work scope and costs in the team. Subcontractors often prepared data sheets, presented alternatives and indicated a suggestion. One interviewee described the decision-making process as follows: "We just sat in that room, we decided what the best options were [and] we ran over options, which we thought would be the best." Other interviewees described the decision-making process as a negotiation to find the best solution. The team was aware that decisions contained lots of information from different individuals because of interdependencies. Therefore, the scope between the participants needed to be balanced and the cost impact considered. Not always was the right team member in the room to proceed with the decision, because of a lack of manpower, which was inefficient. Nevertheless, the team managed to make decisions on time. In the OAC meeting, alternatives were discussed with the owner and the owner made the final decision.

CASE 2

The UCSF Mission Bay Medical Centre is a complex building which consists of hospitals specializing in children, women, and cancer, and an energy center. The hospital opened in February 2015. At the time, the team co-located on site in June 2009, 95% of design development was completed. The public project consisted of many challenges. One challenge was to design just enough to get the permit, with the knowledge that the design will change based on the evolution of the equipment, because the technology in the healthcare industry is changing rapidly. To handle the ideas and innovations and to work productively through the design phase, the team developed a decision-making process to make timely decisions at the lowest responsible level. The decision-making process consisted of four hierarchical levels: (1) individual cluster group, (2) captains level, (3) senior leadership principles, and (4) management committee. The cluster group consisted of the eight divisions: site, structural, exterior wall, M&P, electrical/ low voltage, special systems, interiors, equipment, and focused on the technical issues. They interacted, discussed, negotiated, and traded targets to move forward and meet the budget. If ideas turned into alternatives, they were documented, shown to the affected party, and recommendations were collected from all corresponding parties before making the decision. The responsibility of each decision-making level depended on the amount of money a decision contained. If a decision couldn't be made at a low level or an amount of money was exceeded, the decision got escalated to the next hierarchical level. For example, the cluster group was limited to decisions of up to US$ 50,000. Most decisions were made on the captain's level and approximately only 2% of the decisions were escalated to senior level management. If decisions impacted the design, schedule, cost, or sustainability, they were escalated to level (3). In level (4) the director of design and construction was involved. Issues that were decided at the management committee were things such as the redesign of the interior. Besides the clear structure, a timeframe to make a decision was restricted. For example, the captains level had three days to decide and the senior leadership had one week. The bottom-up approach resulted in people spending less time on ideas that wouldn't be realized, faster and on time decision-making and higher productivity. The design process ended successfully because the decision-making process produced US$ 55M worth of design changes, as additional value.

CASE 3

The Lower Thames Crossing is a complex infrastructure project located east of London. It will consist of a double bored tunnel with 13.2 miles of connecting roads. The project will create 70% extra road capacity across the river, connecting Kent with Essex and creating growth in the local area. In 2016 the project was out in consultation and received 47,000 responses. This led to the Preferred Route Announcement in 2017 and currently the project is in preliminary design preparing for the statutory consultation and DCO application. The preliminary design phase will refine the designs from the options phase and thereby several decisions will be made. It is crucial that these decisions take all considerations into account, for example stakeholders that expressed concerns, environmental considerations, traffic flow, safety in operations and so forth. It is also important that the decisions are transparent and documented to be able to understand the current state of design during consultation. Therefore, a design decision process based on principles from CBA was designed to handle decisions in a structured and efficient way. The first step in the process is to agree whether it is a decision that includes several disciplines. Thereafter the decision is scheduled through the LPS to ensure interfaces with other important decisions are considered. Often the decision is split into two workshops: (1) an engineering workshop where disciplines co-design and discuss alternatives that all meet the minimum criteria and (2) a decision workshop where relevant disciplines agree on key factors, criteria and attributes relevant for the decision, and make an assessment ending up in a recommendation for the decision. The recommendation thereafter goes through an agreed approval process with the client. The CBA process has been adapted throughout the project as a way to take cross-disciplinary decisions. The method has shown to be an efficient way to reach consensus on decisions. Furthermore, the structured nature of the assessment leads to value adding ideas and solutions and is now regarded as a value management tool. The team has explained that this method has given confidence that the decisions are of high quality delivered through an efficient process.

CASE 4

The project is an IT campus that will be located in California. It is a challenging and iconic building consisting of 595,000 sf, and several other amenities for the city, such plazas, recreation areas, and parking spaces. It must comply with stringent city requirements. The project decision-making method during design evolved from WRC and not a structured decision-making process to the systematic implementation of CBA and A3s. This happened after an intervention led by the project manager with the support of lean coaches. The structure of the decision-making process after the implementation of lean thinking, was developed through several collaborative decisions meetings. The meetings to discuss decisions were held remotely, due to the nature of the project having several locations of designers (California, New York, and London). The timing of decisions was informed by LPS; decisions were pulled by the design planning process. For each meeting, the team followed a structured conversation process to identify the decision to be made, the factors and criteria for evaluation according to target values for design, possible design alternatives, attributes of the alternatives, and advantages of the alternatives. Cost was treated separately as a constraint, and finally the team agreed on a recommended alternative based on advantages, which were assessed as valuable to the client and community. Value and costs of each alternative were given to the owner for review. Many decisions were made simultaneously. Each collaborative decision meeting lasted for about 2 hours each, and any decision could require multiple meetings. The governance process was initiated by the team identifying decisions to be made from issues discovered in the design process or opportunities for improving the design, according to the plan. Then, the team would recommend a solution with a rationale for it and the owner would make the final decision. The documentation of the decision was based on an A3 report that contains CBA decision principles. All team members could write parts of the decision in a "virtual" A3 that is publicly shared for project members.

FINDINGS

In summary, a decision-making process must support an adequate exchange of information and effective coordination. Table 3 provides an overview of the discussed decision-making processes based on the: (1) decision-making method, (2) structure of the decision-making process, (3) governance process, and (4) documentation process.

All four projects used LPS, BIM and the big room concept (case 4 virtually). In case 3 and 4 the decision-making was strongly connected to the LPS, whereas in case 1 and 2 the actions of a decision were connected to the LPS, but not the decision itself. Tracking the tasks throughout the decision-making process through LPS helped the teams to stay focused and make decisions on time, especially if the owner participates in the LPS. For example, decisions are cross disciplinary which means all disciplines need to prepare thoroughly before the decision can be made. The LPS makes it clear what the required timing is and how much time is given to prepare. In case 1 and 4, A3 reports were used to represent the decision in a clear manner. In all cases the governance process was hierarchical, with the final decision made by the owner. However, in comparison to the other cases, case 2 provided a very clear structured decision-making process with hierarchical levels depending on decisions' impact on design, quality, schedule, and cost, and the amount of money the decision required. It was always transparent who was accountable for a decision and who participated in the decision-making. Members of the project team where empowered and had the autonomy to make decisions. Thus, "for one of the first times in their career [senior managers] were required to actually make senior management decisions, based on hard data, and that worked" (Interviewee, 11/03/2014).CBA was used as the decision-making method in cases 3 and 4. Team members participating in a CBA workshop in case 3 felt assured that CBA is an efficient group decision-making method. It was beneficial to separate opinions with facts (attributes). The process made it possible for different personality types to contribute, and through evaluations, the participants expressed that they felt heard. Furthermore, ideas for further improvements and value adding opportunities were identified and agreed on in workshops. In case 4, the design team reported better decisions were made, resulting in an 11% cost saving for the client, and less confusion and iterations in the design process. Also, decisions were contrasted against the Target Value Delivery (TVD) targets defined by the owner and design team and new alternatives were created to deliver higher value according to these targets and compared against the baseline design.

Table 3: Overview of the findings

Case	Decision-making method	Structure of the decision-making process	Governance process	Documentation of the decision
UCSF Mission Hall	no specific method, but A3s	Generic process, no specific structure	Hierarchy approval process	Partly Documentation via A3 report
UCSF Medical Centre	no specific method	Straight structure with different levels, clearly defined responsibilities	Integrated bottom-up process with hierarchical levels	Documentation of alternatives and decision in a specific template
Lower Thames Crossing	CBA	Generic process for taking decisions integrated with LPS	Hierarchy approval process	Documentation of alternatives and recommendation in a specific template
IT Campus Project	CBA with A3s	Collaborative process integrated with LPS and TVD	Horizontal among design team, owner made final decision	Shared A3 reports, Systematic collaborative documentation

DISCUSSION

A structured group decision-making process enables more people with different opinions to participate in the discussion. In accordance to the characteristics of an effective decision-making process defined in the literature review, the four cases achieved a different degree of intensity regarding positive interdependence, face-to-face promotive interaction, individual accountability, social skills, and group processing (receive feedback, analyze and reflect, improve, celebrate). Besides and although trust was not particularly measured, the authors observed a high level of trust among team members which affected the decision-making process in all four cases and therefore define trust as another factor impacting the decision-making process. Using CBA supports the team to identify must have criteria at the beginning of the decision-making process, which avoids wasting time in alternatives that will be discarded later. It provides transparent documentation which helps to discuss alternatives and create a shared understanding. Moreover, CBA helps to write the rationale of a decision which is important to document it in a proper way for final approving, and bad documentation can lead to mistrust in the decision-making process. Expectations to the different disciplines and professions relevant for the decision are clear, and by separating facts provided by subject matter of experts from opinions better quality decisions will be made. The structured process leads to value adding opportunities. For example, advantages from one alternative can be added to another alternative without or with few additional costs. Therefore, the decision-making process should be considered as an important part of the value management activities on the project. In addition, it is more important to map the interrelations between decisions than between deliveries, because if the decisions are coordinated, the deliveries (e.g. reports and analysis) will reflect this.

Thus, based on these findings, the authors give the following recommendations for an effective decision-making process: (1) Define a clear structured decision-making and governance process, and define responsibilities for every hierarchical level. (2) Use an integrated bottom-up process for decision approval. (3) Use CBA as a method to choose between alternatives. (4) Connect the timing of the decisions with the LPS. (5) Document and share decisions among the team using a clear defined template such as A3s. (6) Test the value of the alternatives against TVD identified by the project team.

CONCLUSION

This paper showed and discussed the value of an effective decision-making process and presented recommendations on how a decision-making process should be designed by answering three research questions. The first research question was answered based on literature and findings from the case studies. In summary, value is created when decisions are made within targets and constraints. Collaborative decision-making creates value, because group decisions increase the quality and the acceptance of the decision, interdependence and effects on certain team members are discussed, resulting in an easier implementation process. Thus, it is essential to address the decision-making process and clarify how decision will be made on a project. For effective decision making, (second research question) coordination, a clear structure (e. g. Dean and Sharfman 1996; Johnson and Johnson 2009), and a governance process that fully utilizes the team's resources, using an integrated bottom-up approach, are necessary. Furthermore, a transparent decision-making method such as CBA that supports the involvement and the collaborative discussion about alternatives is required. Linking CBA with LPS and TVD provides effectiveness and reduces waste in the design process.As stated in the discussion section, the decision-making process should be designed to involve different hierarchical levels and to enhance the effectiveness of the team based on the five points listed (third question).

The findings are limited to four cases and the full potential of Lean methods in the decision-making process has not been fully tested in design. A more structured research comparing different project types regarding decision-making in combination with Lean methods such as CBA could give transparency to the benefits and strategies for implementation.

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ENABLERS FOR SUSTAINABLE LEAN CONSTRUCTION IN INDIA

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ABSTRACT

Sustainability and Lean practices are two modern philosophies that are wielding influence in the construction industry. Researchers have observed that Sustainability and Lean implementation go hand in hand and there are benefits in implementing them together as 'Sustainable Lean Construction' (SLC). However, it was observed through a literature review that the contractors' top management support for implementing sustainable practices was not as evident as that of Lean implementation. In the Indian construction scenario, with the Sustainability initiatives and Lean implementation in preliminary stages, time is ripe for viewing them as concepts that complement each other and look for its widespread application as a combined credo. Commitment by owner organizations, compatibility with an existing contractual framework, design ability, constructability, government policy support, financial attractiveness, long-term relationship and increased market penetration are among the enablers that support the implementation of SLC in Indian conditions. The identified enablers and action points, therefore, pave the way for achieving the benefits of lean implementation and sustainable construction practices for fostering SLC practices in Indian construction.

KEYWORDS

Sustainability, Lean, Construction, Sustainable Lean Construction, Organizations, Enablers

INTRODUCTION

The word Sustainability means "to meet the needs of the present without compromising the ability of future generations to meet their own needs" as articulated by The World Commission on Environment and Development (WCED1987). Sustainability has greater relevance in the construction industry owing to the nature of operations involved. Approaches like 'triple bottom line', help in viewing sustainability through the lens of the

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environment, economics, and social relevance. Sustainable solutions in construction aim at processes that have minimal or no detrimental impact on ecological and social systems.

With reference to Lean Construction (LC), the universal view is value addition and waste reduction (Koskela 1992). In other words, lean concepts emphasize that non–value adding activities consume resources, and therefore are wasteful and not economically sustainable over the long run. Without waste reduction, and subsequently elimination, processes, and operations are less likely to be sustainable.

The Construction industry, particularly in India, is facing twin problems. The first problem is about the detrimental effect on people, society and the environment (sustainability issues) and the second being the decreased financial attractiveness of the business. The concepts of Sustainable Construction (SC) and Lean Construction (LC) are, in the opinion of the authors, well designed to address the twin problems facing the Industry in Indian conditions. Generally, SC and LC are viewed as management frameworks that can independently provide solutions to manage the sustainability issues and provide financial incentives (through waste reduction and value addition) respectively. Research has shown that SC and LC mutually reinforce each other and there is a synergistic output that can be achieved by considering them as a combined credo (Salvatierra-Garrido and Pasquire 2011; Vieira and Cachadinha 2011; Bae and Kim 2007; Campos et al. 2012; Carneiro et al. 2012; Holloway and Parrish 2013; Johnsen and Drevland 2016; Novak 2012). While this concept is existent, there are limited studies to understand the enablers for the same in the Indian context.

Adoption of sustainable practices is still considered a part of the mandatory 'Corporate Social Responsibility' (CSR) initiative. It has unfortunately not entered into the mainstream focus of construction businesses (Holloway and Parrish 2013). Assuming that there is a valid need for implementing sustainable practices in Indian construction industry, the long-term research objective is to develop means to bring sustainability in the mainstream focus of Indian construction organizations. The authors strongly believe that the required focus is achievable through the implementation of sustainable practices as a Lean concept rather than as a standalone concept. As a first step, the authors validate the assumptions as stated above through a review of existing literature. Subsequently, the 'enablers' that would help to implement 'Lean focused – SC' in Indian construction industry are conceptually identified with its perceived potential to eliminate wastes.

METHODOLOGY

In the initial sections of the paper, existing literature is reviewed to understand the extent of top management support for the implementation of Lean methods and sustainable practices in the construction sector in India. The importance of adoption of sustainable practices in the Indian context and the urgency for the same is established in the subsequent section. It is then followed by a review of existing literature on Sustainable Lean Construction (SLC). The authors then conceptually identify the enablers of SLC that help in its implementation in the Indian context.

LITERATURE REVIEW

IMPLEMENTING LEAN PRACTICES IN INDIAN CONSTRUCTION INDUSTRY

Over the years, there is an increased interest in the adoption of lean practices by the Indian construction organizations. In the recently concluded Indian Lean Construction Conference (ILCC 2017), held at Chennai, India, it was heartening to note that the construction industry in India had embraced lean practices and documented success stories. Raghavan (2017) notes that, even though the lean awareness in India is low, there are very good indicators indicating growing inclination towards Lean. Lean techniques like Last Planner System (LPS), and Location-Based Management System (LBMS), when implemented at project sites, resulted in improved cycle time, reduced instances of delays and enhancing coordination and communication among various stakeholders (Vaidyanathan et al. 2016). Mathew (2017), in the study on lean implementation ina building construction project, observed improved resource utilization, waste minimization among others.

It is seen from the existing literature that is specific to Indian construction companies that top management is actively involved in adopting Lean practices that can make a difference to their bottom line.The Table 1 below tabulates the adoption of Lean practices by Indian construction organizations in papers that were published in 2017 alone.

Table 1: Papers on Lean implementation in Indian construction industries

Sl.No.	Organization	ILCC 2017 Conference paper author(s)	Lean Methods adopted
1	Godrej Construction	Mathew 2017 Bhandarkar and Sawant 2017 Lahoti and Rathore 2017	Kaizen, 5S, Total Project Management, Value Stream Mapping (VSM), Last Planner System
2	L&T Construction	Kumar and Prabhakaran 2017	Autodesk BIM 360 to digitize and optimized workflows
3	Tata Projects	Danthi et al. 2017 Murthy et al. 2017	VSM
4	Maha Metro Rail Corporation Limited	Dhopte 2017	Enterprise Resource Planning & 5D BIM
5	AFCONS Infrastructure Limited	Giridhar et al. 2017 Lad et al. 2017	Knowledge management as an enabler of building a lean culture
6	Godrej Properties	Potdar et al. 2017	Collaborative planning and VSM
7	Tata Realty and Infrastructure Limited	Patil et al. 2017	

SUSTAINABLE PRACTICES IN INDIAN CONSTRUCTION INDUSTRY

Traditional Indian architecture incorporates the concept of sustainability in its very design. However, with the growth in the construction complexity and the influence of modern day practices, there is a need to bring back the focus on sustainable construction (Arif et al. 2009). Unlike adoption of Lean practices, the primary thrust to adopt Sustainable methods is provided by the regulatory agencies of the government and the owner organizations that are willing to implement green practices (Shen et al. 2006; Arif et al. 2009; Holloway and Parrish 2013; Liang et al. 2014). It is observed by researchers that the commitment of top management provides a significant impetus towards the adoption of sustainable construction practices (Tan et al. 2011; Athapaththu and Karunasena 2017).

In summary, the commitment of the top management of Indian construction organizations in the adoption of sustainable technologies is more due to external pressure than an internal requirement and therefore, the initiatives that are taken are mostly to ensure the minimum compliance requirement (Arif et al. 2009).

SUSTAINABLE PRACTICES IN INDIAN CONSTRUCTION INDUSTRY – ESTABLISHING THE URGENCY

Gort (2008) observes that sustainability is looked upon as a ‘nuisance,' and companies are not incentivized to fully engage as sustainable practices are still considered to be an additional cost, not delivering profits in the short-term. To establish the urgency and relevance of implementing sustainable practices in the Indian construction sector, the authors have adopted the ‘dimensions of sustainability’ framework identified presented by Piercy and Brammer (2012) (as quoted by Piercy and Rich 2015). Piercy and Brammer (2012) (as quoted by Piercy and Rich 2015) observed that sustainability had six dimensions that include “environment, workforce, supply chain, community, governance, and quality issues”. In addition, the authors have identified an additional dimension ‘Contractual Arrangement’ that is observed to impact sustainable practices. Dimension D1 to Dimension D7 is the sustainability dimensions described below:

D1 - Environment

The detrimental impact on the environment due to the construction industry is considered to be more severe in developing countries than in developed countries due to the volume of work and practices that are not sustainable (du Plessis 2002). It has been observed that the two major raw materials of construction, cement, and steel, alone are accountable for a large quantum of greenhouse gas emissions (du Plessis 2002). The problems of deforestation, soil erosion, groundwater pollution, health deterioration, unscientific landfills are closely associated with construction in the Indian context too. Sustainable practices are hence in need to protect the environment from further decline.

D2 -Workforce

Developing countries like India, which has still not reached the levels of automation practiced in the developed economies, rely heavily on the manual workforce for construction activities. India is already facing a shortage of quality workforce supply (Loganathan and Kalidindi 2016) for the construction sector, and the situation is bound to worsen if there is no immediate action for improvement. To compound the availability issue, a study by Patel and Jha (2016) estimated that there are around “38 fatal accidents per day in the Indian construction sector" and categorized the building industry as the second most hazardous sector in India. Women workers in the unskilled category face routine difficulties that include wage discrimination, harassment and poor working conditions (Devi and Kiran2013; Anvekar and R 2015). The available workforce is not trained for the right skills and quality (Loganathan and Kalidindi 2017). As a profession, the construction industry has become unattractive (du Plessis 2002), rising questions on the future of the livelihood of millions of people who are associated either directly or indirectly with the sector. Hence, there is an immediate need for sustainable practices in this domain without which the future of the sector is bleak with a short supply of quality workforce.

D3 – Supply Chain

Piercy and Rich (2015)noted that supply chain sustainability should be achieved not only in material sourcing but also in labour management, ethical trade practices, on-time payment and supportive behavior. The construction industry remains highly fragmented with over 95% of the enterprises employing less than 200 persons (Planning Commission 2013) and mostly unorganized. Highly sophisticated and non-linear supply chains (Negi et al. 2017) serve these enterprises, resulting in the accumulation of the unsustainable practices in almost every level. Therefore, it is not only urgent but also a herculean task to bring sustainable practices across construction supply chains. The policy intervention and Government support are critical in this domain.

D4 - Community

Construction activities have a profound impact on communities. Organizations relate themselves to communities through activities as part of corporate social responsibilities (CSR). CSR is also now a part of mandatory sustainable initiatives to be demonstrated by organizations with atleast Indian Rupees (INR) 5 Crore net profits or INR 1000 Crore turnover or INR 500 crore net worth (Indian Express 2014). With over 95% of the construction organizations employing less than 200 persons (Planning Commission 2013) and not falling under the CSR criteria described above, the effectiveness of the CSR initiatives may not be significant.

D5 - Governance

Piercy and Rich (2015), define governance (in this context) as 'transparency in corporate governance and legal compliance with clear and written ethics policy and communication channels'. Kardos (2012) opines that good governance may not assure sustainable development, but its absence impedes it. The Organization for Economic Co-operation and Development (OECD) Principles (2004) elucidates that an "effective corporate governance system within the company and across the economy helps in creating efficient markets" which in turn lowers the cost of capital, supporting efficient use of resources (Kocmanova 2011). Mukherjee and Ghosh (2003) observed that corporate governance in India was in 'a nascent stage'. Pande and Kaushik (2013) have noted that the business management structure in India is entirely different (due to the constant conflict between the majority and minority shareholders) from other developed countries and that the existing corporate governance framework does not adequately address this uniqueness.

D6 – Quality Issues

Achieving the product and service quality (Piercy and Rich 2015) by meeting or exceeding the customer expectations is perhaps at the center of any philosophy or a framework, including sustainability. Organizations whose products and services have not fulfilled the minimum customer requirements have not sustained for long. Though there has been significant progress in the product quality, in the opinion of the authors, the service quality in construction needs critical improvement. In their study, Jha and Iyer (2006) identified the following factors that adversely affect the quality performances of Indian construction projects are: "conflict among project participants; hostile socio-economic environment; harsh climatic condition; project manager's ignorance and lack of knowledge; and aggressive competition during tendering." These quality issues need to be addressed for sustainable construction.

D7 – Additional Dimension – Contractual Arrangement

In addition to the six dimensions identified by Piercy and Brammer (2012) (as quoted by Piercy and Rich 2015), the seventh dimension that needs sustainable practices in place is the 'contractual arrangement'.' Contractual practices continue to be transactional rather than relational. From authors' point of view, the transactional contracts have primarily resulted in growing mistrust and disputes affecting the sustainability of construction business.

In summary, the discussion above shows an urgent need to implement sustainable practices in the Indian construction industry, failing which, without quality resources and favorable environment, there will be irreparable damage caused to the future of the industry. However, the urgency required in implementation has not translated into action due to lack of top management commitment in implementing sustainable practices.

ACHIEVING SUSTAINABLE LEAN CONSTRUCTION IN INDIA

Several authors have noted the benefit of integrating Lean and Sustainable practices (e.g. Huovila and Koskela 1998; Lapinski et al. 2006, Ogunbiyi et al. 2014, Salvatierra-Garrido and Pasquire 2011; Rueff and Cachadinha 2011; Bae and Kim 2007; Campos et al. 2012; Carneiro et al. 2012; Holloway and Parrish 2013; Johnsen and Drevland 2016; Novak 2012; Marhani et al. 2013; Jamil and Fathi 2016; Dixit et al. 2017). Gort (2008) discusses SLC in the context of manufacturing industry. Fliedner and Majeske (2010) presented on how sustainability can help in adding economic value to an organization with illustrations from across sectors. Salem et al. (2014) explained how Lean practices helped in reducing the impact of construction on environmental, economic and social aspects of the pavement construction projects.

In summary, SLC helps the organization to expand its thinking beyond the organizational boundaries, while LC focuses within the organization (Fliedner and Majeske 2010). However, it is noted that the research focus in the area of SLC has been limitedto understand how Lean concepts and its tools reinforce primarily three dimensions of sustainability, namely, environment, social and economic development. In this paper, the authors therefore consider it essential to integrate Lean principles with six-dimensional Sustainability framework proposed by Piercy and Brammer (2012) along with the additional dimension on 'contractual agreement' in the Indian context and in doing so, identify a set of enablers that would enhance SLC implementation. By demonstrating the possibility of Lean benefits through Sustainable practices, the authors expect to find greater support for the implementation of SLC from the top management.

ENABLERS

Lean and Sustainability are mutually supporting concepts, and with some incremental steps, it is possible to achieve the benefits of Lean implementation, through sustainable construction practices and thereby gain management commitment. Authors term these 'incremental steps' as enablers for SLC in the Indian context. The enablers identified below help in Lean implementation in addition to wielding a positive influence on all seven dimensions of sustainability. The enablers for SLC are described from E1 to E6 below based on the combined industry experience of the authors. While it is discussed how each Enabler enables incorporation of sustainable practices, its Lean impact (in the seven-dimensional framework)is illustrated in detail in one specific case in Table 2.

E1 - OWNER COMMITMENT

Committed owners ensure all the stakeholders in the supply chain commit to the requirements of sustainable construction. The commitment must be manifested suitably through the terms of Contract between the parties.

E2 - DESIGNABILITY AND CONSTRUCTABILITY

For the construction process to be sustainable, its design must be sustainable first. The project design must be in line with the end-user requirement. A conflict-free design is possible only with due consideration of designability and constructability aspects in the early stages of construction. In terms of Lean benefits, the enabler helps in the reduction of rework, waiting times and over-processing.

E3 - GOVERNMENT POLICY

Support by the Government in implementing sustainable practices would go a long way in nurturing sustainable practices in organizations. Mandatory reporting of CSR activities, corporate governance among others, are some of the steps in this direction. Government policy support in the form of incentives helps in reducing the resistance of organizations to make their practices sustainable (thereby automatically make their project sites Lean).

E4 - LONG-TERM PARTNERSHIP

Long-term partnerships are a result of trust. Such partnerships help in the faster adoption and smoother implementation of sustainable practices. Lean benefits include minimized learning curve impact, lesser attrition, the reduction of rework and waiting times, among others.

E5 - HIGH MARKET PENETRATION

Organizations having high market penetration have considerable influence over their contractors/subcontractors, suppliers and vendors. In all such cases, implementation of sustainable practices across the supply chain is facilitated, enabling ts quicker adoption. The organizations down the line would have to fall in line with their influential customers (who are market leaders) failing which they have the risk of losing their businesses. High market penetration also implies the presence of greater acceptability amongst user-communities. When organizations reciprocate through community-focused sustainable initiatives, the local support is further reinforced. The mutual support helps in reducing typical construction delays due to protests from local communities.

E6 - COMPATIBILITY WITH EXISTING CONTRACTUAL FRAMEWORKS

Construction projects in India, especially in the public sector are executed using standard contract formats. Owner organizations are typically hesitant to deviate from the existing formats. Introducing sustainable practices seamlessly within existing contract frameworks will receive greater acceptance amongst the stakeholders.

Table 2: Illustration of 'Owner Commitment' as an Enabler

Dimension of Sustainability (Piercy and Brammer 2012)	Suggested Action Points	Lean Impact that may motivate organizations to adopt sustainable practices
Environment	• Limits on allowable material wastage with incentive/penalty system • Store audits to ensure compliance with acceptable preservation requirements	• Reducing overproduction/ over-processing
Workforce	• Minimum facilities to be provided to the workmen for their living, dining, and recreation to ensure ethical treatment • Regular audits of labor camps • Safety audits to ensure workplace safety requirement	• Improving worker morale and reduction of attrition - Reduction in waiting times due to lost man-hours as a result of accidents/injuries
Supply chain	• Emphasis on long-term partnership sub-contract agreements • Vendor development, evaluation, and training by main contractors	• Reducing waiting times for deliveries
Community	• Local community involvement through part time/ full-time employment opportunities • CSR activities in association with contractors and subcontractors	• Reducing travel time for workmen transportation/ reduction in dependence on migrant workmen

Governance	• A communication protocol, frequent meetings, constructability workshops, team-building exercises.	• Reduced waiting times for instructions with clarity in communication • Such processes would help in contractor/ subcontract organizations to internalize such practices within their organizations
Quality	• Process quality improvements through KPI (Key Performance Indicator) scoring for contractor's approach to resolve issues and differences	• Minimized defects/waiting times
Contractual Arrangement	• promoting relational contracts that work on the principle of risk and reward sharing in a blame-free culture	• Reduction in waiting time/delays/inventory pile-up

CONCLUSION AND LIMITATION

From the experience and understanding of the authors and the support of the existing literature, it is vivid beyond doubt that there is a need for an increased focus on implementing sustainable practices in Indian construction industry on an urgent basis. However, the urgency has not translated into concrete action because of the lack of contractor organization top management support. The absence of interest seems to stem from the fact that the construction organizations are more focused on the achievement of financial goals rather than environmental goals. Paradoxically, the efforts to bring in sustainability in construction require additional cost and time (Shen et al. 2006; Saggin et al. 2015) and the returns are realizable only in the long run (Tan et al. 2011), and hence management focus is lost. In the Indian construction domain, there seems to be an increased focus on adopting lean practices. Lean implementation has been receiving necessary top management support. Fortunately, Lean and Sustainability are mutually supporting concepts, and with some incremental steps, it is possible to achieve the benefits of lean implementation, through sustainable construction practices. These 'incremental steps' are termed as enablers for Sustainable Lean Construction in the Indian context.

The paper is purely conceptual and is not supported by any formal survey data. The authors have put down their view based on their experiences in discussion with some academic and industry professionals. The research can further be extended to validate the enablers listed out by the authors in construction projects through a survey or case study based research.

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REDUCING HUMAN FAILURE IN CONSTRUCTION WITH THE ‘TRAINING-WITHIN-INDUSTRY’ METHOD

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ABSTRACT

The purpose of this paper is to explain how a lean production tool, the ‘Training-within-Industry’ (TWI) would help to identify and eliminate safety related waste in construction. TWI is commonly used to transfer knowledge and skills needed to improve work methods. The tool also helps to maintain a good working relationship between the employers and employees. This paper presents a multiple case study conducted to understand the application of TWI in a worksite better. The research shows that inadequate training of workers contributes to variability and waste manifestation that precede accidents in construction. The study also contends that there is a significant scope TWI deployment in construction due to the inability of supervisors and working to ‘see’ safety waste unfolding on their worksites. For example, the guidelines herein outlined could reduce human failures (safety errors and violations) with the use of the lean construction tool.

KEYWORDS

Construction industry, Human Failures, Knowledge, Skills, Training-within-Industry

INTRODUCTION

According to Reason (2008), human failure in the form of errors and violation is a set of unplanned actions that produce unforeseen incidents and accidents within the workplace. It is connected to multiple factors that beget complex cause analysis (Misiurek and Misiurek 2017; Dekker, 2014). It is a significant problem in the labour-intensive and mechanical workplaces. For example, Sarhan et al. (2017) argue that the working conditions in the construction industry affect the behaviour of the workers.

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The literature shows that accidents produced by human failure are part of the waste in the workplace (Sarhan et al., 2017; Misiurek and Misiurek, 2017). Waste is described as losses produced by activities, which influences the direct and indirect costs of the project, but do not add value to the project from the point of the client (Aziz and Hafez, 2013). An accident is waste that is linked to people in construction, because it costs both human and non-human lives (Larios et al., 2012). It typically results in either minor or major injuries or even fatalities (Albert et al., 2014). Accidents are often highly complex and are the result of unsafe acts and conditions in industry (Smith et al., 2017).

Perlman et al. (2014) explain that most accidents in the construction industry are the result of system failures situated in human actions. However, there is a notion that an accident that is linked to human activities and decisions should not be blamed on employees alone. Dekker (2014) states that people do not intentionally under perform, and when there are accidents at the workplace, management must investigate the events beyond the victims.

Furthermore, most people are of two minds regarding the role of people in creating and breaking safety systems (Dekker, 2014a). Human behaviour across all industries plays a significant role in accidents (Chidambaram, 2016). Most accidents across all sectors occur because of failure with causes rooted in human behaviour that include lack of maintenance and a poor safety culture (Chidambaram, 2016). Most of the time, accidents are influenced by the employers' and employees' working culture that is connected to actions and decisions in the workplace (Gibb et al., 2014; Yorio and Wachter 2014). Safety culture is described as a framework of reference for employees to make sense of safety measures in the workplace and adapt their behaviour (Shen et al., 2015).

According to Reason (2008), there is no universally agreed definition of human failure, but there are four essential elements, namely the intention, the action, the outcome, and the context. Furthermore, human failure can be viewed with two main modes, which include the person model and the systems model (Reason, 2000). The person model focuses either on the mistake, error, slips or lapse of individuals (employees) by blaming them for forgetfulness, inattention, or moral weakness. The system model focuses on the condition under which individuals work and tries to build defences to avert the error and or mitigate their effects (Reason, 2000).

The preceding discussion indicates that human failure and its effects distort project outcomes. In other words, there is a need to remove it from construction. A method for removing it is called TWI, which is succinctly explained in the next section of the paper.

TRAINING-WITHIN-INDUSTRY (TWI) METHOD

The foundation of the TWI method was laid in the United States of America (USA) in 1940 during World War II (Dzubakova and Koptak, 2015). TWI formed part of the Toyota Production System (TPS), which is also known as "Lean Production System" (Dzubakova and Koptak, 2015). TPS is a management system designed for the absolute elimination of waste in the workplace (Shingo, 2005). The literature shows that human failure causing accident is a waste. In construction ‘accidents' is an activity that consumes time due to investigation process which needs to take place without adding value to the final product due to the absence of the injured person (Misiurek and Misiurek, 2017).

The implementation of TWI is focused on training production leaders, masters, foreman, and experienced operators (Huntzinger, 2016; Allen, 1919). TWI help to transfer knowledge and skills of management in instructing employees (Job Instruction), building good relations between employees (Job Relation) and improving working methods (Job Methods) (Sinocchi and Bernstein, 2016). TWI is grounded on the three J-program (Huntzinger, 2006). The relation between TWI and lean is recognised in the three J-program. For example, Job Instruction relates to standardization of work, job method affects continues improvement, and job relation influences respect for people (Pereira et al., 2016).TWI promotes 'learning by doing' that implies solving production problems with the guidance of a properly trained instructor (supervisor) (Allen, 1919). The impact of this method is influenced by management since an instructor must have a sound knowledge of the problem before training someone else (Graupp and Wrona, 2010). The introduction of TWI in a workplace is grounded on the three J-program (J=Job), the job instruction (JI), job methods (JM), and job relations (JR) (Huntzinger, 2006). The three programs are highlighted as follows:

Job Instruction Training (JIT): the principal objectives of JIT, which is linked to standardisation of work, in human activities are to teach instructors how to develop a well-trained workforce (Huntzinger 2016 citing Allen, 1919). Allen (1919) states that it is essential for an instructor to be skilled in instruction or training to be able to reduce waste. Such waste is not limited to defects, rework, accidents, and damage to a plant. An instructor must be skilled with respect to how to instruct regardless of how much he/she knows the work because knowing the work does not mean that an instructor will be able to teach his/her team how to do the job (Allen, 1919). Dinero (2010) argues that if an individual has not learned the work, then an instructor has not taught the learner how to do the job correctly, which explains the slogan of JIT.

Job Method Training (JMT): The aims of JMT that is related to continuous improvement is to help instructors to produce quality products in suitable or less time by making the best use of employed workers, machines, and material (Huntzinger 2016). According to Dinero (2010), JMT is like JIT in that the workers analyse a given task detailed by the instructor, but the difference is that it focuses on improving how the job is done. JMT is very important in reducing mistakes, errors, and lapses. Huntzinger (2006 citing Imai, 1986) states that JMT is relates to teaching instructors how to schedule jobs into their fundamental processes, reorganising, and simplifying job tasks to improve production.

Job Relation Training (JRT): The notion of respect for people, which is at the heart of lean construction, is expressed in JRT. JRT aims to help instructors improve their skills to work with workers and endorse collaboration at the workplace (Imai, 1986). In terms of human activity in industries, the relationship between employers and employees is significant. Graupp and Wrona (2010) explain that JRT enables the instructor to possess the skills in leadership by teaching workers how to sidestep personnel problems by building a standard for good relations with all workers. JRT also influences the positive handling of personnel problems by treating every worker as an individual (an end).

RESEARCH METHODOLOGY

This research aims to establish possible ways of reducing human failure on construction sites using TWI. To achieve this goal, a case study strategy explains in Yin (2012) was adopted. The approach is chosen because of the need to learn from the causes of human failure and to provide a solution from the utility of TWI (Scott, 2016). The project cases were in Sandton and Bloemfontein cities in South Africa. The selection of the case projects was based on purposive sampling technique as explained by Yin (2014). The selected case projects provided access to site management contact sessions. There were four case projects, three in Sandton and one in Bloemfontein.

The data were collected using semi-structured interviews. The interview period was between 30 to 60 minutes in duration. The interview session in each case project was recorded. After that, the interview recording was transcribed and analysed using emergent themes and pattern matching (Yin, 2014).At the start of each interview, the description of the TWI method was presented to the interviewees because most of them were not familiar with the TWI method. This might be because lean is not yet mainstream in South African construction where conventional work procedure is the norm. The construction industry is still relying on labour-intensive methods to deliver the projects.

In this stage of the study, contractors were interviewed. Efforts were made to engage workers as well. But site managers who can implement form the cohort interviewed at this stage (Table 1).However, project consultants and construction workers will be interviewed at a later stage. After that, the researcher will evaluate the findings of the three teams and formulate the hypothesis, which will be tested to answer the broader research questions of the study.

Table 1: Research site and participants

Case projects	Interviewees	Response (No)
Case 1: General building project	Site agent (one) Supervisor (one) Health & safety manager (One) Health & safety officer (one)	4
Case 2: General building project	Construction manager (one) Site agent (One) Supervisor (One) Health & safety manager (one) Health & safety officer (two) Health & safety representative (one)	7
Case 3: General building project	Construction manager (one) Health & safety officer (one)	2
Case 4: General building project	Construction manager (one) Supervisor (two) Health & safety officer (one) Health & safety representative (one)	5
Total Interviewees		**18**

RESULTS FROM THE INTERVIEWS

The central research question guided the 18 interviews. The data was collected through semi-structured interviews. The interviews were unstructured so that the interviewees could reply to each question, based on their lived experience. The sub-headings are used to present the analysed data as follows.

FACTORS LEADING TO HUMAN FAILURE

This section focuses on describing the factors influencing human failure in construction. According to the interviewees, human failure is an area concerned with the development and advancement of the worksite, policy and regulations. It was mentioned that the construction industry is one of the industry employing a high number of unskilled workers. Most of the interviewees responded that human failure is a disease that is resistant to a natural cure. Because of this 'disease', there is a high number of accidents in the construction industry. For instance, a construction manager and site agent in case 2 responded that they are working very hard to promote safety on their site as they aim to comply with the tenets of the Construction Regulations fully. But they are still the victim of accidents, because they have so far failed to produce the zero-accident target indicated in the organisation policy. There are several reasons why the construction industry is failing to achieve the zero target. A health & safety manager in case 2 said that it is difficult for management to control the decisions and actions of the workers. The decisions and actions of the workers are one of the factors leading to accidents and these interviewees, for example argued that workers are often exposed to extreme inclement weather conditions that influence their choices. Interviewees in case 2 say that often, fatigue and working condition influences the decisions of workers. The working condition influences the way in which an activity will be carried out, for example:

"We are working day and night to deliver this project three months ahead of schedule. This has changed the method of construction; we are working Monday to Saturday. You can imagine the pressure we are working under not to forget that we are the human being who needs proper rest to be active and to think properly". The site management also mentioned the contributions of ignorance and negligence linked to general workers.

The construction industry comprises a wide range of activities that rely on workers, machinery and equipment. Machinery and equipment are operated by the workers in the industry. This lead to the explanation of a site agent and supervisor in case 1 where they argued that accidents should be blamed on the workers because they engage in many activities that expose them to mistakes and errors. According to them,

"Construction is a labour-intensive driven industry, it relies intensively on labourers, and most of our labourers put themselves in danger by not following the safety rules or comply with the risk assessment issued by the safety manager per activities".

The blame game continued as some interviewees argued that accidents are caused by clients and designers. The reason is that some clients propose building projects with constructability issues since they are then complex and dangerous to build. The architects and engineers design the proposed building, according to the client's specification, and the contractor must deal with the health &safety planning and monitoring while producing the project. Further, a construction manager and a health &safety officer in case 4 supported the statement of the interviewees in case 1 (blaming accidents on the workers). The interviewees mentioned that some workers on their sites are currently under investigation for failing to comply with health &safety regulations. The Department of Labour in South Africa is investigating them due to an incident which happened on the 08 October 2017. A worker was instructed to cut steel reinforcement. He failed to wear safety goggles while completing the task. The result of his omission is that a spark entered his eyes and he nearly lost his sight (vision). In contrast, other interviewees disagreed with the tendency to blame workers for all accidents. They argued that workers follow instruction, which was given by the site agent and the foreman. They asked, "why do we have to blame the workers when things go wrong?" In their opinion, the blame game accounts for the reason why the industry is producing a high number of accidents instead of implementing measures to identify, analyse and control accidents.

DISCUSSION

This section discusses how TWI could help to reverse the issues outlined earlier. As explained in the methodology sections, a short presentation on the introduction of the TWI method was presented to the interviewees before the start of each interview. However, it was observed that in all the four cases the contractors had appointed a health &safety team on site. Most of the interviewees explained that their safety management system is designed with compliance with the Construction Regulations in mind. The muted compliance is supported by education and training customised for workers upon appointment. They also have a risk assessment tool to identify, analyse and control factors which might lead to accidents.

To overcome these challenges of human failure in construction, knowledge regarding the causes of accidents is required to examine the level of safety and directions for changes of the construction culture (Sanchez et al., 2017). There are various methods which could be adopted to improve safety in construction. However, this study adopted the TWI method to reduce human failure in construction. It was discovered that all the respondents were not familiar with the TWI method. But in four cases, the contractors have health &safety appointees instructed to promote safety culture. Safety culture is described as the whole group of knowledge, habits, and behaviours that drive organisations to willingly apply safety approaches and procedures in the construction industry (Sanchez et al., 2017).

The TWI method could be introduced through the three J-Program. The first step to is to test if management, especially the construction manager and principal designers, fully understand the impact of human failure in terms of causing accidents in the construction industry. The second step is to introduce and teach standard work or job instruction. For management to be able to identify and reduce hazards, they should train their workers to follow standard work. This step would help management to stop blaming workers because standard practice would help them to know if they are complying with the safety rules. In the third step, JM is responsible for defining the method of construction to be adopted by management, and it would also help to identify hazards and to measure the safety risk of the activities. This process is akin to continuous improvement, which allows site management to improve their method of construction and be able to reduce waste while producing the greater quantities and quality of work in less time. The fourth step known as JM serves the respect for people purpose. JM is responsible for influencing how management teaches the notion of respect for people to foster positive working relationships on site. Failure to adopt this step would result in a waste of human actions. For example, an interviewee stated that human behaviour is a problem causing human failure on the site and that other workers are ignorant and negligent. A manager who respects his workers would not blame his workers but would try to investigate causes of failures before making a judgement. In effect, the TWI method would teach management some basic techniques regarding supervision of the work and how to improve the skills and knowledge of workers to promote an optimum safety culture on site.

CONCLUDING REMARKS

This paper highlights human failure concerning the TWI method. Figure 1 illustrates how the reduction of human failure could be promoted in construction. The factors of human failure are underlined in the literature were mentioned by the interviewees that participated in the construction site fieldwork. There are four essential elements of human failure. These include the intention, the action, the outcome, and the context. These elements are linked to the factors causing human failure as demonstrated in the graphical representation in Figure 1.

Although, the preliminary findings of the reported research do not provide answers regarding how to introduce the TWI method, the literature on the TWI method has been analysed to help in the design of the framework. The framework supports the idea that human failure in construction could be resolved and should not be blamed on workers alone. The framework is an attempt to guide construction firms in terms of how to reduce or eliminate human failure using the TWI method. The framework emphasises that the working culture in an organisation is a fundamental cause of the research problem. The organisational working cultures, decisions and actions often cause a systematic failure, which is connected to the human failure in the construction industry. The effect of human failure pushes either the intentional or unintentional failure causing accidents in the workplace. Most of the time when an accident happens, there are often people who are blamed. To solve the human failure issue, this study proposes that designers and construction teams should identify the problem (human failure) in the design and the execution phase of the project. After that, they should have the knowledge of work and responsibility regarding the impact of human failure in the workplace. After that, management must be trained and skilled regarding how to give instruction (job instruction (JI)). After that, they must be skilled in terms of how to improve construction methods (Job method (JM)). Then, they must be proficient in terms of how to develop respect (job respect (JR)) for people in construction. In effect, the skills of instruction flow with the skill of methods and relations.

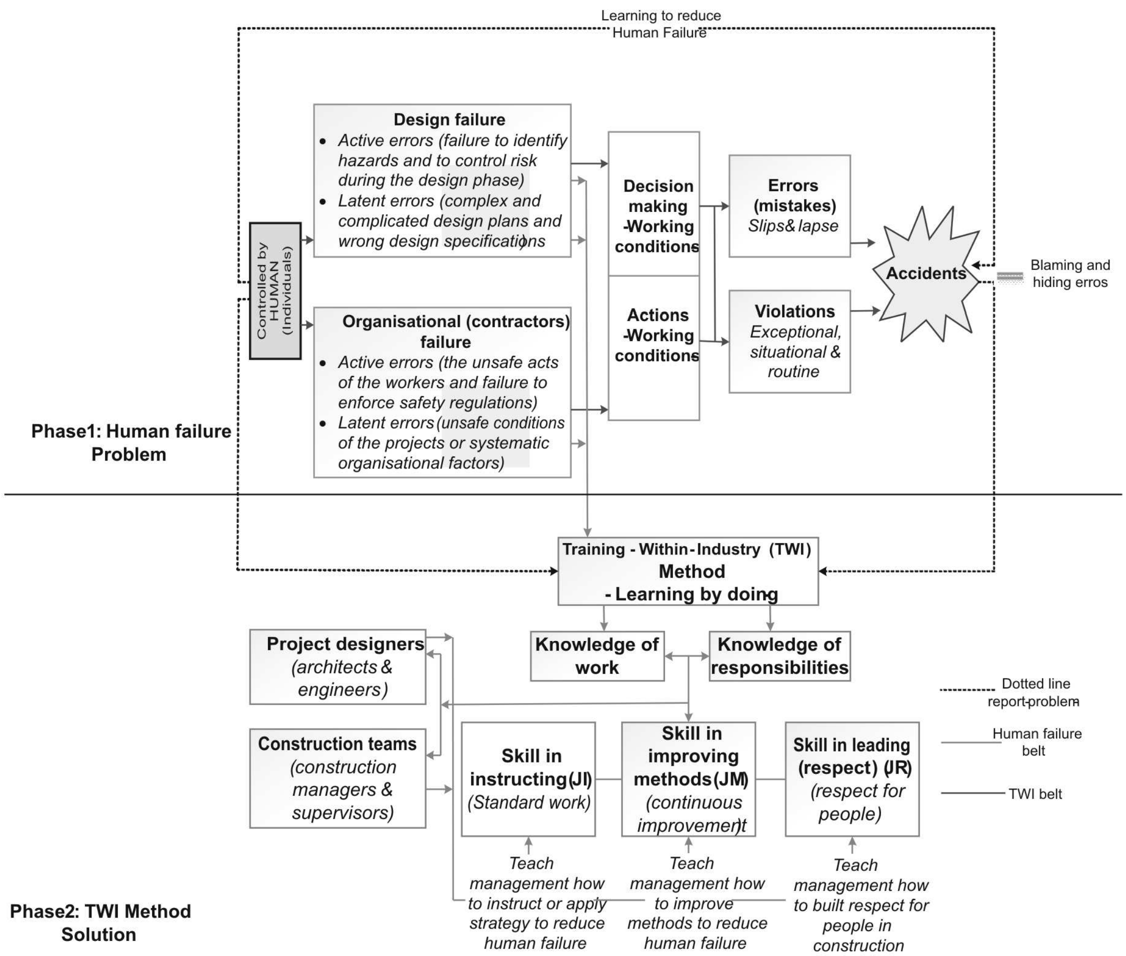

Figure 1: A conceptual human failure resolution framework (Author, 2017)

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LEAN CONSTRUCTION AND SUSTAINABILITY THROUGH IGLC COMMUNITY: A CRITICAL SYSTEMATIC REVIEW OF 25 YEARS OF EXPERIENCE

Saad Sarhan[1], Amira Elnokaly[2], Christine Pasquire[3] and Stephen Pretlove[4]

ABSTRACT

It has been argued that Lean Construction (LC) offers the conceptual basis and the appropriate methods and tools needed for helping the construction industry meet the challenges of sustainable development. Since 1998, a growing body of knowledge has been emerging from the IGLC community, in relation to synergies between LC and Sustainability. Both seek to reduce waste and maximise value, but through different approaches and perspectives. The most common mistake, however, is a tool-focused framework for integration, which overlooks the conceptual differences between these two initiatives. The aim of this study, therefore, is to review the progress made in understanding the linkages and inconsistencies between the two initiatives, through conducting a critical systematic literature review (SLR) and synthesising the findings of 'LC and Sustainability' studies published in IGLC conferences over the past 25 years. The findings of the study provide an overview of previous studies about the topic, reveal major limitations in approaches to LC and Sustainable Construction (SC), and divulge significant opportunities for further work that remain unexplored.

KEYWORDS

Lean Construction, Sustainability, Green, Value, Waste

INTRODUCTION

The construction industry is a significant growth industry on a global level and is a fundamental part of the economy in many parts of the world. The 'Construction 2025'

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industrial strategy report published by UK Government forecasts the global construction market to grow by up to 70% between 2013 and 2025 (HM Government, 2013). However, the construction sector is known to be one of the largest environmental polluters, physical waste producers, and energy consumers throughout its lifecycle (Huovila and Koskela, 1998; Oyedele *et al*, 2013; Weinheimer *et al*., 2017). Due to these challenges in our built environment, including issues relating to rapid growing populations and anthropogenic climate changes, there is a significant need in advancing the industry towards sustainable development. The concept of sustainable development was first coined in the Brundtland Commission, which was set up by the United Nations, as an initiative to improve the global environmental, economic and social conditions (WCED, 1987). Sustainable Construction (SC) is the response of the construction sector to the challenge of sustainable development (Huovila and Koskela, 1998). SC could be defined as "*the creation and operation of a healthy built environment based on resource-efficiency and ecological principles*" (Kibert (2005, p.2). According to Kibert (1994), while the traditional approach to construction project management focuses on cost, time and quality objectives, 'sustainability in architecture and construction' expands on these criteria to include minimisation of environmental degradation, minimisation of resource depletion, contextual, social and cultural consideration and creating a healthy built environment (Elnokaly and Vyas, 2014).

At the same time, the construction industry is also frequently criticised for its inherent inefficiencies, confrontational relationships, and low rates of productivity and profit margins, in comparison to other industries (for example see, Egan, 1998; Koskela, 2000; Sarhan *et al.*, 2017). Lean construction (LC) has been shown to be effective in helping to solve many of the industry's problems and to maximise value to the customer, through helping us to understand, identify and eliminate many of the causes and sources of (process and physical) waste in the end-to-end design and construction process (Koskela, 2000; Koskela *et al*., 2013; Sarhan *et al.*, 2018). There is no commonly agreed definition of LC, but it is mostly attributed to the application of the Transformation-Flow-Value generation (T-F-V) theory of production to the construction environment (see Koskela 2000). The flow dimension of the theory (F) reveals the interdependency of tasks across the whole project process (Sarhan *et al.*, 2018), and thus introduces the reduction of waste as an objective of production management; whilst value generation (V) brings the customer into the focus (Koskela *et al*., 2010). The construction sector typically recognises clients and more recently stakeholders and users, but the term 'customer' is not commonly used (Sarhan *et al*., 2018). In this sense, a 'customer' in LC principles could include any of the aforementioned, including the concept of next customer in the production process (see Leong and Tilley, 2008), which aims to improve integration and information flow between project suppliers; thereby reducing waste and driving behaviour towards the final product and end user value.

For these reasons, it has been argued that LC has the potential to contribute towards helping the industry to meet the challenges of sustainable development. To the best of the authors' knowledge, it is Huovila and Koskela's (1998) work that first, at least within the IGLC community, put forward the proposition that sustainability in construction can effectively be promoted and supported through LC principles. According to them, the principles of LC converge to the sustainability objectives in two main ways. First, through the focus on the concept of waste-reduction, LC can also reduce pollution, material and energy wastes during construction and maintenance. Secondly, through the concept of 'value', LC could be useful to clients aiming for both business and environmental and social excellence simultaneously.

Since 1998, a growing body of knowledge has been emerging from the LC community, in relation to synergies between LC and SC. From a production management perspective, it has been suggested by Koskela *et al.* (2010) that LC is an innovation in production theory, and that SC could be regarded as an innovation in product requirements. The link between them has also been increasingly recognised and implemented in practice. Furthermore, the concepts, tools and techniques of LC and SC themselves have been under constant refinement. This study, therefore, aims to review the progress made in understanding the linkages and inconsistencies between the two approaches, through conducting a critical systematic literature review (SLR) and synthesising the findings of 'LC and Sustainability' papers published in IGLC conferences over the past 25 years. SLRs are valuable for presenting knowledge that is unlikely to be obtained from an isolated review of individual studies (Carvalho *et al*., 2017). Following this introduction, the study will be divided into three parts. The next section describes the methodological approach of the study, followed by an overall summary of the research findings and analysis. Finally, the conclusions are provided.

RESEARCH METHODOLOGY AND OBJECTIVES

This study adopted a SLR and a qualitative approach to research synthesis, following the protocols recommended by Siddawy (2014) and Mellow *et al.* (2017). SLRs entail the use of a transparent and rigorous approach for the entire research process, in order to reduce bias and enable future replication (Mallet *et al*., 2012). A SLR usually relies on the use of databases that contain a large set of research publications as well as effective search mechanisms. Typically, the planning process for a SLR consists of the following steps: (1) Search method; (2) Inclusion and Exclusion Criteria (3) Search Outcome. This study used the search engine provided by the IGLC website (available on http://iglc.net/Papers), to search for 'LC and Sustainability' peer-reviewed papers published in IGLC conferences over the past 25 years. The IGLC database was selected, as this conference represents the state-of-the-art of LC research and practices from all around the world (Koladiya, 2017). The keywords used for the search query and the search outcomes are summarised in Table 1 below.

Interestingly, only 43 papers, out of all conference papers published by IGLC over the past 25 years, were found to match the various search queries conducted. Out of these, two papers were excluded based on title screening followed by an abstract review, due to their irrelevance. Thus, as a result of these efforts, 41 papers out of all IGLC papers over a span of 25 years, were found to be relevant and thus thoroughly reviewed and analysed by this study.

The study used a deductive-inductive approach for data analysis, utilising QSR NVivo 11 software, and following a "*lean coding*" procedure (Creswell, 2007, p.152). As opposed to purely inductive coding approaches where researchers usually struggle to reduce the numerous lists of generated codes to the five or six main categories or themes that they must end up with for most publications; in lean coding, the researcher starts by developing a short list of five or six themes with shorthand codes, and then continues to expand and refine their coding structure as they proceed with reviewing their databases (Creswell, 2007). Accordingly, during the data coding and analysis of the 41 papers selected for the SLR, the study focused on identifying, critically evaluating, and generating the overall picture related to the following six themes: (1) Limitations in approaches to LC; (2) Limitations in approaches to SC; (3) Opportunities for future work; (4) Main synergies between LC and SC; (5) Main Trade-offs or inconsistencies ; and (6) Potential enablers for the successful integration of LC and SC. Under each of these themes, initial codes from the SLR sample were generated, followed by axial coding leading to the development of subcategories and categories (Strauss and Corbin, 1998). Due to page constraints, this paper presents the findings and a critical discussion of the first three themes.

Table 1: Search queries and outcomes

Keywords	**No. of papers matching search queries**
Sustainability	43
Sustainable	43
Sustainable + Development	6
Green	31
Environmental	42
Energy	23

RESULTS AND DISCUSSION

SAMPLE ANALYSIS

The analysis of the SLR sample enabled the study to gain an overview about the: (1) Frequency of studies over time; (2) Countries that are leading and focussing on the research topic; and (3) Research methods and approaches used.

Frequency of studies over time

As shown in Figure 1 below, studies on the integration of LC and sustainability started in 1998 with the work of Huovila and Koskela (1998). Surprisingly, no further work on the topic was explored until 2004 except for one study conducted in Brazil by Degani and Cardoso (2002) promoting the concept of ‘Clean Construction’. Then, IGLC publications on the topic remained stagnant until 2005, where only one study was conducted in the USA by Luo *et al*., (2005) to explore how benefits of LC approaches to prefabrication can impact green project goals. Studies on the topic started blooming from 2011, and peaked in 2012 where seven studies were published in that year. Interest in the topic continued until 2016, but momentum dropped in 2017 with only 2 papers concentrating on the topic, out of 111 published papers (IGLC-25 in Greece). These findings reveal the slow uptake and limited amount of current research on the topic of 'LC and sustainability' within the IGLC community, despite the various theoretical and empirical supports for the synergies and benefits of their integration (see for example, Lapinski *et al*., 2006; Koskela *et al*., 2010; Nahmens and Ikuma, 2012; Ogunbiyi *et al*., 2014; Carvalho *et al*., 2017).

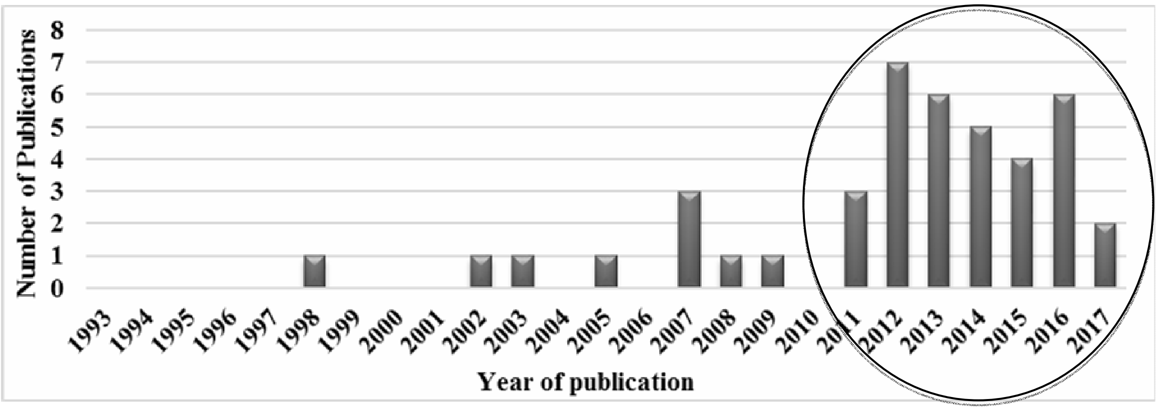

Figure 1: Number of LC-Sustainability studies per year between 1993 and 2017

Geographical distribution of studies over the 25 years span

The geographical distribution of studies scopes across 14 different countries (Figure 2), with USA and Brazil leading the way with 22 publications out of 41 (representing around 54% of the total SLR sample).

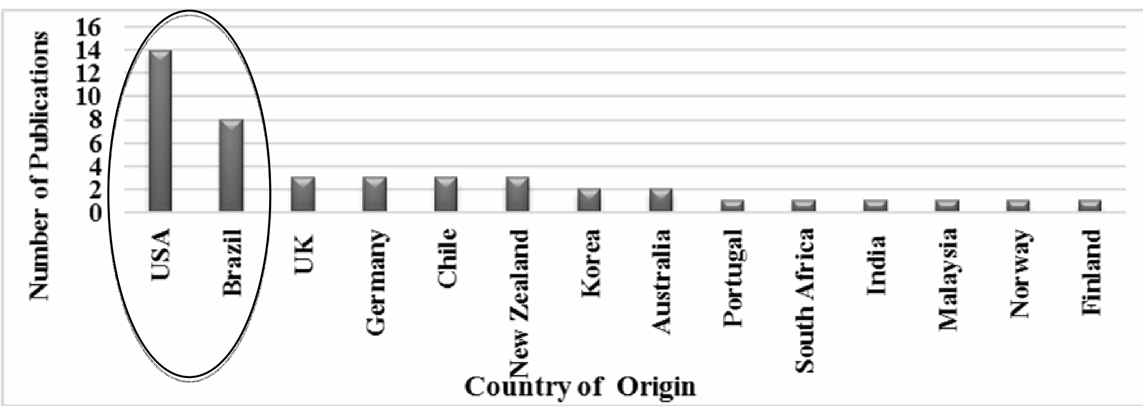

Figure 2: Geographical distribution of LC-Sustainability studies between 1993 and 2017

Research methodologies and approaches used

The SLR identified a number of varied methods used within the IGLC studies investigated (Figure 3). The results revealed that 'case-study' is the methodology mostly used (41%) reflecting the practice-oriented nature dominating IGLC research. These findings suggest that IGLC research has possibly responded to widespread criticisms related to the extensive use of quantitative methods, associated with positivism, in mainstream construction management research (Seymour *et al*., 1997; Koskela, 2017). At the same time, the SLR also identified four research purposes and approaches utilised in the studies (Figure 4), following the classifications defined by Wu and Wang (2016).

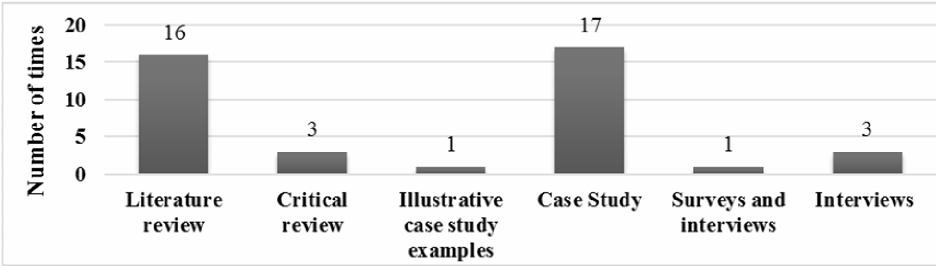

Figure 3: Research methodologies used for topics investigating LC and sustainability

The results revealed that more than two thirds of the studies were exploratory in nature, either conceptually or practically investigating the links between LC and sustainability. Furthermore, only 10% of all studies were carried out to implement and empirically quantify the results of the implementation. The first empirical implementation study was carried out in 2008, and no similar studies were conducted again until 2014. These findings clearly indicate that the integration of LC and sustainability is a topic that is still poorly researched and applied within the IGLC community. This is a growing field and much more work discussing the application of such an approach is hence needed

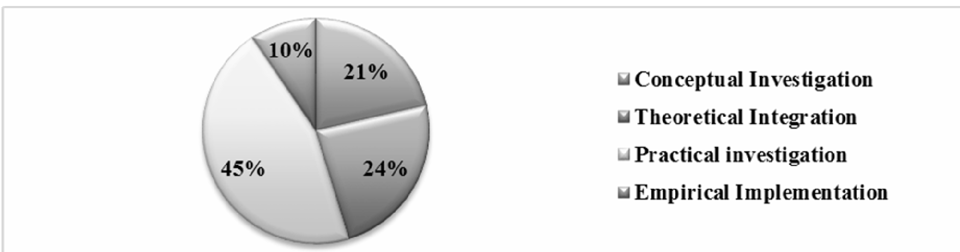

Figure 4: Research purposes and approaches

LIMITATIONS IN APPROACHES TO LC RESEARCH AND PRACTICE

The study qualitatively synthesised how the reviewed studies highlighted limitations in approaches to LC as well as the suggestions they provided for theoretical integration. A summary of results is shown in Table 2.

Table 2: Limitations in approaches to LC as identified from the SLR sample

Author and Year	Categories and Subcategories
	Predominance of a ‘limited’ customer-focused perspective of ‘Value’
Bae and Kim (2007); Carneiro et al. (2012); Huovila and Koskela (1998); Maia et al. (2011); Maris and Parrish (2016); Novak (2012); Salvatierra-Garrido&Pasquire (2011)	▪ Value delivery is limited to a ‘project’ rather than a ‘global’ perspective ▪ Main focus of lean construction is on client satisfaction and not necessarily the wider society and environmental performance • Notion of customer needs to be expanded to include ‘all’ stakeholders • The focus of value is on the end product based on clients' needs, which may not consider environmental impacts • Value generation must be considered in relation to the external

	environment and social problems • The notion of value is mostly focussed on waste-reduction rather than value-creation • Notion of customer needs to be expanded to include the 'Environment'
Arroyo and Gonzalez (2016); Bae and Kim (2007); Huovila and Koskela (1998); Parrish and Whelton (2013); Ramkrishnan *et al.* (2007); Weinheimer *et al*. (2017)	**Little focus and attention paid to the management of the project life cycle requirements (e.g. facilities, operations and maintenance)** • Most studies focus on reducing wastes and costs at the construction stage only; only a very few take a whole project-life cycle perspective
Arroyo and Gonzalez (2016); Bae and Kim (2007); Bae and Kim (2008); Belayutham and Gonzalez (2015); Salvatierra-Garrido and Pasquire (2011)Vieira and Cachadinha (2011)	**The prevailing conceptualisation of 'Waste', which does not account for environmental and social impacts** ▪ The need for a wider understanding of 'Waste' that should consider sustainability. ▪ Traditionally limited in literature to Ohno's 7 wastes (i.e. TIMWOOD) ▪ Most studies focus on assessing LC methods from an economic perspective only

LIMITATIONS IN APPROACHES TO SUSTAINABLE CONSTRUCTION

The analysis of this study led to the generation of two overarching limitations in approaches to 'sustainability in architecture and construction', as illustrated in Table 3.

Table 3: Main Limitations in approaches to SC as identified through the SLR

Author and Year	Categories and Subcategories
Arroyo and Gonzalez (2016); Holloway and Parrish (2013); Johnsen and Drevland (2016); Novak (2012); Weinheimer (2016)	**The over-reliance on formal 'Green Performance Certifications' (e.g. BREEAM and LEED), which limits opportunities for sustainability improvement** ▪ Building in a sustainable manner should be pursued whether or not an environmental performance (e.g. BREEAM or LEED) certification is desired ▪ LEED certifications as a barrier to sustainability goals outside its frameworks ▪ Paying less attention to social and economic aspects of sustainability ▪ Strictly following a criteria catalogue choosing cheapest options or the line of least effort does not lead to sustainability at large. ▪ The current small number of Green Buildings does not realistically help in reducing the greenhouse effect ▪ Focus during certification process is often on achieving credit points, rather than on adding value to the building and developing a useful concept for it. ▪ BREEAM or LEED lead to extra documentation, causing delays and thus productivity losses
Bae and Kim (2007); Carneiro *et al.* (2012); Holloway and Parrish (2013); Koskela and Tommelein (2009);	**Much of the approaches to SC are based on the assumption, in the economic theory of production, of 'fixed input-output relations'** ▪ Main focus is on design and operational stages of projects, but much less attention is given to production delivery stage ▪ Tools and methods used for assessing sustainability impacts of designs/materials in buildings overlook the means and management of production delivery.

Maris and Parish (2016); Parrish (2012); Rosenbaum *et al.* (2012); Weinheimer (2016)	▪ Sustainable design mainly focusses on health, comfort and welling being of occupants and the community, but gives less attention to accident reduction and safety of workers during construction. ▪ Focusses on reducing environmental wastes but less attention to process wastes; ▪ The need for new cost paradigms that consider sustainability 'value', rather than simply 'costs'. ▪ Overlooking the significance of contracts and project delivery systems as ‘means to an end’ ▪ Sustainability valuations often overlook or fail to account for differences in installation and operational time and quality ▪ Use of ‘Prescribed Specifications’ in Sustainable Design as opposed to ‘Performance Specifications’ in Lean Design ▪ Reliance on the use of ‘Green outcome-based’ performance measures, as opposed to ‘process’ performance measures in LC ▪ Without an efficient project management and delivery system, a waste of resources in all possible forms can result, which is not in conformity with the principles of sustainability

OPPORTUNITIES FOR FUTURE RESEARCH ON LC AND SUSTAINABILITY

A comprehensive list of gaps and opportunities for further work has been collated (Table 4). Interestingly, many of these research opportunities are still unfilled and could potentially help to overcome many, if not all, of the flaws and limitations in approaches to LC and SC identified by this study in Tables 2 and 3 above.

Table 4: Opportunities for future research on integrating LC and sustainability

Author and Year	Categories and Sub categories
Novak (2012); Saggin *et al.* (2017); Vieira and Cachadinha (2011); Wu and Wang (2016)	Conducting empirical studies to capture the measurable benefits of integrating LC and sustainability
Ahuja *et al.* (2014)	Developing a BIM-based framework for supporting and measuring LC and sustainability improvements
Arroyo and Gonzalez (2016); Golzarpoor and Gonzalez (2013)	Developing a broader list of wastes to eliminate and to account for environmental and social wastes in all project´s lifecycle stages
Valente *et al.* (2013)	Developing an empirical relationship matrix between LC practices and green practices related to environmental certifications (e.g. BREEAM)
Parrish (2012)	Developing and implementing new cost paradigms (e.g. value-led) when evaluating sustainability options
Emuze and Smallwood (2013)	Development of methodology that would allow the integration of H&S, lean and sustainability for the delivery of project value in construction
Bae and Kim (2007); Luo et al. (2005); Golzarpoor and Gonzalez (2013)	Developing a multi criteria decision-making framework to support the selection of various lean construction practices for sustainable facilities
Holloway and Parrish (2013)	Empirical studies quantifying and highlighting life-cycle costs and pay-back periods to further support growth in sustainable construction
Novak (2012)	Empirical studies to investigate the relationship of the specific project-centric values with company sustainability-values, and the impact on

	project processes.
Huovila and Koskela (1998); Novak (2012); Salvatierra-Garrido and Pasquire (2011)	Examining the opportunity for project 'value' to be understood relative to a broader perspective of global sustainability value. ▪ Project value expressed as economic, social & environmental value ▪ Widening the concept of value in LC to consider society and future generations as potential customers
Weinheimer (2016)	Identifying and eliminating sources of waste that occur within the process of obtaining a sustainable building certification
Bae and Kim (2007)	Evaluating JIT and pre-fabrication techniques from a holistic perspective to increase the sustainability of a construction project.
Valente *et al*. (2013)	Incorporating sustainability plans for purchase and installation of sustainable materials and equipment into LPS look-ahead plans
Salvatierra-Garrido and Pasquire (2011)	Empirical studies to explore how Lean Design can contribute to enhancing client and social values from an early stage of projects.
Holloway and Parrish (2013)	Assessing the changing roles and responsibilities of project stakeholders in sustainable construction projects
Gomez et al (2015)	Investigating the Architectural Technologist's role in linking LC and sustainability
Weinheimer *et al.* (2017); Bae and Kim (2007); Arroyo *et al.* (2012) and (2013)	Using lean Value Stream Mapping and Choosing by Advantages techniques for supporting sustainability choices and purposes

CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to systematically review and critically assess the research progress made by the IGLC community, over a span of 25 years, in relation to integrating LC and sustainability principles. SLRs are valuable for their ability to synthesise and uncover connections between separate studies, describe directions for future research, and provide implications for practice and policy. The findings of this study revealed the slow up-take and limited amount of existing research on the topic (only started in 1998 with a total of 41 studies to date). These 41 studies were conducted in, or produced by authors from, 14 different countries, with USA and Brazil leading the research and practice of this topic (more than 50% of all publications). The study also revealed that only 10% of the reviewed studies were conducted to empirically implement and quantify the measurable benefits of integrating LC and sustainability.

Three major limitations in approaches to LC were identified: (1) The predominance of a 'limited' customer-focused perspective of 'Value'; (2) The limited focus on the management of project life-cycle requirements; and (3) The prevailing conceptualisation of 'Waste', which does not account for environmental and social impacts. However, two major limitations were associated with approaches to SC: (1) The over-reliance on formal 'Green Performance Certifications', which limits opportunities for sustainability improvement; and (2) Approaches to sustainability in architecture and construction that assume 'fixed input-output relations'. Tackling these identified flaws and exploiting the opportunities for future research collated by this study could certainly help to move the research agenda forward and potentially lead to sustainable improvements in practice.

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LEVERAGING TECHNOLOGY BY DIGITALIZATION USING "I REPORT APP" FOR SAFETY AT CONSTRUCTION SITES

Rishikesh Ahirrao[1]

ABSTRACT

Construction industry is highly unorganized in most developing countries and prone to major risks and safety non-conformances. Identification of unsafe conditions and unsafe acts at construction sites is a huge challenge due to less participation from stakeholders, reluctance in filling up the manual formats and inconsistency in hazard reporting, recording and timely closure of safety issues resulting in various wastes affecting organization's Occupational Health and Safety (OHS) performance. Digitization has its issues such as unavailability of a user-friendly systems at construction sites etc. This slows down the safety improvements and risk mitigation initiatives.

In order to address the operational challenges of delivering "Safe projects with the aim of "zero accidents" the organisation took up the task of exploring Information Technology (IT) to create an App suitable to all stakeholders and which would provide a platform for quick redressal of safety concerns and improvement of existing safety processes. The paper explains how the mobile App I-Report was developed by collaborating with all internal stakeholders and how it succeeded in improving the safety performance of the organisation. How digitization helped create safe work sites, reduce accidents and incidents by continuous improvements of safety processes based on IT enabled data analytics is answered in this paper.

KEYWORDS

Lean App, Safety, hand held assistant, hazard identification and reporting.

INTRODUCTION

Hazard identification is fundamental to construction safety management and it is often the unidentified hazards that present the most unmanageable risks. Maximum hazard identification levels were found to be 89.9% for a construction project within the nuclear industry, 72.8% for a project within the railway industry, and 66.5% for a project within both the railway and general construction industry sector. The results indicate that hazard identification levels are far from ideal and an IT tool for construction project safety management is helpful (Gregory Carter and Simon D. Smith, 2006). BIM-based fall

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hazard identification and prevention in construction safety planning with only limited automation in modelling and planning safety processes has been exploited so far (Kristina Sulankivib, Ilkka Romoc Charles M.Eastmand, Jochen Teizere (2015).Also, Javier Irizarry(2012) explores Drone Technology as Safety Inspection Tools while pointing out that the construction industry lags behind many others in the rate of adoption of cutting edge technologies in the area of safety management. Advances in information technology could provide great benefits to this important aspect of construction operations and innovative use of these tools could result in safer jobsites. A comprehensive study by Jochen Teizer (2015) evaluates the capability of the developed Self-Monitoring Alert and Reporting Technology for Hazard Avoidance and Training (Smart Hat) technology, a novel battery-free sensing and communication prototype that also provides alerts in real-time when hazardous proximity conditions are present between heavy construction equipment and ground workers. The construction industry generally struggles to achieve the psychological safety needed for people to speak up. And that same challenge applies beyond safety, to other improvements in work processes, to promoting experimentation - in short, to achieving a lean culture. (Howell, G., Ballard, G. and Demirkesen, S,July 2017).

Construction sites are messy and chaotic places with materials, equipment, vehicles and people all over the place in a constant state of motion. The intrinsic nature of construction activities gives rise to safety hazards galore. At construction sites, multiple trades work simultaneously such as civil work, plumbing, carpentry, tiling, electrical installations etc. and that too under pressure to meet the deadlines, results in a 'perfect storm" giving rise to dangerous, life threatening hazards at its core.

The paper demonstrates how the efficacy of development and implementation of the Application were enhanced using a Lean Approach adopting stakeholder's collaboration, innovative thinking, continuous improvement and Value Stream Improvement. The paper also shows statistics of improvements in safety achieved by using the Lean based App.

CHALLENGES FACED BY THE ORGANIZATIONS FOR HAZARD REPORTING:

The organisation was faced with many existing challenges in hazard reporting at its various construction sites. Listed below are some of the key challenges to safety as felt by various stakeholders:

- Frequent changing workforce at construction projects
- Real time information about hazard available only with the individual observing hazard
- Less participation from all stakeholders
- System inaccessibility leading to reluctance in filling up the formats etc.
- Reporting done only when on duty.
- Non-availability of any user-friendly system at sites.
- Inconsistency in Hazard reports received
- Delayed recording and closure of safety issues
- System generated Trends Analysis not available
- Cumbersome to make available trends and their analysis for safety improvements.

OTHER METHODS OF SAFETY HAZARDS REPORTING PRIOR TO APP

The organisation explored alternate available platforms for Hazard Reporting prior to going Digital with App Development such as:

- Reporting Hazards & Incidents on printed formats.
- Online system to report Hazards & Incidents - The Speed-flow System
- Reporting on social media through WhatsApp Groups.
- Monthly reports to Senior Management using Power Point presentations.
- Telephone calls to team, vendors and other stakeholders involved about prevalent hazards.

However, the challenges of reliable reporting were not addressed by the processes mentioned above.

RATIONALE FOR ADOPTING A MOBILE APP FOR SAFETY REPORTING:

- **No formal training requirement**: The world has seen lot of increase in the mobile users who use variety of apps for online shopping, banking apps, etc. The main advantage of a Mobile App is that there is no formal training required for usage.
- **Ease of Hazard Reporting**: The organization wanted to identify all hazards however insignificant and ensure proper capturing of the hazard transmittals to the authorities concerned for prompt corrective action, analysis and development of preventive action practices by well mapped processes. The App had to be a perfect mix of an automated, streamlined, paperless process that made reporting hazards at sites instantaneous, traceable and easier.
- **Acts as a Lean Tool for ensuring Psychological Safety with Stakeholder Empowerment**: The App was named "I Report" App and the prime requirement was to boost psychological safety to empower construction workers, supervisors, contractors, and management staff by encouraging hazard reporting and their immediate closure thus creating a medium for fast hazard closure using the user friendly App.
- **Help address Lead Indicators versus Lag Indicators for futuristic safety improvements across construction activities**: The hazards provided lead indicators as reported on the App which could be used modifying existing safety to eliminate any incidents or unsafe conditions or acts.

research methodology and stages of app development:

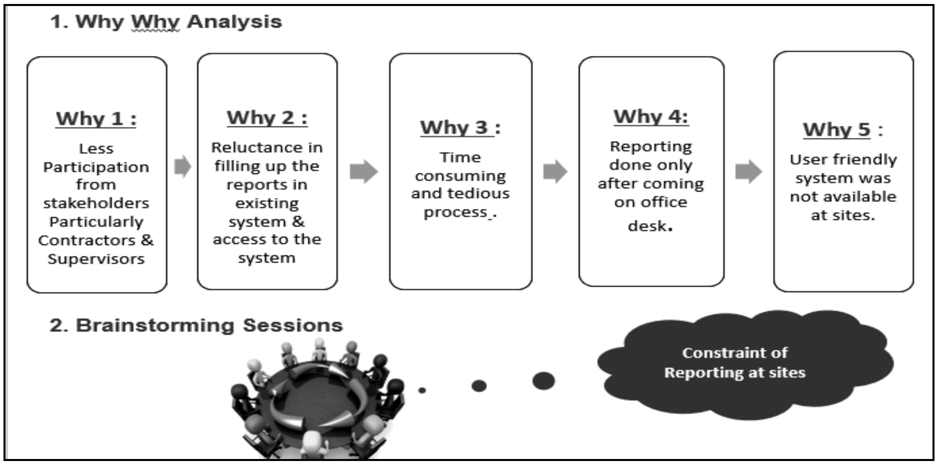


Figure 1: Root Cause Analysis

STEP 1: Capturing Needs and Expectations of the Application:

The organisation conducted a Root Cause Analysis along with a series of brainstorming sessions of Senior Management and stakeholders and a need was felt to have efficient system leveraging technology for timely actions on hazards. Severe constraints such as scattered site locations and deficiencies of existing system as described previously were identified.

STEP 2: Adoption of a Focussed Approach for Lean App Development:

a. Modification of existing Online “Speed flow System”

Despite modification in the existing online system, there were certain drawbacks such as:

Limited Accessibility: Accessible only to the management and other stakeholders were not in a position to report hazards.

Lack of Pictorial or visual information: No feature for attaching the photograph of the hazard in the system for clarity of the person taking action for hazard closure.

Limited safety empowerment: Contractors and other vendors comprising of more than 80% of the work force who working at site were did not have any access to the system.

Delayed Hazard Reporting: Real time reporting from site / area of safety violation not possible.

Reports/Trends Generation Ability: No reports were generated through the system.

b. Collection of Reports from Stakeholders on monthly basis:

In the interim period during the development of the Lean App, in order to ensure complete stakeholder involvement, all the teams were requested to compile and share reports for incidents, hazards, near misses at various construction locations on manual formats.

c. Exploration other Digital Platforms:

The collection of reports, their analysis was cumbersome and there was inconsistency in the reporting as the hazards were not getting captured real time nor was their closure traceable. Also, the information available by the reports were limited to the centralized Safety Team. This made the horizontal deployment and sustainability of good safety practices a huge challenge.

The organisation decided increase the data availability to create trust and transparency by leveraging the existing Social Media platforms like WhatsApp in an attempt to bridge the gap for better communication management .

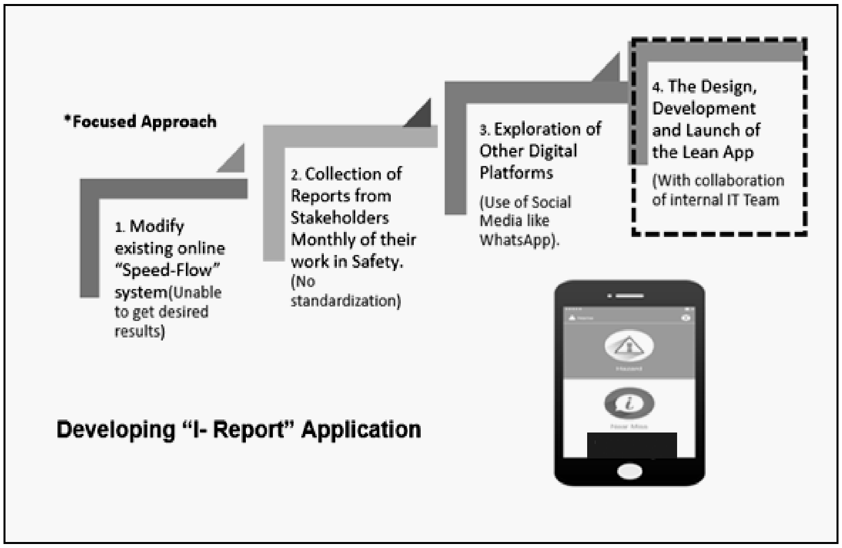
d. The Design, Development and Launch of the Lean App:

Finally, based the shortcomings of the above initiatives made the organisation design the I report App and it was developed internally by the organisations IT department. All that "I-Report" required was a smart phone, mental alertness and a sense of responsibility to report the hazard. It was ensured that interface of the app remained simple and intuitive it did not require any extensive training. Supporting the app at the back-end was the organisations database where all the reported hazards were captured and analysed for initiating corrective measures to avoid such unsafe conditions in the future.

This APP is not just a smart way of reporting hazards, incidents or get data metrics, but is a start of new safety revolution Since inception of this App, reporting and closure of hazards at the organisations construction sites has improved significantly.

This is one of the most effective safety communication system and is likely to become the best practice of not only of the organization but also industry wide.

Figure 2: App Development Stages



A Smart Way to report Hazards & Incidents

Figure 3: "The I Report App"

Uniqueness of The I Report Application:

First Application in India for hazard reporting

Customised to suit stakeholder's expectations.

Low Cost for design, development and maintenance

This App is a perfect mix of an automated, streamlined, paperless process that makes reporting hazards at sites instantaneous, traceable and easier.

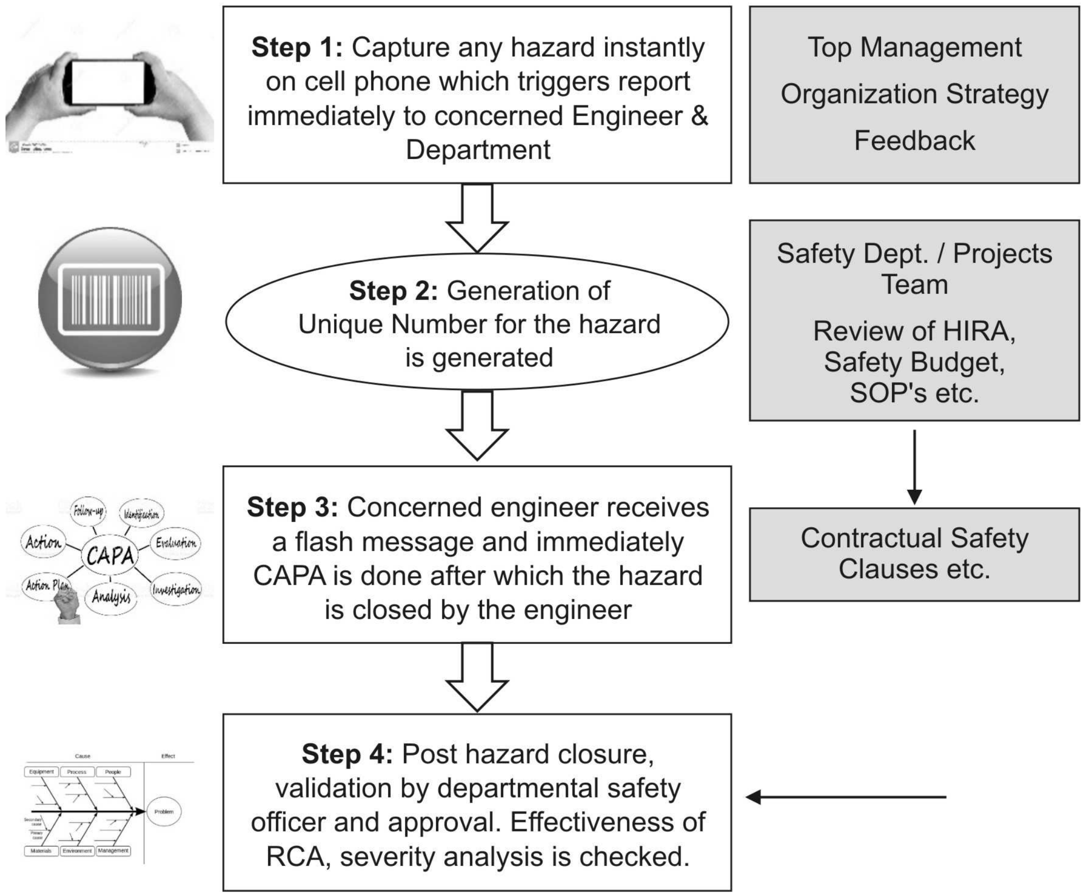
Every hazard has a unique no generated after being reported.

Supported by a strong database system.

Benefits of "I – REPORT" APP

Real time hazard reporting
Boosts Psychological Safety
Futuristic in its approach towards Safe Working Sites
Fast Recording and Hazard Closure
Easy Recording and Closing Near Miss Incidents
Waste Minimization (Time, Cost)
Effective communication management across team
Horizontal Deployment for best safety practices
Consistency and Standardization in reporting of hazards.
Easy Trends analysis with minimal human intervention
Accountability and responsibility in line managers
Availability of safety trends and their analysis activity wise, location wise etc.

What the "I report" App facilitates:
Flow Chart aiming for "continuous improvement"



Flow Process for Hazard Report and closure through the "I Report App"

SUCCESS MEASURES AND RESULTS

TANGIBLE BENEFITS

Hazard Identification increased Multifold: The amount of reporting the hazards has been improved, earlier the hazards in the year 2015-2016 was 1045 and post successful launch and use the hazards reported in the year 2017-2018 were.

Root Cause Analysis of all Hazards: A Detailed Root Cause Analysis (RCA) is being done for all the hazards identified and the results categorised for further actions.

Going Green & Paper less Records: Post launch of the I report app ,100 percent hazards were reported on the app, which helped us in our go green and save paper.

Trend Analysis for futuristic action on Safety Focus Areas: Post report generation shared with teams, stakeholders and Top Management trend analysis for causes of hazards, Senior Management could easily identify its Focus Areas for safety.

Saves Cost of Accident: Hazard reporting, closure, analysis drive process improvements and this reduces the chances of accident and the cost of the accident direct cost and indirect cost is saved.

Continuous improvement of Safety Processes and regular updating of Hazard Identification and Risk assessment (HIRA) Register:
Post the I report App the organisation has updated and added more than 150 safety processes and HIRA register updated on quarterly basis as compared to yearly basis prior to App launch. Proactive and futuristic approach rather than reactive approach has resulted.

INTANGIBLE BENEFITS

Improved Quality of reporting: The quality of reporting the hazards also has improved post "I – Report" launch and Implementation.

Enhanced Responsibility and Accountability: The I report application makes accountable the Plant Managers, Project Managers to close the hazards reported within the specified time (72 hours maximum). Aging analysis of hazard closure drives performance of Project Managers, Safety Officer and their teams.

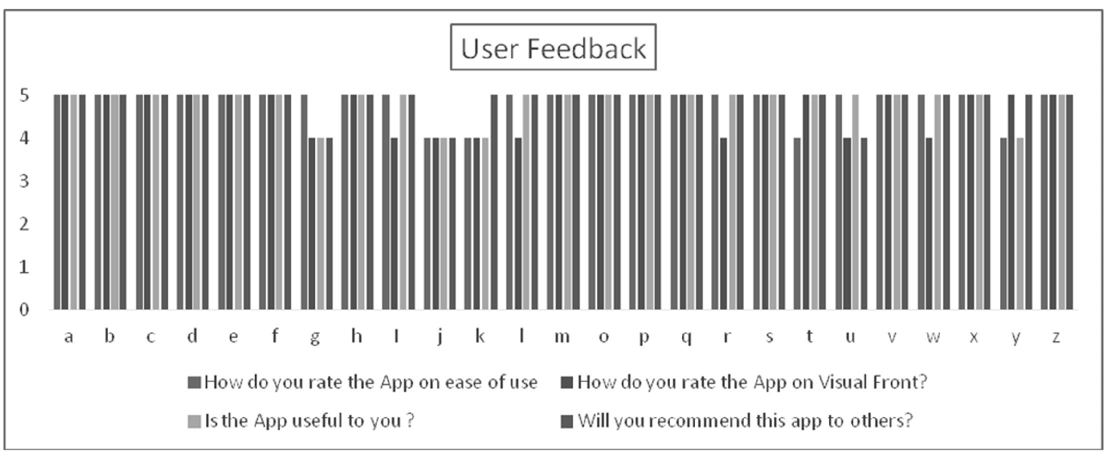


Figure 4: Graph indicating stakeholders feedback

FEEDBACK (VOICE OF THE STAKEHOLDERS) OF THE APP:

Customer A

"I report App" - Great Initiative by the organisation to attain the goal of Zero Incident.

Customer B

User Friendly App, now my team can capture all the hazards without going to desk to report it and saving a lot of time

Customer C

Great App, for safety, looking forward to using new apps reducing work load

Customer D

Good Initiative by the organisation and extending the use to its vendors and contractors.

CONCLUSION

Adopting a safety philosophy emphasizing "Respect to Human Life "which improves morale of all stakeholders ultimately leads to improved business performance. Apps such as "I report" facilitate collaboration for creating accident free sites by providing a platform for quick hazard reporting and their immediate closure thereby reducing probable accidents which can cause human losses, productivity losses ultimately affecting overall project performance and hampering brand image. The whole purpose of bringing technology was to improve psychological safety by empowering every stakeholder working for the company with the ultimate aim to make construction sites in the organisation safe and motivating workplaces.

Diligent Root Cause Analysis and Corrective and Preventive Action for repeated hazards leads to elimination of unsafe conditions by driving change initiation activities in conventional operational procedures or workflow methodologies followed in the industry thereby setting a benchmark by f continual improvement enabling the organisation set standards in safety to the nation.

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TOWARDS CREATIVE LEAN (CLEAN) CONSTRUCTION: FROM LEAN PRODUCTION TO LEAN CONSUMPTION

Vishal Singh[1]

ABSTRACT

The current approaches in lean construction are primarily production oriented. More recently, there has been greater attention towards what we design, based on approaches such as Target Value Design. Despite these developments, the need for production is taken as the default starting point in the design explorations. On the other hand, new business models and approaches such as Space-As-A-Service may at times eliminate the need for any production at all, and yet deliver the desired functionalities and values to the target users and customers. Such solutions, based on principles of shared resources and sharing economy can be viewed as ‘Lean consumption′ models that eliminate waste in consumption patterns itself. Since such alternative approaches require divergent thinking, there is need to integrate creative design methodologies in lean construction practice. Therefore, this paper aims to initiate this discussion on Creative Lean (CLean) Construction, as a step from lean production to lean consumption.

KEYWORDS

Creative Lean Construction, Lean design management, Lean consumption, missed opportunity, disruption

INTRODUCTION

Together with digitalization, lean construction and management is one of the key goals driving the future of construction (Armstrong et al 2016, Agarwal et al 2016, WEF and BCG 2016). Nonetheless, the current discussions and approaches in lean construction are primarily production oriented, aiming to reduce waste in how we design, build, construct and manage built facilities (Koskela 2000). More recently, there has been greater attention towards what we design, based on approaches such as Target Value Design, which emphasize lifecycle value proposition and value analysis (Zimina et al 2012). Despite these developments, in general, the need for production is assumed, and that is taken as the default starting point in the design explorations. On the other hand, new

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business models and service-oriented approaches such as Space-As- A-Service may sometimes altogether eliminate the need for any physical production at all, and yet deliver the desired functionalities and values to the target users and customers. For example, services such as Air BnB can in some instances eliminate the need for a new hotel because there might already be accommodation alternatives for visitors in a given locality (Zervas et al 2017). This not only changes the dynamics of the real estate business, but it also affects decisions pertaining to design and construction. Thus, solutions based on approaches such as shared resources and sharing economy may be termed as 'Lean consumption′ approaches such that we eliminate waste in our consumption patterns itself. The proposed lean consumption view can also be seen as extending the 'waste in overproduction' concept to higher levels of abstraction, opening new opportunities in how we conceive what and how we design and use spaces and the built environment in the future. Given that the exploration of such alternative approaches requires divergent thinking, there is need to integrate creative design methodologies in lean construction. This paper *aims* to initiate this discussion on the Creative Lean (CLean) Construction, as a step from lean production to lean consumption.

The *primary questions raised in this paper are*: How do we build an understanding of lean consumption, and how is it going to be different and complementary to lean production? Are the established theories and methodologies in lean construction adequate to explain the scope of lean consumption or can we extend them building on theoretical models from cognitive design research? How does a lean consumption approach fit within the scope of lean construction? This paper takes the first steps *towards building a theoretical and conceptual understanding* of lean consumption in construction.

METHODOLOGY

This paper is based on theoretical arguments, reflective research (Fook 1996, Schön 1983) and thought experiments (Brown and Fehige 2017). Both reflective research and thought experiments are qualitative research methods suitable for abductive reasoning on topics where inductive and deductive reasoning is difficult, and where empirical data is either not available or not particularly useful.

Reflective practice is considered particularly useful as an iterative process in building what-if scenarios, where new solutions and problems emerge as the iteration progresses through multiple steps. Building such iterative scenarios can be part of thought experiments. As Brown and Fehige (2017) write about thought experiments, "...Historically their role is very close to the double one played by actual laboratory experiments and observations. First, thought experiments can disclose nature's failure to conform to a previously held set of expectations. Second, they can suggest particular ways in which both expectation and theory must henceforth be revised…".

Therefore, we used thought experiments to assess whether the current discussion on lean construction meets the expectations, or whether we can identify gaps and theoretical lenses to revise the scope and objectives.

BACKGROUND

TRENDS IN LEAN CONSTRUCTION RESEARCH AND PRACTICE

Some of the key concepts that have gained particular attention and traction in the lean construction research in recent years include:

Last Planner Systems (LPS) (Ballard 2000a) has been a popular lean method that emphasizes collaborative planning, weekly updates, feedbacks and revisions, with clear decision protocols has shown proven results. The delegation of responsibility and power of influencing the master plan to the “last planner”, the people on the team responsible for making the final assignment of work to specific performers and ensuring that they have the materials, equipment, and information available to complete their assignments.

At the interface of BIM and Lean, there is increasing recognition of how BIM tools and processes can support several lean construction principles, including reduction in cycle times, increased flexibility, standardization, use of visual management, improving flow and value, and so on (Sacks et al 2010). While there is increasing role of technology in achieving lean objectives, there is also a greater realization that technology alone will not solve the problem, and the social and organizational aspects need to be improved in BIM processes and practices. The emergence of Integrated Project Delivery is one of the most significant contractual and collaborative practice to emerge at the interface of BIM and lean (Matthews and Howell 2005). The relational contracts, and shared responsibilities and rewards, mark a notable shift in how construction projects can be managed more efficiently.

Target Value Design (TVD): The emphasis on delivering value has always been a critical part of lean philosophy, but more recently the emphasis on identifying and targeting core customer value, taking the lifecycle perspective upfront in the design phase has grown significantly with the TVD approach (Zimina et al 2012). TVD relies on early and continuous engagement of customers and key stakeholders in the design process; close collaboration between all stakeholders, and; focusing on designing to a target value and estimate, rather than estimating the value after the design is done. TVD draws early attention towards the need for continuous improvement; expecting teams to deliver innovation that requires learning and re-planning, and; work with set-based design allowing multiple options to be retained in the design process.

TVD builds on the objectives laid out in the Lean Project Delivery Systems (LPDS) (Ballard 2000b, 2006, 2008), which emphasizes iterations and learning loops across the project lifecycle, including the need for attention towards project definition, purpose and use. LPDS reiterates the need for better articulation and mapping of ends, means and constraints in a project, consistent with the Theory of technical systems (Hubka and Eder 1988) and associated methodologies such as value analysis, function-means trees, etc.

Design management: The growing discussion on various aspects of design including early engagement of various stakeholders, TVD, collaborative and concurrent design, set-based design, etc is reflective of the recognition of the importance of design management (e.g. Koskela et al 1997). There is need to reduce waste in the design process, reduce rework, and focus on value added activities. Based on the review of design management literature in construction, Uusitalo et al (2017) identified the following key categories associated with lean design management (LDM):

- Social processes (LPS, Big Room, co-location, Integrated Concurrent Engineering, Collaborative Planning in Design)
- Methods (Level of Detail, Location-Based Design Management, TVD, Set-Based Design, Choosing By Advantages, Real-time cost estimation)
- Tools/ Technologies (Virtual Design and Construction, Design Structure Matrix (DSM), Dialogue Matrix, A3 Report, Scrum)

LDM is an emerging sub-research area, and together with greater industrialization, prefabrication and process improvements in the construction process, several other methods and approaches from engineering design research such as Design for Manufacturing and Assembly (DFMA), etc are increasingly being explored and discussed in the lean construction research. Therefore, it is timely to review the scope of current approaches to LDM in construction, identify the core assumptions and basis for LDM discussion, and ascertain areas where LDM can benefit from the prior research in complementary areas of design research (e.g. Gero 1990, Dorst and Cross 2001, Lawson 2005). Following are the notable points associated with LDM:

- As the name goes, LDM is about design management, with the focus on reducing waste in how design is managed. Thus, the focus is on the management of the design process, rather than the design process itself, where design process refers to the cognitive act of designing, generation of design and design alternatives. LDM discussions currently do not go deeper into questions such as how ideas or solutions are generated or how design alternatives are arrived at? Instead, it goes onto aspects such as how many ideas or solutions were generated, how many of those were detailed further, how the set of ideas were managed and retained until later phases, and so on. Thus, LDM and design management adopts an operational view of design, dealing with tangible, tractable, and observable tasks, while intangible, covert processes associated with thinking and reasoning are not adequately accounted for. Even the iterative design processes are described differently in the design management literature and the cognitive design literature, such that the iteration in design management is described in terms of Plan-Do-Check-Act (PDCA) cycle of tasks and activities (Ballard and Howell 1994), while the iterations in cognitive design literature is described in terms of cognitive processes such as the Exploration- Generation- Evaluation-Communication steps described by Cross and colleagues (Cross 1992, Dorst and Cross 2001) or the iterative Function-Behaviour- Structure (FBS) framework and situated FBS framework of Gero and colleagues (Gero 1990, Kenningiesser and Gero 2004).

- The distinction between operational and cognitive views of design process is not trivial, especially in terms of tractability of value added activities and the assessment of waste. Since operational view is tractable and more transparent, it lends itself more accessible for external assessment of productivity and waste. In contrast, the cognitive processes remain mostly opaque, and hence, difficult to track and identify productive and non-productive sessions. Nonetheless, cognitive processes are the basis of decision making, and hence, cannot be overlooked for the lack of adequate measures to track and assess productivity.

- Another notable difference in the cognitive view of design is the recognition of the co-evolution of problems and solutions. In the cognitive design process, problem formulation and reformulation are considered an integral part of design iterations (Schon 1983). The openness to reformulation of the problem lends cognitive view more conducive to radical and disruptive changes in the definition and formulation of the design problem, unlike the operational view which tends to constrain the scope to incremental changes.
- LDM and the design management discussion in lean construction is currently focused at the design of the artefact, that is, the design of the target built facility. Consequently, the methods and approaches are product and production oriented. In contrast, the cognitive design literature takes a wider view of design, including design of processes and organizations.

DIGITALIZATION DRIVEN TRENDS IN BUILT ENVIRONMENT

Digitalization is expected to bring about a paradigm shift in the built environment and the construction sector (Armstrong et al 2016, Agarwal et al 2016, WEF and BCG 2016). Several notable trends are emerging, both in terms of the production process as well as the consumption process. In the recent years, the scope of BIM has continued to grow across the project lifecycle (Yalcinkaya and Singh 2015). Technical advancements in diverse areas are being proactively introduced across several pilot projects with potential for radical changes across various traditional activities. Similarly, there is opportunity and discussion around intelligent products, wireless monitoring and other advancements, which have potential for transformative impact.

In general, several of these technologies are being explored on experimental basis, occasionally based on open-ended and unstructured brainstorming of potential use case scenarios. There is limited evidence on whether these experimentations follow a planned process or opportunistic shift and exploration in solution approach based on novel technical paradigms. If it is the latter, it raises the question whether these paradigm shifts can be explained adequately using any of the LDM methods or current theories in lean construction, or if we need to draw upon the theories and models from creative design methods to explain the novelty of explorations and paradigm shifts. For example, a single-family unit can be constructed using different production systems ranging from traditional and labour-intensive brick-mortar construction to fully automated contour printing process. Using lean principles and theories we can compare which of these processes is better, and how each of these processes can by themselves be improved further through continuous improvements. However, none of the lean methodologies adequately explain or support coming up with alternative production methods. That is, lean methodologies support requirement analysis, explain iterative processes, explain transformation, flow and value in the design process, but none of these methodologies adequately explain or support disruptive reformulation of the problems and solutions.

In contrast, the cognitive design models and methodologies are open to problem reformulation and expansion of the conceptual design space. The design cognition based models and methodologies can explain and support both incremental and radical solutions, including disruptive paradigm shifts. Several of the creative engineering design and ideation methodologies such as TRIZ (Theory of Inventive Problem Solving), morphological charts, 6-3-5 brainwriting, etc are aimed at expanding the design space, creating new opportunities and alternative solutions which can lead to incremental as well as radical improvements (e.g. Altshuller 1984, Savransky 2000). Therefore, it is timely to integrate some of the methodologies and insights from the cognitive design models into LDM to keep up with the wider disruptive trends emerging in the society.

WIDER SOCIO-TECHNICAL TRENDS AND THE CONSTRUCTION SECTOR: EXPECTATIONS FROM DESIGN AND INNOVATION

The current optimism and expectations for significant leap in productivity and quality in the future of construction is consistent with wider global trends, including rapid technical advancements across various digital technologies, recognition of aggravating mega-challenges such as resource constraints and issues listed in sustainable development goals (UN 2015), and resulting changes in ways of working and operating at all levels. Following are some of the factors transforming societal expectations from the construction sector:

- With several technical advancements maturing at the same time, the visions towards industry 4.0, towards a highly connected, smart society, autonomous systems, mass customization, etc are beginning to take more realistic form. Given the expectations of the next major cycle of societal revolution, various aspects of construction sector are likely to be challenged. We are entering the phase of widespread ideation and experimentations. How do we account for these experimentations and opportunities in the lean methods in a methodical way?
- With greater technical maturity, several of the new tools and hardware have also become readily available and affordable for wider consumption. The scope for innovation and systemic disruptions is not only limited to established companies and firms, but small group of individuals have unprecedented opportunity to trigger such disruptions with innovative solutions. Thus, established companies can hardly afford to focus entirely on established methods and practices, and they need to be alert to potential opportunities and threats that can escalate and diffuse rapidly, even in sectors that have traditionally been slow to respond to societal changes.
- The greater connectivity to build peer to peer networks and distributed systems has also resulted in the decentralization and horizontal expansion of the supply chain. The distinction between who can produce, who can supply and who consumes is getting blurred. Anyone with skills and resources can offer their

services through online marketplace, produce goods in remote locations through digital manufacturing, and deliver it to customers through a logistics company.

- The peer to peer network and online marketplaces have also contributed to the rapid rise in service-oriented thinking, disrupting several product based industries that are moving towards product service systems to remain competitive. This has also led to emergence of the shared economy paradigm that allows greater sharing of resources and changing consumption behavior. It provides the alternative to deliver customer value through realignment of existing resources, without the need for production of new products. AirBnB is one such example.
- With greater emphasis on sustainability goals, lifecycle considerations, as well as improved ability to track and monitor the lifecycle details of produced goods and services, there is greater social, economic as well as political pressure towards approaches such as sustainable consumption and circular economy.
- There is an explosion in organized entrepreneurial activities, and new business models are being explored (Lindgardt and Ayers 2014). Established business models, management theories, and best practices may not necessarily be useful in all cases. Creative explorations will be expected, while at the same time following lean theories and approaches. For instance, lean startup methodologies (Ries 2012) have evolved emphasizing the need to focus on minimum viable products (MVP) and establish a build-measure- learn feedback loop.

Given these trends and rapidly changing technical as well as business landscape, established theories and best practices may need a closer inspection to plug the conceptual and theoretical gaps. The next section makes conceptual and theoretical propositions for further research and development of lean theories and methodologies.

CONCEPTUAL AND THEORETICAL PROPOSITIONS FOR FUTURE RESEARCH AND DEVELOPMENT

LEAN PRODUCTION TO LEAN CONSUMPTION

The lean construction methods and theories need to expand beyond lean production models to include lean consumption models. With the changing supplier-consumer relationship, greater emphasis on service oriented thinking, emergence of shared economy and similar approaches to resource realignment and reuse, there is opportunity to respond to as well as change consumption patterns and consumption behavior, while still delivering customer value. However, that would need a change in the mindset of traditional production- based sectors to acknowledge and embrace these possibilities, and identify these changes as business opportunities rather than threats.

In addition, there is need to develop the concept of lean consumption further to distinguish it from the concept of sustainable consumption, which primarily focuses on lifecycle management and circular economy. Similarly, such an approach can draw upon several complementary themes such as ‘adaptable use’ or design for adaptability (Beadle et al 2008), sharing in design (Chakrabarti2001, Chakrabarti and Singh 2007), etc. While the sustainable consumption objectives should be included in the lean consumption approach, it is argued that the scope of lean consumption can be broader, applicable at various levels of details and from individual tasks to industry level activities and processes.

LDM TO LEAN DESIGN MANAGEMENT AND DESIGN PROCESSES (LDM-DP)

There is a need to distinguish between design management, design methodology, and design thinking (Gerbov et al 2017). While design management adopts operational view of design, design methodology and design thinking focus on the cognitive view of design. Though operational and cognitive decision making are related, the current scope of LDM is limited to the operational aspects, giving only partial opportunity to realize and improve the potential of the design phase. Including the design methodology and design thinking in the lean design methodology should allow wider exploration, and greater exploitation of alternative opportunities that may arise from structured creative engineering methods.

'MISSED OPPORTUNITY' AS ANOTHER CATEGORY OF WASTE

The primary objectives of lean principles revolve around reduction and elimination of waste. The seven categories of waste in production (Ohno 1978) including overproduction, waiting, transportation, processing, inventory, movement, and making defective products, provide the foundation for the lean theory and methodologies. Besides these categories of waste that apply to any production system, additional waste categories have been proposed specifically based on insights from construction projects including 'making- do' (Koskela 2004), as well as 'Not listening' and 'Not speaking' that were proposed by Macomber and Howell (2004). These additional categories of waste are interesting because they extend beyond the strictly observable production related wastes to include more subjective aspects that are closer to decision processes. As Bertelsen (2004) notes, categories such as 'Not listening' and 'Not speaking' broadly refer to waste due to inaction. However, inaction is not merely limited to conversation and communication, but it can have a much wider implication, especially when we argue the need to extend the scope of lean construction from a production view to include the consumption perspective as well. Consequently, 'missed opportunity' is proposed as a category of waste that subsumes 'Not listening', 'Not speaking' or any other opportunity lost due to inaction or neglect.

While 'Missed opportunity' as a waste may be applicable to a wide range of production and operational scenarios, it is particularly relevant to lean construction, especially if we aim to achieve creative lean (Clean) construction proposed in this paper. This claim is based on the fact that unlike the traditional manufacturing industry that relies on fixed assembly lines, moulds, and production infrastructure that constrains the production system for years after setup, the project based nature of construction industry allows opportunity for construction firms and organizations to make changes in their production system both within and between construction projects. Thus, there is greater flexibility to spot or create opportunity for changes and improvements to be made, and to realize them in practice.

Similarly, as emphasized in TVD as well as the models of design process, the iterations and feedback in the design process allow opportunities for reformulation of the problems and solutions, including radical shift in the approach. But are those opportunities for problem reformulation exploited or does the sunk-cost effect lead to wasted opportunities?

Such wasted opportunities can be found across several phases of the construction project, but they can be particularly detrimental in the early conceptual design phases or early planning phases when critical decisions are made. Since most construction projects are unique, and have unique design development requirements, 'missed opportunity' as a waste is particularly relevant to construction projects. In the end, the changing socio-technical landscape offers a wide range of opportunities for improvement in the productivity of the construction sector, and the rate of adoption of new technologies and processes is contingent on whether we begin to see 'missed opportunities' as waste or not.

CONCLUSIONS

This paper argues the need to extend the scope of lean construction beyond lean production to include lean consumption. To achieve this objective creative engineering methodologies need to be included as part of the lean design methodologies. It is expected that incorporating creative design methodologies in the lean design methods will widen the exploration of potential opportunities to achieve lean objectives. 'Missing opportunities' is proposed as another category of waste, which is particularly relevant to capturing value from feedbacks and iterations. The discussions and arguments presented in this paper are aimed to initiate a discussion on lean consumption and creative lean methodologies.

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INNOVATIVE QUALITY MANAGEMENT IN A LEAN WORLD

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ABSTRACT

By strict definition, the appraisal of quality is waste. It consumes resources, but does not directly add value to the work that is being appraised. It indicates what the actual value is, and in many cases why the work might not have met the required value. However, the appraisal of quality is a necessary waste. Without the appraisal of quality, those who are ultimately accountable for the work do not know whether or not the work meets requirements before it is accepted and incorporated into the project. And, even though it does not add value to the work itself, it adds value to our confidence about the quality of the work, which is often necessary to be paid for the work, to warranty the work, to insure the work, or to even allow public occupancy of the work. So how can stakeholders reduce the resources necessary to appraise quality without reducing the level of their confidence? Can the right type of innovative practices reduce the expenditure of resources but at the same time actually increase the confidence in the quality of the work? This paper will discuss actual methods of innovative quality management that have been used on public infrastructure projects within the United States by licensed professional engineers.

KEYWORDS

Value, waste, process, quality, innovation

INTRODUCTION

DID YOU FILL OUT THE PROPER FORM?

For decades, the primary tool for documenting the quality of design and construction project delivery has been the paper form: forms for check prints, forms for checklists, forms for inspections, forms for sampling, forms for testing, forms for reporting measured quantities, and even forms to request more forms. Forms were a development of the industrial revolution, where information had to be collected in a standardized structure to allow for efficient filing and forwarding to the proper department. But, in spite of the new, enabling capabilities manifested by the information revolution, these legacy practices of filling out forms remain with us. Project delivery needs new practices better suited to collecting, managing, analyzing, and reporting actionable data.

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Many of these obsolete practices reflect the way traditional project delivery manages the quality of the constructed project. Which evolved in the world of industrialization and organization of work by task. Terms such as “Quality Control” (QC) and Quality Assurance (QA) are often used ambiguously. In many cases, it is difficult to determine exactly what the “QC” person is controlling, or exactly what the “QA” person is assuring. Worse yet was the all-encompassing term of “QA/QC”; regularly invoked as the culprit for any problems where the actual causes are not even known. In the pursuit of accuracy, the American Society for Quality (ASQ) has worked to replace these terms with 1) “Prevention”, which is the activity which ensures value is incorporated into the work, 2) “Appraisal”, which is the activity which determines what the value is, 3) “Internal Failure”, which is the consequence of discovering defective work before it is incorporated into the project, and 4) “External Failure”, which is the cost of undiscovered defects remaining latent until they fail during use. Each of these categories has a cost that is increasingly greater the further the work progresses before the defect is discovered. Prevention consumes some resources but is needed to create the value; Appraisal consumes additional resources but only determines value, Internal Failure consumes even greater resources (removing and replacing the faulty work) and only provides the value that should have been there in the first place, while External Failure can consume a catastrophic level of resources and threaten public health, safety, and welfare.

FASTER, BETTER, AND CHEAPER?

Lean Construction, found in various forms and stages of maturity in an increasing number of non-traditional project delivery models such as Integrated Project Delivery (IPD), Integrated Form of Agreement (IFOA), Public-Private Partnerships (PPP), Design-Build (DB), etc, is improved if we can work towards the elimination of the obsolete quality management philosophies. Postma et al. (1998) documented the requirements for ISO 9000 certification by the contractor on the I-15 design-build project in preparation for the 2002 Winter Olympic Games in Salt Lake City, UT. Gargione (1999) argued for the implementation of Quality Function Deployment (QFD) on middle class apartment units. This was focused primarily on QFD in the design phase. Goh et al. (2001) argued for the use of the Internal Quality Audit (IQA) within an overall Quality Management System (QMS), and also argued for the benefit of a company obtaining ISO 9000 certification. Marosszeky (2002) argued for a more process-focused approach to quality management. By concentrating primarily on process, an organization can avoid the negative effects of trying to impose the document-focused ISO 9000-1994 philosophy onto construction projects. The paper also argued for improved deviation detection, as well as shorter cycle times from detection to correct. Thomas (2002) argued that the traditional market focus of quality is too heavily focused on error detection, but a “clan” approach to quality will focus on error prevention. Misfeldt (2004) argued that the quality control systems that are an integral part of lean manufacturing were still maturing in lean construction. Walsh et al. (2004) found evidence for a relationship between delays and failed inspections (internal failure), which would indicate a failure of prevention. Marosszeky (2005) argued that quality control mechanisms can help to prevent construction defects. Saha (2005) argued that certain cultures might be incompatible with the concept of total control. Tilly (2005) argued that deficiencies in design and construction documents are a key contributor to errors in construction. Hofacker (2008) argued that the leanness of quality on a project could be measured in a systematic model. Lima et al. (2008) argued for the use of visual displays and QFD for low-cost construction. Tommelein (2008) argued for the incorporation of mistake-proofing so that appraisal would be unnecessary. Sullivan (2011) argued that quality could be found by selecting the most qualified constructor through best value. Fireman, et al. (2013) argued for more integration between production and quality control. Bjornfot (2013) argued for a QFD based on human experience rather than technical requirements. Leao (2014) argued for integrating production with quality control using information technology; this focused on the type of work being performed, such as "making-do." Ibarra (2016) continued the argument for the integration of production and quality control.

Clearly, the subject of how to improve systems of quality in the built environment has a wide spectrum of theories about the problems and the best practices to address them. However, regardless of the type of quality management philosophy, the basic fundamental concepts of responsibility and control still apply. These concepts assert that the *entity in the best position to control a process should be responsible for it, and that an entity assigned responsibility for a process should be allowed to control it without unnecessary interference* (Fischer, 1999).

To assist in the analysis of innovative quality management methods, we can separate the concepts into a taxonomy of five key categories: Requirements, Design Process Control, Design Appraisal, Construction Process Control, and Construction Appraisal (Kahler, 2012).

INNOVATIONS IN REQUIREMENTS

Requirements Management comes from Systems Engineering, which is an engineering discipline developed during the Cold War that educates engineers in the integration of multiple disciplines into complex systems. Requirements management is a process to objectively document requirements so they can be agreed upon and controlled. One of the keys to modern requirements management is the relational database.

Traditional construction contracts usually communicate requirements in narrative-style scenarios that are intended to be read and interpreted by the person responsible for producing the work that needs to meet requirements. In systems engineering, requirements are structured in a relational database that links each requirement to other requirements that affect it or depend on it. This relational database of requirements is modified by the negotiating parties until agreement is reached, at which time the data becomes the contract document. This approach of developing the contract as a relational database makes it easier to manage the communication, fulfilment, and verification of requirements in a structured system.

A number of innovative delivery projects have attempted to extract legacy, narrative-style construction contracts into a requirements management system. However, a weakness of extraction is that formal changes to contracts are done in the source document, causing any extracted data to become quickly obsolete. A requirements management system that only points to sections in the contract without mirroring the actual text would mitigate the problem of requirements not being current, and allow some minimal automation of quality management data.

If nothing else, communicating specifications in traditional civil engineering contracts as structured requirements can help with the disparity between narrative-style writing and automated requirements management. The general characteristics of good requirements, as defined by the International Council on Systems Engineering (INCOSE), are:

Necessary –must be necessary for performance of the system;

Appropriate - must be regularly re-evaluated to make sure it's still needed;

Unambiguous - must have only one interpretation;

Complete - must contain all the information needed to define it;

Singular - must address a single characteristic;

Feasible - must be reasonably achievable;

Verifiable - must be capable of being measured;

Correct –must accurately represent the desired outcome;

Conforming – must be consistent with an overall style;

Consistent - must support and not contradict other requirements; and

Comprehensible –must be written in understandable language.

Focusing on the development of good requirements can reduce the need for the "tribal knowledge" that is so prevalent in the traditional project delivery model. This "tribal knowledge" consists of things that practitioners know in the design and construction process that are critical for project success, but remain undocumented in the official contract documents. In traditional project delivery, the same design and construction professionals are often used for the same agency or geographic area, so this knowledge can be retained and applied even in the absence of writing. But in modern global project delivery, design and construction engineers are often pulled together from all over the world, and can only rely on the written contract documents for the standards and specifications necessary for performance.

Innovations in Design Process Control

Traditional design process control is based on legacy technologies, namely ink and mylar plans sheets and paper calculation pads. These were the primary documentation tools of the profession until about mid-1990's. However, even with the enabling technologies developed in our digital age, design quality management for process control is often still based on the *old methods of the checkprint and checklist*.

The checkprint was originally a design quality management tool that allowed engineers to control the quality of the mylar plans sheet without having to come in physical contact with it. The checkprint was a cheap, expendable reproduction of the mylar that allowed the professional to check the drafting quality, and communicate additional changes that the drafter needed to make to the original plans sheet. The archived checkprints also served as an audit trail of each element that was designed, drawn, checked, and approved.

Digital design environments have made the old methods developed around ink and mylar technology obsolete. These enabling technologies make the checkprint, even those produced as a an electronic PDF, unnecessary for the purpose of allowing the engineer to review, comment on, and direct changes to, the master design. The reviewing design professional can reference the source 2D or 3D design models in real time, and make their comments in separate 2D or 3D design models that give the production design professionals nearly instant feedback. Archived 2D or 3D review models also provide an unlimited audit trail of how the design evolved and comments were implemented.

The checklist is also a holdover from legacy production methods. Often checklists will ask drafting-based questions as a proxy for issues that are really about design. This may have been useful back in the days of preparing graphical information on mylar, but are not effective in a modern design process. A more innovative approach would be to have process check points that ask questions customized for that particular level of development, so they ask questions relevant to the requirements for that part of the process.

Innovations in Design Appraisal

Even in innovative project delivery where control of the design is transferred to the project delivery team, the owners, owner's representatives, and other key stakeholders demand some early proof of whether or not the evolving design is meeting their needs and requirements, even if those needs and requirements are subjective or not in writing. In traditional project delivery this was usually accomplished by labor-intensive interim submittals of the in-progress design in the format of the final construction documents. However, on innovative projects, even with all design in digital form, we still see legacy contract requirements for the project delivery team to submit these interim documents for review as if they had still been created in ink on mylar sheets.

Owners and stakeholders often mandate the legacy processes. Many do not have access to, or training in, the same technologies that firms use to create the design. There are ways to ease the anxiety of owners and stakeholders faced with modern design information. Design firms can, and have, sponsored regular design reviews where no physical document is produced for review. Instead, the live design is projected on the wall and all interested parties are walked through each design element.

While this may require some investment in time and technology on the part of the design firm, this cost can be more than offset if the stakeholders will *then relieve the design firm from producing interim construction documents*. An additional benefit, which is often more powerful than the design review itself, is the fact that the reviewing stakeholders are in the same room, where they can work out differences in real time, instead of *using conflicting comments to the design firm as an indirect form of resolving different design opinions*. The practice of various reviewers fighting each other with the design team in the middle not only adds time and cost without adding any value, but often introduces easily avoidable errors and omissions that would not have been created if the design team received consistent direction.

Innovations in Construction Process Control

In innovative project delivery, the construction team has greater access to the digital design information than in traditional project delivery. This can provide opportunities for construction process control that would be more difficult to achieve using only information obtained from traditional construction documents. Some of these innovations include automated machine guidance based on certified design models, tailoring of the design model to take advantage of specific digital production technologies preferred by the contractor, customization of specifications to focus on better indicators of construction quality in lieu of traditional metrics, and real-time response for redesign caused by unforeseen conditions. While the traditional goal of construction process control has been to merely conform to the contract requirements, an improved digitally-enabled goal can focus on the fundamental performance characteristics from which those requirements were derived in the first place. requirements, particularly in an era of long-term maintenance warranties being introduced into delivery systems such as Public-Private Partnerships.

Innovations in Construction Appraisal

Similar to the design process, innovations in construction process control will have limited return on investment if they are still constrained by traditional appraisal and acceptance. *This area probably has the greatest potential for innovation in the entire construction process.* Because one of the key goals of innovative project delivery is to quickly produce work that meets performance requirements, the appraisal and acceptance must be *nimble enough* able to react to constantly changing plans and specifications, *productive enough* to stay ahead of the construction process control, and *accurate enough* to give stakeholders that are funding a project solid data to continue to manage their major capital investment.

Facilitating Further Innovation

Further innovation can be supported by structuring quality management processes the same way a writer structures a good story - by asking the six basic questions of *Who, What, When, Where, Why, and How*.

Who?

There are typically specific people who are accountable for a particular aspect of quality. In a digital design and construction environment that is data-intensive, the provenance of that accountability becomes even more important. Similar to the traditional craftsman's mark, but far more complex, the trail of quality, and who was in custody of it, from production all the way to acceptance can be tracked by the very data the processes produce. Even in a highly automated environment, it is important to know every time a process has been touched by a human.

What?

We need to ask the question: "What is the specific work whose quality is being managed?" Is the work made of concrete, steel, or soil? Is it something that must resist load, transmit electricity, or reflect light? Each element in a project has its own form, its own requirements, and its own place in the cost and schedule. If it does not have a specific function in the project, then we might question why its quality needs to be managed. We also have to ask what data we're collecting on it, and how that data is to be used.

When?

The date and time of activities are often important for quality management. Usually the date and time of quality management activities can be automatically generated by modern data collectors, but we also have to ask ourselves what we want to do with that information.

Where?

Where is a very important characteristic of construction projects. Everything in the built environment project has a place defined by the design, with location tolerances defined by the requirements. For some elements, the question of "where" needs to be answered with expensive survey-grade equipment, but most aspects of quality do not require that level of accuracy. Some quality management data could even be assigned general boundaries, such as an area representing the limits of construction for a particular schedule activity.

Why?

The "why" of our activities should be based on the written requirements. Asking this type of question becomes more important when new enabling technologies allow us to appraise performance by measuring different characteristics. These new developments need to be reflected in the written requirements if they are to be achieved.

How?

"How" addresses the means and methods we use to produce and appraise the work. While it may be a written requirement in older, method-based specifications, it should only be a means to an end in newer performance-based specifications. How becomes even more important for processes for which the performance is difficult to measure. The innovation in how we do things is probably the most fluid, given the rapid changes in the enabling technology.

Can We Innovate For Traditional Project Delivery?

Every one of these innovations, and more, can be applied to traditional, non-innovative project delivery. It is only the fast schedules of innovative project delivery that have forced engineers and constructors to quickly look for improved ways of doing things. However, traditional projects can have their own innovation drivers as well. Because many claims and delays are based on faulty plans and specifications, improving written requirements can become even more important for tight budgets and underbid projects. Contractors with low margins could benefit from the use of certified design models, eliminating the need to reverse engineer plans if they wish to take advantage of automated machine guidance. Inspection can be faster and more efficient, reducing the need for contractors to place contingency budgets in their bid to account for unknowns in the appraisal and acceptance of their work.

Innovations in quality management can be looked at to reduce certain things:

Reduce time **–** Time is money in project delivery and faster quality assurance means more profitable results. The key is to look for innovations that shorten schedules by reducing unnecessary or obsolete appraisal methods, as opposed to applying all of the pressure to the production methods.

Reduce cost **–** Resources cost money, so innovations that reduce the effort needed to assure quality, while maintaining the accuracy of its depiction of the actual work, can release these same resources into the production system, preventing defects and appraising quality at the time of production. Better prevention can further reduce the cost of projects by offering an opportunity to reduce the standard design factor of safety, which is based on the historical level of variability, not the variability of the actual work.

Reduce waste **–** Technically, anything that consumes resources without adding value is waste. Even an activity as traditionally sacred as inspection could be considered waste, because it does not improve the value of the thing being inspected; it only tells you what its value is. Innovation can be used to scour through the entire "value chain" to constantly ask the question of why an inspection, sample, or test is being done, and ensure the way it is being done is compatible with the latest production methods.

CONCLUSION

Innovative methods of delivering projects need equally innovative methods of managing quality. Forcing new project delivery methods and new methods of improving construction efficiency to conform to the constraints of traditional mass-inspection, after-the-fact based quality management removes much of the financial incentive to innovate in the first place. The licensed professionals who are ultimately accountable to the public for the quality of the delivered project need methods of quality management that take advantage of all the enabling technologies that are available, such as relational databases, digital models, and global positioning systems. By exploiting these new methods, the appraisal of management can cease to be a waste. By creating a continuous awareness of the quality of the work, combined with rapid feedback into the production process, the appraisal of quality can immediately add value to the work that is about to be performed. Then the appraisal of quality changes from a necessary waste to a value-adding process.

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SOURCES OF WASTE ON CONSTRUCTION SITE: A COMPARISON TO THE MANUFACTURING INDUSTRY

Koichi Murata[1], Algan Tezel[2], Lauri Koskela[3], and Patricia Tzortzopoulos[4]

ABSTRACT

The wastes of the supply chain should be reduced to achieve the stabilization of construction operations in lean-based construction management. The aim of this paper is to investigate the communication related sources of waste on construction worksite when compared to the manufacturing industry. The methodology used involves several observations of Japanese construction worksites and interviews with worksite managers and executives of some construction companies, and public institutions, and participation at forums for exchanging practical construction experiences conducted over the last few years. Two main results are obtained. The first one details the three peculiarities of construction, specific customer, site production, and temporary organization as described in prior research. The second one proposes a structural model to depict wastes caused by temporary organization, one of the three mentioned peculiarities. These findings contribute to better understanding of the peculiarities of construction in view of applying lean techniques, and to broadening the practitioners' viewpoint by providing a guideline to gain the capability of a sharp and systematic understanding of their worksite.

KEYWORDS

Lean construction, waste of production flow, waste of organization

INTRODUCTION

The key behaviour underpinning successful lean management involves the exploration of waste hidden in a production system. The performance of a production system will be strengthen by eliminating wastes through continuous improvement. This paper

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investigates, from a lean viewpoint, the source of waste occurring on construction worksite. As the starting point, two perspectives are adapted to discuss the issue: (1) the wastes in operations at construction worksites and (2) the organizational wastes caused by the constraints of place and time, peculiar to the construction industry.

This paper endeavours to contribute to the systematization of waste elimination for the construction industry. Related previous publications have concentrated on wastes of just one production flow to improve construction production systems by industrial engineering approach (dos Santos 1999). This paper aims to present a more general theory of common waste hidden in construction production systems.

In general, practitioners have valuable practical insights to the subject. The important role of academia on the theory of lean management concerns with providing support to broaden the practitioners' viewpoint by offering guidelines for them to gain the capability of accurate and systematic understanding of their worksite.

In Toyota Motor Corporation, where lean thinking first emerged, seven wastes have been proposed, based on automobile production (discrete manufacturing) (Ohno 1988). This taxonomy continues to be a very useful approach considering the production management generally. In the area of industrial engineering, Therbligs established basic motion elements to add a value to management resources through analysing manual operations (Gilbreth 1915). Recently, the meaning of waste was explored in a literature review (Thürer 2017). These forerunners contributed to clarify the classification of wastes existing in a production system.

It is well known that massive operational wastes exist on construction worksites (Koskela 1992; 2002). There are many publications on wastes under lean construction. Researchers and consultants have mainly reviewed the seven wastes, and analysed them from the viewpoint of construction projects (Alarcón 1997; Fearne 2006; Mandujano 2017; Sarhan 2013; 2017; Somani 2017; Serpell 1995). Koskela (2004) has also proposed 'making-do', as the eighth category of waste, which refers to a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased. Macomber (2004) also indicates 'the two great wastes', not listening and not speaking, which relate to organizations managing the production flow.

This paper focuses on the four peculiarities of the construction industry in relation to elimination of wastes. These peculiarities are reviewed as follows, based on (Koskela 2013):

- Specific customer. The idea of overproduction as the most important waste is conceptually and experientially not consistent with one-of-a-kind production. Construction is usually a produce-to-order process. This is in contrast with the situation in mass production, where it can be necessary or tempting to produce before there is a customer order. From experience, we know that construction projects get completed more often after the due date than before it. If there is the possibility of completing before the planned due date, it may be possible to take the facility into use earlier. All in all, the claim of overproduction as the most important waste of construction cannot be justified.

- Design stage. Although the seven wastes can largely be interpreted as applying also to design, there may be aspects in design that are not covered. Thus, for example, the failure to achieve the best possible solution in design, certainly a waste for the customer, is not pinpointed.
- Site production. In manufacturing we find three types of transportation: The transportation of resources to the location of production, internal transportation of the incomplete / intermediate product in production and transportation of the complete product to the customer. The first type of transportation occurs also in construction, the two last not. In site production, it is the teams and equipment that move around the product. Thus, intermediate (or complete) products do not move at all, whereas workers will by necessity move around the site. However, in our estimation, these differences can be taken care of by a suitable slight redefinition of the waste of movement.
- Temporary organization. This characteristic may lead to think about the vagaries of communication and requests and promises between parties previously unknown to each other. The language/action perspective has been used to analyze such a setting in construction (Azambuja 2006). However, there we may be dealing, not with wastes as such, but primarily with the causes of waste.

Especially, this paper involves the following two discussions to understand the above three peculiarities of the four (except design stage) because the investigation of this paper is mainly focused on construction worksites. The first one involves the survey of the details of the three peculiarities, specific customer, site production, and temporary organization, which relate to wastes in production process. The second one proposes a structural model of causation of wastes by a temporary organization.

Four contributions are expected in this paper. Firstly, the seven wastes are deeply discuss for construction. Secondly, an original approach to eliminate wastes for the construction industry will be developed by understanding the details of each peculiarity as the starting point of the problem-solving. Thirdly, it becomes easy to connect the wastes to the lean toolbox, to detect and eliminate wastes through visual management, karakuri, poka-yoke and so on (Murata 2010; 2013). Fourthly, practitioners can concretely visualize the sources of wastes.

The methodology of the following discussions is based on several observations of Japanese construction worksites, interviews with worksite managers and executives of some construction companies and a public institution, and on participations at forums for exchanging practical construction experiences, conducted over the last few years. These events have been arranged by organizations located in Tokyo and adjacent prefectures, having an interest in the TPS for improving construction worksites. The lead author has implemented and studied lean management in the manufacturing industry for a long time. His investigation approach is the inductive method to demonstrate and clarify the difference of the implementation of lean management between the construction industry and the manufacturing industry. This paper reports an initial result of the analysis.

BASIS OF OPERATION WASTE ON CONSTUCTION SITE

This section describes the results from investigating peculiarities of the construction worksite, comparing the construction industry to the manufacturing industry.

A product of the construction industry, such as a building or a house, is produced on a construction worksite. Once materials are delivered to the site, they don't go outside and only wait to be consumed. After completing the project, a constructor needs to hand over the finished product to users in the same place as the construction worksite. Therefore, it is necessary not only to ensure the product's quality but also to develop the living environment for users of the product during the construction process at the same time. These conditions are considered as the different points of supply chain management to control management factors, compared with operations within the factory environment, which provides finished products to the market that is accessed by end users.

The size of the managed resources, including materials and machines/equipment/ facilities on a construction site is much larger than that of the manufacturing industry. Actually, depending on the nature of tasks, construction professionals may track the progress of a project by calculating the amount of materials/components installed or constructed. However, the same control is executed by the number of finished products in case of a factory. The same production lead time approach as in the manufacturing industry can be used in the construction industry by diving larger tasks (ie., building or floor) into smaller work chunks or even into smaller areas (location based planning and control). Such a difference caused by the physical and temporal scales of management resources brings the result that a reliable picture of the whole of production and progress against plan cannot be confirmed at a glance.

In addition, regarding the variability reduction principle for increased quality and productivity, many repeated operations are included in the mass-production system that caters to mass-consumption.

Table 1 summarises the above differences in the attributes of a production system between the two industries, in reference to the three peculiarities. These indicate that it is difficult to directly apply lean methods from the manufacturing industry to the construction industry, and that it is necessary to develop the theory of lean construction though studying construction worksites' operations.

FOUR BOUNDARIES THAT OBSTRUCT COMMUNICATION

This section focuses on temporary organization, one of the peculiarities for construction. While carrying out research on the organizational problem-solving scheme on construction worksites, based on experience in manufacturing industry, it was observed that there were two clear differences in communication among worksite members when compared to the communication in the manufacturing industry (Murata 2015; 2017).

First, construction projects that have different specifications are executed at the same time and in different locations. Second, although many different specialists join one project, they can't witness the completion of the project together. The former causes a geographical boundary and the latter draws out a temporal boundary for communication among company members. In addition, this two-boundary structure has other structures nesting inside it.

Table 1: Difference of the attributes of a production system between manufacturing and construction, with reference to construction peculiarities

Attributes of production system		**Manufacturing industry**	**Construction industry**	**Peculiarities of construction worksite (Koskela 2013)**
Operations	Repeated operations	Mass products	Same structures built in one product	Specific customer
Product and supply chain	Flow of martials and finished product	Supplier-Factory-Market	Supplier-Construction site	Specific customer
	Places of production and utilization of finished product	Different	Same	Site production
Management resources (Physical and temporal scales)	Size of managed objects (martials, machines/ equipment/ facilities)	Small	Large	Site production
	Production lead-time	Short (Daily, In minutes or, Seconds)	Long (Yearly or Monthly)	Site production
	Participants	Same members	Different specialists	Temporary organization

Each structure involves each worksite of each project at present. The characteristics of this communication in the construction industry is shown in Figure 1.

Generally, information sharing among worksite members involves the important process of reliable and successful problem solving. However, a construction site including this structure, which disturbs communication among project members, is shown in Figure 1. The structure consists of the following four sub-boundaries of the two-boundary structure that are prone to lead to a communication loss:

- Boundary between today’s you and tomorrow’s you (imagine ‘you’ as one member on worksite at present)
- Boundary between the head office and a worksite

- Boundary among members of different teams
- Boundary among projects in different locations

The first and third boundary are the sub-boundaries of the temporal boundary. The second and fourth boundary are the sub-boundaries of the geographical boundary. The first to third boundary concern the execution of a construction plan within one worksite.

The first, second, and fourth boundary can also be found in the manufacturing industry. For example, same people operate together every day in the same factory.

Regarding the first boundary, information sharing among those people is realized in their workplace every day to reduce the variation in management of resources such machines operated and materials used.

For the second boundary, in the overall competition environment, the geographical distribution of factory networks brings that the information of operation status of each one has to be gathered and analysed to receive quick support from the head office.

The fourth boundary relates to the advanced information sharing including technology transfer and knowledge management. Even if all factories manufacture different products, the exchange of valuable experiences with each other ought to be recognized as valuable opportunities to innovate for production system performance.

The third boundary is the special obstruction factor of the construction industry when compared to the manufacturing industry, where the same people work every day together. A construction project is realized by many different specialists such as architects, surveyors, plasterers, carpenters, and plumbers. They join together in one project, however they don’t work continuously together from the start to the finish of a project. The situation disturbs the accurate delivery of information of plan progress to the next participants. The main countermeasure for the problem rests on their understanding based on both their experiences from past projects and continuously ensuring the existence of process transparency through information sharing in a project. Overcoming this boundary will be more important to proceed with a production plan on construction worksites.

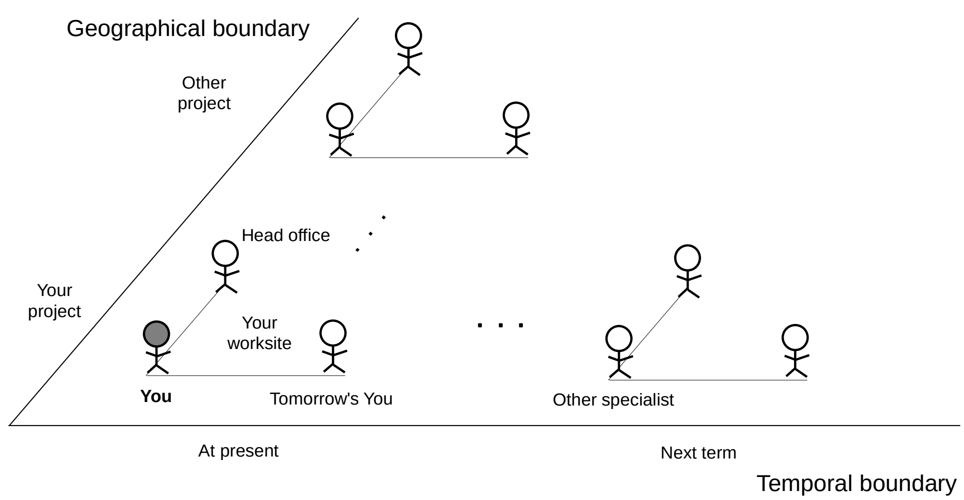

Figure 1: Nested structure model of communication in the construction industry

CONCLUDING REMARKS

This paper discussed the sources of waste on construction worksite with the aim of strengthening the theory of lean management in the construction industry by comparing it to the manufacturing industry. It is a finding of this paper that there are two kinds of waste in construction:

- Organizational waste due to lack of connection due to temporal and geographical boundaries
- Operational wastes, hidden in construction production systems

Such two types of waste will be recognized as the implication of the special structure of worksite operations executed within temporal and geographical boundaries in the construction industry. The causes of each one are clearly different. The cause of the first waste is associated with communication among different specialists. The cause of the second waste is associated with management of resources and operations on worksites. In other words, the former is the issue of the design of communication scheme and the latter is about the contents of communication. Lumping them together can possibly be misleading, because the core object of waste reduction in traditional lean management is the second one. This means that it is necessary to establish a scheme to overcome the first one, before eliminating the second one.

The offered perspectives on the lean management theory, and the academic results of this paper are expected to contribute to broadening the practitioners' capability of a sharp and systematic understanding of their worksite.

In future studies, the clarified wastes have to be linked with a lean counter-measure, to minimise their effects on construction production systems. The investigation and systematization of visual management, as part of the related lean toolbox, has recently been on the rise in the lean construction community (Murata 2015; 2016; 2017; Tezel 2016; 2017; Valente 2017). In the next step, the relationship between the wastes and visual management should be developed to realize an original systematic approach to problem-solving for lean construction management.

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A CONCEPTUAL MODEL FOR VALUE CHAIN MANAGEMENT IN CONSTRUCTION CONTRACTOR ORGANISATIONS

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ABSTRACT

Lean techniques focus on value maximisation while minimising waste. Waste is commonly interpreted as waste of material even though, waste in construction industry also relates to activities such as defects, movement, waiting time and processing. Such waste can be minimised through an in-depth understanding of the organisation. Herein, Value Chain Management (VCM) can be used to facilitate organisations to categorise the activities in terms of their value addition.

The generic value chain model developed by Porter in 1985 focuses on the manufacturing industry thus, a framework is required for contractor organisations based on which Value Adding Activities (VAAs) and non-VAAs can be identified. This paper is aimed at proposing a conceptual model for VCM in contractor organisations.

Three case studies were conducted in selected contractor organisations and data was collected through fifteen semi-structured interviews. Collected data was analysed using content analysis.

Altogether, 46 VAAs were identified classified under four primary functions and six secondary functions. The findings were used to develop a VC model applicable to contractor organisations based on Porter's generic VC model. This in turn could be used by contractors to adopt strategies to enhance Value Adding Activities (VAAs) and to minimise non-VAAs.

KEYWORDS

Conceptual model, contractor organisations, value adding activities, value chain, value chain management.

INTRODUCTION

Waste in construction industry is inevitable due to the complex nature of its activities (Broft, Badi andPryke2016). Waste predominantly results due to lack of resources and

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information, poor planning, inappropriate methods, ineffective control and issues relating to decision making (Serpell, Venturi and Contreras 1995). Activities carried out in an organisation has a major impact on waste creation. Yet, it is common that managers have limited perspective on the factors that contribute to creation of waste (Ballard and Howell 1998). Even if many of the waste creating factors are not visible, the identification of such can provide valuable information for an organisation, and in turn the industry, to improve (Alarcon 1997).

According to Rahman, Wang and Lim (2015), value stream mapping, lean management, construction process analysis, mud a walk and spaghetti diagrams are some of the commonly adopted tools for waste identification. In addition, Value Chain Management (VCM) can also be used since the concept highlights the importance of focusing on the value of each activity that contributes to the delivery of goods and services (Broft, Badiand Pryke 2016).

However, Lindfors (2000) has argued that companies find it difficult to differentiate the Value Adding Activities (VAAs) with non-VAAs. The models developed so far for VCM focuses on manufacturing industry rather than the construction industry. To address this gap, this paper, based on case study research, develops a conceptual model for VCM in construction contractor organisations.

LITERATURE SYNTHESIS

VALUE CHAIN (VC) AND VALUE CHAIN MANAGEMENT (VCM)

VC in an organisation is identified as the “activities” that are undertaken in order to deliver a valuable product or a service to the end user (Porter 1985). Thus, VC provides a view of an organisation in terms of its value generation process (Rowe, Mason, Dickel, Mann and Mockler 1993). The underlying principle behind VC is that, value creation of a company cannot be recognised as a whole and hence, needs to be broken down into activities (Porter 1985).

Each activity that creates value in the aforementioned process is identified as a VAA. According to Han (2008), a VAA is defined as “an operational effort that realise project requirements as defined by the project contract through the transformation of information and/or material into final product”. While VC of a firm is recognised as the activities, VCM is simply identified as managing the VC of the organisation. Accordingly, VCM acts as “a strategic business analysis tool” that can be “used for the seamless integration and collaboration of VC components and resources” (Technopedia 2017).

GENERIC VALUE CHAIN (VC) MODEL

VC enables a firm to disaggregate its strategic functions, providing a better understanding in terms of cost and value (Nguyen and Kira 2001; StabellandFjeldstad 1998). The underlying rationale behind decomposing is that the activities are the building blocks which are used to produce a product that generates value (StabellandFjeldstad 1998). Even though all the activities need to be taken into account in the VC development of an organisation, the activities considered should either result in a considerable proportion of cost, or have a significant impact on the value (Porter 1985; StabellandFjeldstad 1998).

The generic VC model developed by Porter (1985) provides a useful foundation for identification of a firm's VC. According to Ensign (2001), the model shows the manner in which a product adds value while it moves along the production process. Thus, this can be used as a template to identify the strategic improvements or opportunities within a firm in order to eliminate waste. Although, Porter's generic VC model provides a foundation for identifying value creating activities for a particular firm in an industry, its direct application to the construction industry has come under question. This is mainly due to the significant differences that the construction industry possesses in terms of the process and the parties involved compared to the manufacturing industry. Indeed, intricate characteristics of the industry mean that construction companies find it difficult to differentiate the VAAs with non-VAAs (Lindfors 2000).

This paper, therefore, addresses this gap of lack of research analysing VCM practices in construction industry despite its proven benefits in other industries. Herein, Kearney (2008) has stated that amongst the different stakeholders in the construction industry, the 'contractor' accounts for a higher cost proportion of a construction project. Accordingly, 'contractor' has a greater opportunity to add value to the VC of the construction process (Miles 1995). Therefore, this research focuses on contractor organisations in order to identify the VAAs.

RESEARCH METHODOLOGY

Case study was identified as the most appropriate approach for this research as it allowed in-depth analysis of the activities of contractor organisations focusing upon the value creating process.

Case study research may be carried out in the form of a single case or multi-case approach (Yin 2009). Single case study is adopted in circumstances with similar nature whereas multi case study is undertaken to analyse the collective features (Hyett, Kenny and Dickson 2014). Since activities of construction contractors vary from firm to firm, multi-case approach was adopted using three contractor organisations as the cases. The focus was limited to large-scale contractor organisations only since the activities in the firm are standardised to a certain extent in this type of organisations (Chan 2012). On the other hand, in small and medium scale contractor firms, the activities in the firm and the costs are sensitive to the projects undertaken (Eksteen and Rosenberg 2002). Thus, 03 organisations were selected using convenient sampling from the contractor organisations graded CS2 by the Construction Industry Development Authority (CIDA) of Sri Lanka (which denotes the largest scale construction contractors in the country with the financial, technical and other resource capabilities to bid for projects over LKR 3000 million (CIDA 2009).

Semi structured interviews were used as the primary technique of capturing data until the point of data saturation. In selecting respondents for the interviews, attention was given to gaining a clear picture of the activities throughout the overall process of the organisation. Altogether, 15 interviews were conducted within the 03 cases (refer Table 1). The main purpose of the interviewees was to identify the VAAs undertaken by the contractor organisation in order to add value to the client.

Table 1: Details of Interviewees from the 03 Cases

Interviewee		Designation	Experience
Case Study 1 (CS1)			
1	C1A	Senior Quantity Surveyor	+15 years
2	C1B	Manager in Contract Administration	+20 years
3	C1C	Quantity Surveyor	+10 years
4	C1D	Human Resource Manager	+15 years
5	C1E	Marketing Manager	+20 years
6	C1F	Legal Officer	+15 years
7	C1G	Information and Technology Manager	+15 years
8	C1H	Finance Manager	+15 years
9	C1I	Head of Internal Audit Committee	+20 years
Case Study 2 (CS2)			
1	C2A	Managing Director	+25 years
2	C2B	Director of Marketing	+20 years
3	C2C	Project Director	+20 years
Case Study 3 (CS3)			
1	C3A	Deputy General Manager	+30 years
2	C3B	Project Manager	+20 years
3	C3C	Chief Quantity Surveyor	+25 years

The interviews were digitally recorded with permission, transcribed and analysed using content analysis to identify VAAs within the contractor organisation. Content analysis is a technique that is commonly used in the qualitative research since the approach intersects the qualitative and quantitative measures (Duriau, Reger and Pfarrer 2007; Hsieh and Shannon 2005). Further, content analysis is a step by step analytical approach which aims at enhancing the validity and the reliability of the qualitative data collected (Walliman 2011). The research used QSRNVivo (version 11) software programme to conduct content analysis.

DATA ANALYSIS AND RESEARCH FINDINGS

DEVELOPMENT OF THE CONCEPTUAL MODEL

The generic VC model developed by Porter in 1985 focuses on manufacturing industry and is the commonly adopted template under VCM (Hubbard, Zubac, Johnson and Sanchez 2009). Thus, this generic VC model was used as the basis in developing a VC model for contractor organisations.

Through the case study findings, it was revealed that the VAAs of contractor organisations can be mainly categorised into two categories as primary VAAs and secondary VAAs. Herein, the primary VAAs are those activities that are directly linked to the final output of the firm. The supporting activities or secondary VAAs on the other hand, facilitate the company to perform the primary activities. Accordingly, the success of primary activities depend upon the supporting activities.

The case study findings also revealed that the primary activities of a construction organisation can be classified under four phases namely; the pre-tendering stage (which involves the activities carried out to obtain the project), the tendering stage, the construction stage and the post construction stage. Furthermore, six categories of secondary VAAs were also identified as finance and auditing, human resource management, legal, procurement, technology and development, and other. The VAAs that were not specific for the first five categories of secondary activities were grouped under the ‘other’ category. The proposed VC model for contractor organisations developed using the aforementioned findings is shown in Figure 1.

Figure 1: Proposed VC Model for Contractor Organisations

The ‘margin’ towards which the activities are pointed in Figure 1 implies the difference between the costs that are incurred and the price that the customer is willing to pay (StabellandFjeldstad 1998). Hence, the margin relies on the capability of a firm to manage the relationships among the activities (Durisova 2010). The VAAs identified under each of the above categories are discussed in the next section.

VAAS IN CONTRACTOR ORGANISATIONS

Altogether, 46 VAAs were identified for contractor organisations through the case studies. Table 2 and Table 3 presents these identified VAAs categorised under the different primary and secondary functions as identified in Figure 1.

Table 2: VAAs Identified Under Primary Functions

	Value Adding Activity (VAA)	No. of Respondents that Mentioned the VAA			
		CS1	CS2	CS3	Total
Pre-tendering Stage (Marketing)					
1	Developing relationships with potential clients	1	1	1	3
2	Marketing to create awareness of the company	1	1	0	2
3	Gathering and analysing data of possible projects to bid	0	0	1	1

	Value Adding Activity (VAA)	No. of Respondents that Mentioned the VAA			
		CS1	CS2	CS3	Total
	No. of VAAs identified in the case (Total No. of VAAs in category)	2(3)	2(3)	2(3)	
	Tendering Stage				
1	Participating in pre-bid meeting by the most suitable person	1	1	2	4
2	Participating in site visits by the most suitable person	2	1	1	4
3	Providing value engineering proposals at pre contract negotiations	2	0	1	3
4	Consulting construction experts	1	1	1	3
5	Assessing suppliers in terms of reliability and availability	1	0	1	2
6	Carrying out surveys in site	1	1	0	2
7	Providing an estimate with high accuracy	1	1	0	2
8	Selecting methods and mechanisms to enhance efficiency	0	1	1	2
9	In depth planning at tendering stage to reduce risk	1	1	0	2
10	Cross checking the quantities in the BoQ to compensate from rates	1	0	0	1
11	Maintaining a database of the market rates which is updated	0	1	0	1
12	Referring post project analysis of completed projects	0	1	0	1
	No.of VAAs identified in the case (Total No.of VAAs in category)	9(12)	9(12)	6(12)	
	Construction Stage				
1	In detail planning of material, labor and plant and machinery allocation	1	1	2	4
2	Monitoring actuals vs planned in terms of budget, resources and time	1	2	1	4
3	Maintaining proper records	0	1	1	2
4	Planning the cash flow of the project to suit the method of payment	0	1	1	2
5	Planning the logistics of materials	0	2	0	2
6	Using new technology in construction	1	0	1	2
7	Enabling high level of client involvement in the process	0	1	0	1
8	Planning the activities of the project for a shorter period of time than the contract period	0	1	0	1
	No. of VAAs identified in the case (Total No. of VAAs in category)	3 (8)	7(8)	5(8)	
	Post Construction Stage				
1	Undertaking post project analysis and proper communication of lessons learned	2	2	1	5
	No. of VAAs identified in the case (Total No. of VAAs in category)	1(1)	1(1)	1(1)	

Table 3: VAAs Identified Under Secondary Functions

Value Adding Activity		No. of Respondents that Mentioned the VAA			
		CS1	CS2	CS3	Total
Finance and Auditing					
1	Conducting internal audits	1	1	1	3
2	Establishing financial controls	1	1	1	3
3	Managing the working capital	1	1	0	2
4	Monitoring financial matters of the project	0	2	0	2
No. of VAAs identified in the case (Total No. of VAAs in category)		3(4)	4(4)	2(4)	
Human Resource Management					
1	Providing job related training and development	1	3	1	5
2	Conducting professional-development programs	1	2	1	4
3	Establishing a recruitment plan	1	1	1	3
4	Enhancing staff welfare	1	0	1	2
5	Offering a financial incentive	1	0	1	2
6	Establishing a disciplinary procedure	1	0	0	1
7	Maintaining the organisation culture in the project	0	1	0	1
No. of VAAs identified in the case (Total No. of VAAs in category)		6(7)	4(7)	5(7)	
Legal					
1	Preparing contract agreements to minimise ambiguities	2	2	1	5
2	Consulting legal experts	0	1	1	2
3	Drafting documents for court cases, joint ventures etc.	1	0	0	1
No. of VAAs identified in the case (Total No. of VAAs in category)		2(3)	2(3)	2(3)	
Procurement and Logistics					
1	Establishing an effective supply chain and logistics	1	2	1	4
No. of VAAs identified in the case (Total No. of VAAs in category)		1(1)	1(1)	1(1)	
Technology and Development					
1	Integrating departments in the organisation	0	1	2	3
2	Using computer software in project management	1	1	1	3
3	Carrying out research to provide innovation	1	0	1	2
4	Developing new IT systems to minimise processing time	1	0	1	2
5	Backing up data	1	0	0	1
6	Introducing new service providers to the client	0	1	0	1
No. of VAAs identified in the case (Total No. of VAAs in category)		4(6)	3(6)	4(6)	
Other					
1	Facilitating access to subject-related books and journals	1	0	0	1
No. of VAAs identified in the case (Total No. of VAAs in category)		1(1)	0(1)	0(1)	

Altogether, 24 VAAs were identified under the primary functions. Among the four stages (refer Figure 1), the highest number of VAAs were identified under the 'tendering stage' and the second highest were under the 'construction stage'. These account for 43%

(20 out of 46) of the total identified VAAs. As a result, the findings imply that higher amount of value can be generated in tendering stage and during the construction.

Three VAAs were identified under ‘pre-tendering stage’. In this stage, ‘developing relationships with potential clients’ was identified as a VAA in all 03 cases. This may be because, the ability to add value arises only if a project is awarded the contractor. Among the VAAs identified under ‘tendering stage’, ‘participating in pre-bid meetings by the most suitable person’ and ‘participating in site visits by the most suitable person’ were identified as VAAs in all 03 cases. The highest number of VAAs in the tendering stage (i.e. 09 out of 12) were found in CS1 and CS2 while the least were found in CS3. Further, activities ‘consulting construction experts’ and ‘providing value engineering proposals at pre-contract negotiations’ were also given a high level of importance by the interviewees. In terms of ‘construction stage’, the highest number of activities were found in CS2 (i.e. 7 out of 8) and the lowest in CS1. In this stage, the ‘in detail planning of material, labor and plant and machinery allocation’ and ‘monitoring actuals vs planned in terms of budget, resources and time’ were identified as VAAs in all 03 cases. Under ‘post-construction stage’, interviewees from all 03 cases pointed out that the experience gained and the lessons learnt are highly value creating activities. Thus, ‘Undertaking post project analysis and proper communication of lessons learned’ was identified as an essential VAA during this stage to allow project learning to be shared throughout the organisation. It was how ever noted that this particular VAA cannot add value to the current project but will add value to the future projects.

Under the secondary functions, altogether 22 VAAs were identified under the six categories shown in Figure 1. The highest number of VAAs were identified under ‘human resource management (HRM)’, whereas, the least number of VAAs were identified under ‘procurement’. One VAA was classified under ‘other’.

Altogether, four VAAs were identified under ‘finance and auditing’. ‘Conducting internal audits’ and ‘establishing financial controls’ were identified as VAAs under this category in all 03 cases. Seven VAAs identified under the ‘HRM’ category. The highest number of VAAs under HRM (i.e. 06 out of 07) were identified from CS1, whilst only 4 and 5 VAAs were found in CS2 and CS3 respectively. Among the activities identified, ‘providing job-related training and development’, ‘conducting professional-development programs’ and ‘establishing a recruitment plan’ were recognised as VAAs in all 03 cases. Under the ‘legal’ category, ‘preparing contract agreements to minimise ambiguities’ was identified as a VAA in all 03 cases. This particularly highlights the attention required in making contract agreements with parties such as sub-contractors and suppliers. Under the ‘procurement and logistics’ category, ‘establishing an effective supply chain and logistics’ was identified to have the ability to provide value to the client in all 03 cases. As noted by some interviewees, an effective procurement mechanism can prevent delays and also reduce storage costs. Six VAAs were identified under the ‘technology’ category. ‘Using computer software in project management’ was identified in all 03 cases under this category.

CONCLUSIONS AND RECOMMENDATIONS

This research focused on developing a conceptual model for VCM in contractor organisations. The findings revealed that the VAAs of a contractor organisation can be classified mainly into two as primary (core) and secondary (supporting) activities. Results also showed that primary activities can be further categorised based on the phases of the project as pre-tendering, tendering, construction and post-construction. Altogether 24 VAAs were identified under the primary functions where the highest number of VAAs were found under the ‘tendering’ phase. Similarly, secondary activities were classified under six sectors; i.e. finance and auditing, human resource management, legal, procurement, technology and development, and other. Altogether, 22 VAAs were identified under secondary functions, out of which the highest were from the HRM category.

The research makes a unique contribution to knowledge by proposing a VC model applicable to contractor organisations based on Porter’s generic VC model. The findings of this research can be used by contractor organisations in undertaking VCM in their organisations to gain an in depth understanding in terms of the value addition of the activities, ultimately leading to enhanced value for construction clients.

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A NEW PERSPECTIVE OF CONSTRUCTION LOGISTICS AND PRODUCTION CONTROL: AN EXPLORATORY STUDY

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ABSTRACT

Construction logistics and production control can enhance project performance. Research addressing site material management mainlyaims at reducing hauling distances and transportation costs. Other studies address the effects of logistics on labor productivity, proposing partial solutions instead of comprehensive optimization.Moreover, previous research on logistics optimization covers various stages of supply chain, but stops once materials reach the construction site. However, different techniques can be used to haulthese materials from storage areas to workplaces, including push and just-in-time techniques.These methods along with the effects they can have on crew performance still need to be studied. Pull and push techniques have been studied and applied for production control purposes. However, zooming into the level of project locations, the effects of production control approaches on crew performancestill need to be studied. This paper reviews onsite construction logistics and production control techniques, studies them at the level of locations, and proposes hypothesesto be evaluated in future research, relating logistics mechanisms and production control systems to productivity. This research is valuable due to exposing additional factors affecting labor productivity, and recommending further optimization in production planning and construction logistics.

KEYWORDS

Production control, push, pull, logistics, lean construction

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INTRODUCTION AND LITERATURE REVIEW

Construction logistics management may be defined as the management of the process of delivering materials and resources required at a construction site in a productive way. It is not only the management of the flow of material and information, but includes also delivering quality, ensuring safety, and providing an environment that facilitates construction activities (Guffond and Leconte 2000).

Construction logistics is divided into offsite and onsite material logistics. Offsite construction logistics is a part of supply chain management, in which various firms work collaboratively forming a network of inter-related processes to move material, services, funds and information in an effective way that reduces total costs, decreases total lead time, and improves total profits, keeping customer's value above all goals (Hamzeh et al. 2007). In contrast, site material management may be defined as the practice of allocating spaces for resource delivery, storage, and handling in order to reduce site congestion and excess material movement, so that inefficiencies are minimized (Thomas et al. 2005). Site material management affects then the workers' productivity on site, which is an important factor that substantially impacts time and cost of construction projects.

Considering material management, it can be noticed that material tracking and process optimization happen at various levels covering production, warehousing, and delivery process, but stop when materials arrive to construction sites considering that materials have reached their final destination (Donyavi and Flanagan 2009). Arbulu et al. (2003) for instance studied the implementation of a supplier Kanban system from suppliers to the construction site. However, looking through the eyes of crews on site, material arrival to site does not mean that the materials are in the right place. Crews still need to transport materials to the workplaces where they are installed/used. Then many questions arise, how materials will be replenished from storage locations on site to workplaces? How do the replenishing methods affect labor productivity? What if crews had to get materials from other workplaces? How do the materials for a certain crew at the workplace affect other crews' performance?

All of these questions still need to be answered. Some studies tackled similar issues through considering site material management principles and effective site layout on typical construction sites to reduce logistics costs and time delays (Harmanani et al. ; Said and El-Rayes 2013; Akinci et al. 2002). Other researches considered effective handling of materials on site which reduces waste and increases labor productivity, yet the way this issue is addressed was through material storage techniques and not through on-site material logistics (be it push or just-in-time) from storage places to workplaces. For example, many studies showed that insufficient material distribution methods, extensive multiple handling of material, improper material sorting (mismatching materials to locations), material shortage, and trash obstructing access are factors that reduce labor productivity on construction sites (Tommelein 1998a; Thomas, Sanvido and Sanders 1989a; Thomas et al. 2005; Singh 2010; El-Gohary and Aziz 2013).

Moreover, Seppänenand Peltokorpi (2016) studied the effect of on-site logistics on labor productivity through reviewing what factors (and factor's interconnections) were linked to productivity. The authors found out that the direct impact of storage locations on labor productivity due to skilled labor moving material was not clearly covered in the literature (Seppänen and Peltokorpi 2016).

Moving to production planning and control, it is traditionally defined as a management practice used to reduce variations from schedules and budgets; it tries to manage schedules reactively. To better manage production in construction industry, lean construction principles are applied, whereby value in the eyes of the customer is maximized, waste is reduced, constraints are removed, and workflow becomes more reliable (Howell and Ballard 1998; Hamzeh et al. 2015).

Traditional planning and controlling approaches are mainly applied push-driven techniques. Construction projects are planned by forming the activities along with their relations, resources and durations, and then schedules calculate the start and finish dates based on the critical path method (CPM)(Kelley Jr and Walker 1959). Project control then tries to stick to the planned schedule during execution assuming that all resources needed to start an activity will be available once an activity start date is reached. Thus once the activity is released after its predecessor is done, it waits passively until all the required constraints are removed. Constraints include the availability of material, information, labor, equipment and space. In case of the availability of some ingredients and the lack of others, those available ones have to wait in a queue, or the activity may start with partial requirements, also called making-do (Koskela 2004), with high probability of losing expected productivity (Tommelein 1998b; Thomas, Sanvido and Sanders 1989b; Howell et al. 1993).

Although some schedules account for uncertainties that could arise during execution such as uncertainty in duration and dependency logic, dealing with these uncertainties during real time execution should not be through trying to adhere to the planned schedule. This is because the actual network conditions and resource availability may differ from those assumed during planning (Tommelein 1998b). Thus the traditional push approach used in schedules, and the way of controlling production during execution with no appropriate rescheduling affect project performance negatively.

An alternative approach for production planning and control is the pull system. This system allows the end user to pull value from the producer (Koskela 2004). It is a demand driven system that only allows information and material to pass to a system only if the system is capable of handling them (Ballard 2000). Unlike a push system that forces the implementation of the schedule, pull systems prioritize the release of work based on the actual state of the system (Hopp and Spearman 1996).

Last Planner System (LPS) is considered a pull controlling system, as it ensures that all constraints are removed before allowing an activity to start (Ballard and Howell 1998). Location Based Management System (LBMS) also applies lean theories through aiming at reducing waste, decreasing variability, and increasing productivity. It can be applied in a pull fashion by accepting additional crews on site only when locations are available (Seppänen 2009). Moreover, the combination of both systems (LPS and LBMS) can lead to better project performance (Seppänen et al. 2010).

Although the concepts of push and pull systems are clearly defined, their practical implementations in construction projects are still not clear enough. Thus, there is a need to study what it actually means to push and pull in production control and construction logistics at the level of locations within the project.

THE NEED TO ADD A NEW LAYER OF PRODUCTION CONTROL AND CONSTRUCTION LOGISTICS AT THE LEVEL OF LOCATIONS

Previous research discussed site material management, its principles, best practices for material storage on congested sites, and some techniques to reduce hauling distances and transportation costs. However, on congested sites, labor productivity becomes of primary importance. Some papers address the impacts of logistics on labor productivity (e.g. Thomas et al. 2005; Singh 2010; El-Gohary and Aziz 2013). However, they do not present clear guidance regarding onsite material logistics, be it push or just-in-time. It was noticed as well that material tracking covers all stages of supply chain including production, warehousing, and delivery process, but stops once materials reach construction sites, considering that it arrived to its final destination. Yet, from the crews' point of view, materials still need to be hauled to the workplaces, and different techniques used to procure these materials from storage areas to workplaces have different effects on crew performance and productivity. This issue has received little attention in the literature. Therefore, this research studies push and just-in-time material replenishment systems, *applied to material handling between areas within a construction site.*

As for production control, it was noticed that some pull techniques are studied and applied in LBMS and LPS. Moreover, the traditional push method has been compared to pull technique from scheduling and control perspectives, considering tasks and project durations. However, zooming into the level of crews and locations within the project, the effects of production planning approaches on crew productivity, crew allocation to areas, and interactions between crews on the same location are still not thoroughly covered. Crew interactions include the way a crew working in a location is affected by another crew that reaches the same location/area. Moreover, the effect of applying just-in-time delivery approach for on-site materials along with pull planning is not considered in the literature. All of these gaps bring the need to study these issues and add a new layer of production planning and construction logistics at the level of project locations.

PUSH AND JUST-IN-TIMEMATERIAL REPLENISHMENT APPROACHES BETWEEN PROJECT LOCATIONS

Different approaches used to procure materials to the workplaces have different effects on labor performance and productivity. Figure 1 demonstrates the push technique for material replenishment for workplaces, whereby materials are being replenished to areas/workplaces based on a pre-set schedule, regardless if these materials are to be used straight away by a crew or not, or even if they are replenished with the right amounts and to the exact areas. Although this schedule may meet the demand sometimes, batch amounts replenished to floors may cause partial or complete obstruction to other crews that have to work in the same location that these materials are placed. This may cause loss in productivity due to additional congestion caused by material.

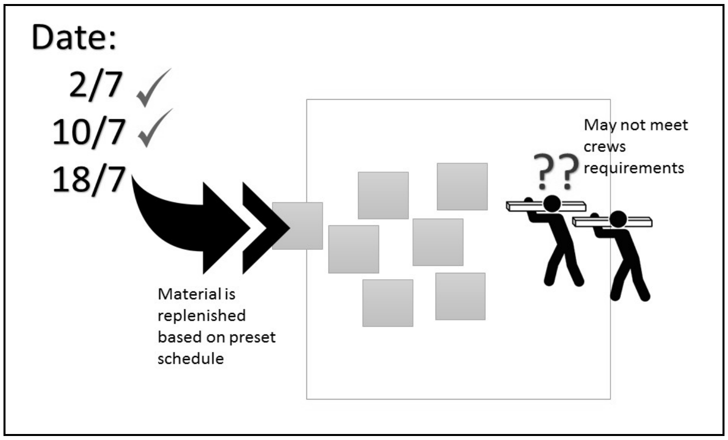

Figure 1: Demonstration of Push Technique for Onsite Material Replenishment

To better illustrate the push technique at the level of project locations, consider Figure 2 that shows how material is replenished through a push technique on a construction site, and its expected effects on crew behavior.

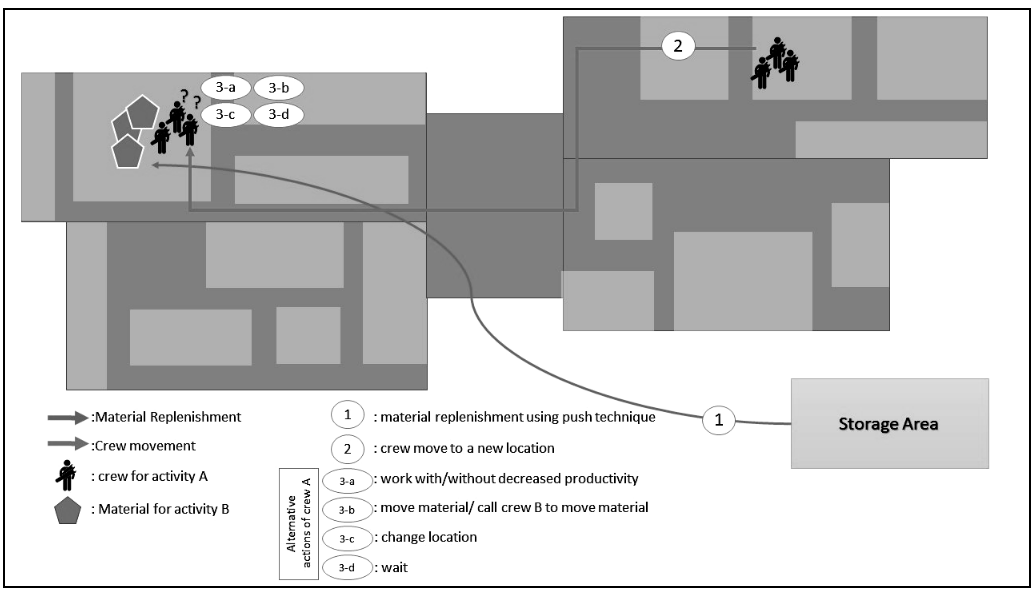

Figure 1: Effects of Push Technique for Onsite Material Replenishment on Crew Performance

According to Figure 2, materials for activity “B” are being replenished from the storage area to the location shown based on a preset schedule and not on the actual demand of crews. In this case, crews for activity “A”, heading to work in the same location where these materials are now placed, may find some issues and thus face one of the following conditions:

- Work with/without decreased productivity: Workers' productivity may decrease depending on the level of obstruction caused by the materials. For example, if materials are placed in the middle of a room and crews are working at the periphery of the same room, materials may cause partial obstruction to crews and thus they may work with decreased productivity.
- Move the materials/ call for crew B to move their materials: In case the crew cannot work in the presence of these materials, the crew may move the materials or call other crews responsible for moving them. For example, material "B" is placed in the middle of a room and crew "A" needs to work also in the middle. Hauling materials depends on their size and ease of handling.
- Move to another location: In case the materials cause complete obstruction and cannot be moved.
- Wait: Crew may wait for a superior decision regarding this situation, or wait if they noticed that they could start working in this location within a short time.

Notice that in almost all of the above situations, productivity is being negatively affected either due to partial material obstruction (condition 1), or due to wasting time in moving others' materials, or waiting for them to be removed (conditions 2 and 4), or even due to losing time to choose another appropriate workplaces (condition 3).

With a just-in-time technique for on-site material replenishment demonstrated in the Figure 3, productivity may be preserved in a better way. Figure 3 shows that materials are being replenished to areas based on actual demand of the corresponding crews. This way, materials are being replenished with the right amount, to the right location, and at the right time, so they do not cause obstruction and productivity loss.

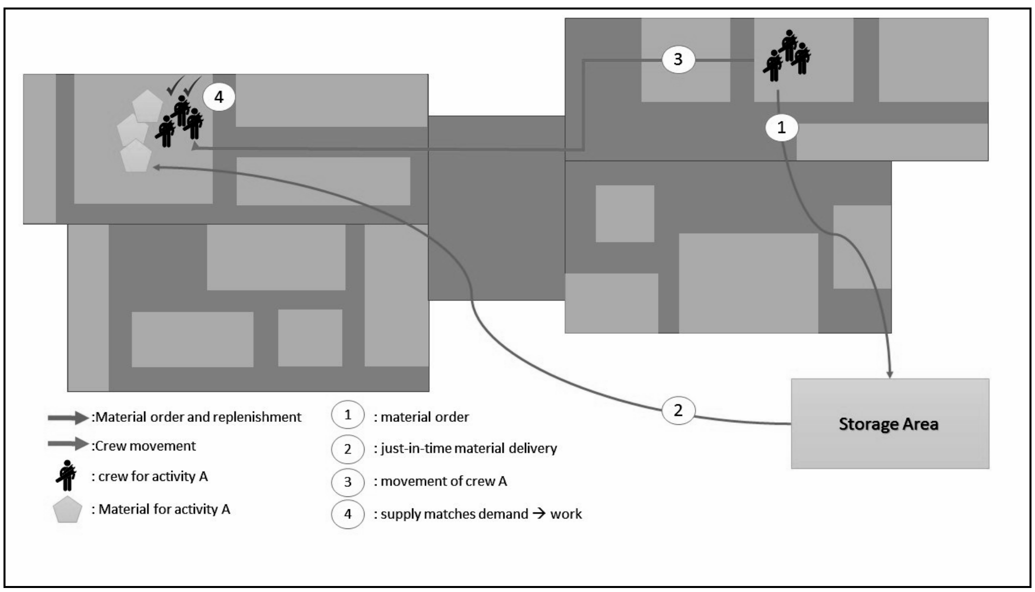

Figure 3: Just-in-time Material Replenishment at the Level of Project Locations

PUSH AND PULL TECHNIQUES FOR PRODUCTION CONTROL AT THE LEVEL OF LOCATIONS:

Push technique at the level of locations means forcing the implementation of the schedule through assigning crews to activities as per the plan, paying less attention to their anticipated productivity. This technique is demonstrated in Figure 4 that shows crew logistics between areas following a push system.

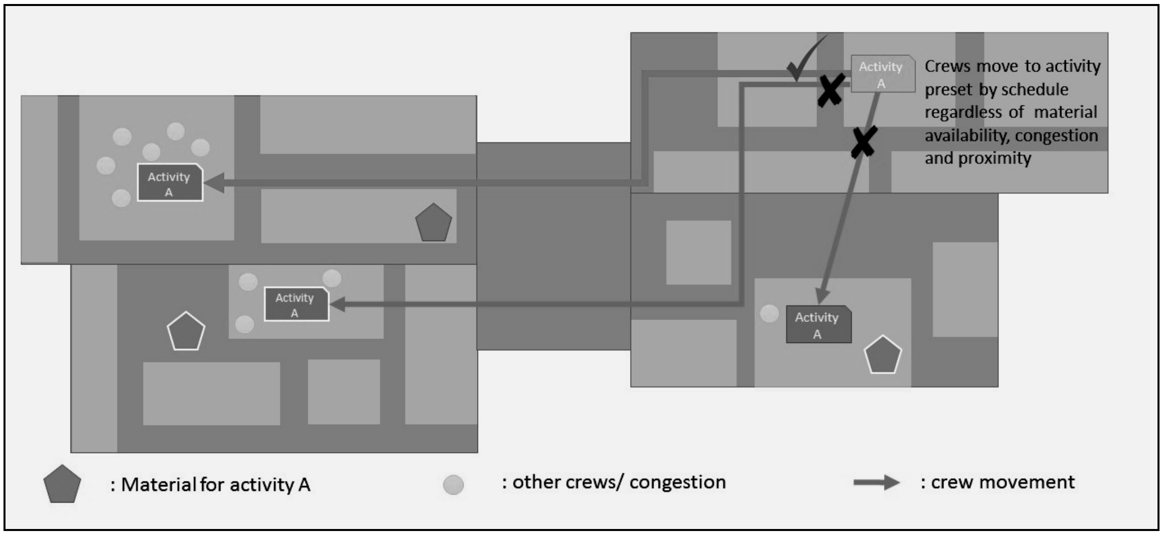

Figure 4: Crew Logistics between Areas Following Push Technique in Production Control

As shown in Figure 4, when the crew finishes activity "A" in a location and needs to perform the same activity in another location, based on a push system, the crew is typically moved to the activity/location that is pre-set by the schedule, which may not account for material availability, material hauling distance, congestion caused by other crews in the location, proximity between locations, and other factors.

In this specific example, it happens that the crew moves to a location that:

- Is relatively more congested than other available areas.
- Requires material hauling over a larger distance compared to that in other areas.
- Is relatively farther than other available locations.

Now consider a pull technique that is applied for the same scenario. This is demonstrated in Figure 5, whereby all of these three alternatives are assessed taking into consideration the schedule, material availability, and anticipated production rate or congestion in the available locations. The main purpose of evaluating these alternatives is to choose the location that allows for higher labor productivity through pulling from milestones (schedule) and from the state of the system (actual conditions of congestion, material availability, etc.).

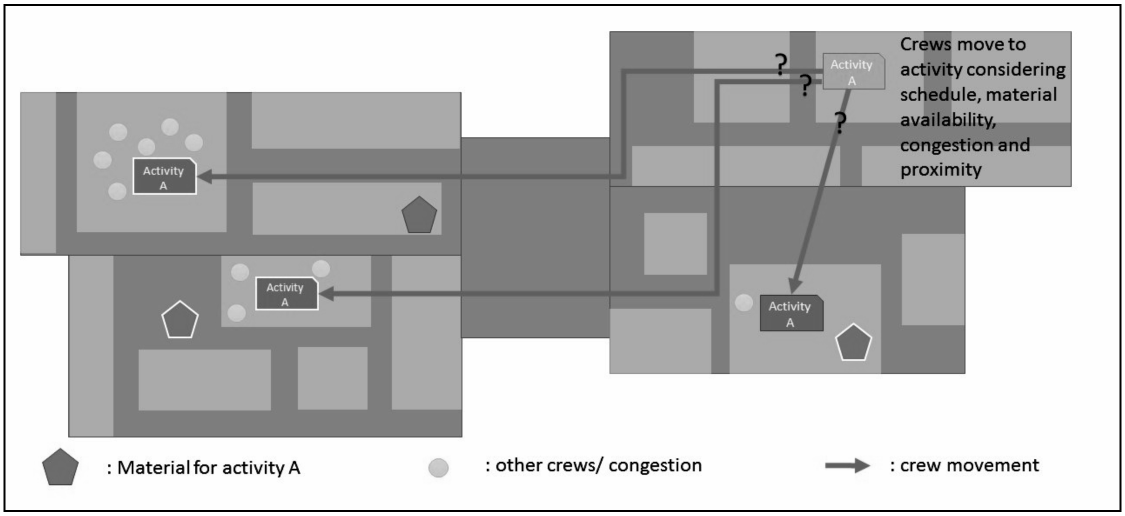

Figure 5: Crew Logistics between Areas Following Pull Technique in Production Control

Another implementation of push technique is when subcontractors work out-of-sequence or in parallel locations leaving unfinished work, without active management from the general contractor. Moreover, subcontractors tend to handle late activities through allocating more crews to a late activity in order to increase its production rate (Seppänen 2012). Push techniques can thus increase production rates when tasks are delayed but they can cause over manning and thus may lead to a loss in productivity(Thomas 1992; Singh 2003). This shows the need to use pull techniques in production control that are expected to help in increasing labor productivity and production rate at the same time.

Therefore, future research should test and compare the effects of push and pull in production control, at the level of locations, on crew performance, and test the following propositions:

1. Over manning can be counterproductive if adopted to finish a late project on time.
2. Pull can increase productivity and production rate unlike push that only increases production rate sacrificing productivity.
3. Pull achieves shorter cycle times and decreases cost.
4. Pull in production planning should be accompanied by pull in production control to be efficient (not pushing the pull schedule during execution).

Moreover, future research should test and compare the effects of push and just-in-time techniques, at the level of locations, on crew performance.

CONCLUSION

Extensive research is performed on many aspects of construction logistics, including research on site material management and delivery approaches to construction sites. Far less attention has been put onto construction logistics of crews and materials between areas within a construction site. Applying a push technique for material replenishment to workplaces shows negative effects on labor productivity. This can be avoided through applying just-in-time material logistics between locations. As for production control, it was shown that push and pull are compared based on their effects on tasks and general project performance without going deep into the level of crew logistics between areas within a project. This paper added this missing layer through showing how a push method reduces crew productivity despite increasing production rate, and hypothesizing that applying pull systems increases both productivity and production rate.

Future research should test the effects of push and pull applied in construction logistics and production control on labor performance, and address the propositions through isolating factors identified in this paper and testing the effect of each on productivity.

This research is valuable for researchers and practitioners seeking improvements in productivity due to exposing important applications in construction logistics and production control that affect labor productivity.

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SIMULATION EXERCISE FOR COLLABORATIVE PLANNING SYSTEM / LAST PLANNER SYSTEM™ (COLPLASSE)

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ABSTRACT

The Last Planner System (LPS™)is becoming popular for project management all over the world. Though the practitioners are able to follow the concepts quite well, they sometimes find it difficult to develop the required processes and templates, particularly in organisations and environments where systematic planning practices are not that prevalent. Structured templates, simulations, or games for LPS are also not freely available in the open domain. A simulation exercise, COLPLASSE (COLlaborative PLAnning System Simulation Exercise), has been developed to cater to this felt need.

COLPLASSE is based on simple Excel spreadsheets and uses work plans for developing Look Ahead Plans and Weekly planning over the many weeks required for project completion. It has provisions to simulate random delays due to inclement external environmental conditions or variations in productivity due to various causes. It computes PPC automatically and simultaneously draws continuous charts for PPC and Root Cause Analysis over the Project completion period. It is simple to use and with further improvements being planned, can develop into a powerful tool for training or simulation or actual use along with LPS. Further research is proposed to be done using this simulation with various groups to evaluate its capabilities for helping early practitioners to use LPS.

KEYWORDS

Collaborative Planning System, Simulation, Excel spreadsheet, Work plans template

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INTRODUCTION

USE OF PLANNING TOOLS

The Last Planner System ^{TM} (LPS) (Ballard 1994) has been a significant game-changer in the construction arena and a dramatic innovation or a fresh breath of air in the humdrum planning domains, improving considerably the certainty levels, flow of work and consistency in performance. Though it has been around for a long time, nascent practitioners, particularly organisations with little track record for systematic planning as in developing countries, took quite a bit of time to develop the processes required for its optimum usage in the field. For construction personnel steeped in the usage of CPM schedules, the processes required for developing and using Phase schedules, Look Ahead Plans (LAPs), measurement systems such as Plan Percent Completed (PPC) or Root Cause Analysis (RCA) appear to be difficult to put into practice in the field. Often coaches have to work with the field personnel to develop templates and schedules for deploying LPS in the projects. For initial training also, the basic concepts of LPS are better understood if templates are used to demonstrate how exactly LAPs, etc have to be developed and used. Over time and across different geographical and industrial arenas LPS ^{TM} has been undergoing adaptations during implementation in different circumstances and contexts and Collaborative Planning System (CPS) being practised in India of late, is one such adaptation (Raghavan, et al 2014, Raghavan 2015). CPS brings in larger support to the Last Planners from the Project Manager and Planning Manager with a Big Room approach for the developmental meetings in contexts where the Last Planners are not that well conversant with planning processes and interactive approaches (where planning as a process is itself not that well developed, as in smaller organizations in developing countries). Over time with continuous guidance and support the Last Planners become more proficient but in the earlier stages a Collaborative approach is required.

The constraint of space precludes detailed exposition of the software or describing an example problem in this paper, though they are addressed adequately in the User's Manual for the software.

AVAILABLE SIMULATIONS AND TEMPLATES

Simulations and games are quite helpful for training in the use of management techniques and would be particularly useful for using Lean construction concepts and applications in projects (Dukovska-Popovska, et al 2008, Loon et al 2015). Though many simulation games are available in the field of Lean Construction management, hardly any training simulation exercise is available to teach and practise the fundamentals of LPS ^{TM} in the open domain. The available games are somewhat complex or take too long to play out and often require an expert coach to play them out with many players. Some spreadsheet applications are available for LPS usage (Ghafari, 2015) but most of them are not directly suitable for training or for those just starting on their Lean journey. A need has been felt to fill this gap and COLPLASSE (COLlaborative PLAnning System Simulation Exercise) is designed to meet this felt need.

The aeroplane game (Visionary Products, 2015) is good for demonstrating the push-pull interplay and effect of variable batch-sizing. The Parade of Trades game (Tommelein, et al, 1999) is an excellent starter to demonstrate the impact of workflow variability. LEAPCON (Sacks, et al, 2007)) is good for use with multi-storey construction, demonstrating concepts such as pull and work structuring. Villego (Villego, 2014) has been a classic game which covers practically the entire gamut of LPS concepts but is somewhat complex, is in considerable detail and not handy enough for classrooms or quick training sessions. LEBSCO (Gonzalez, et al, 2014 and Gonzalez, et al, 2015), an LPS-based simulation game is also in somewhat high detail and needs many players, but each in limited roles. Make-a-Card, The Silent squares, Flow-building or Pull-building Lean games are other games covering multiple players and situations.

For classroom teaching or teaching a number of planners simultaneously, COLPLASSE would be appropriate as the spreadsheets can be replicated for each participant and each can progress with the simulation in his own way with different probabilistic scenarios thrown their ways for the simulations for the same given problem. It also covers the concepts of milestone planning, Phase scheduling, LAPs, Constraint solving, productivities, PPC calculations, Root Cause analysis, etc. It is planned to make the software available freely on the open domain.

OVERVIEW

DOCUMENT STRUCTURE

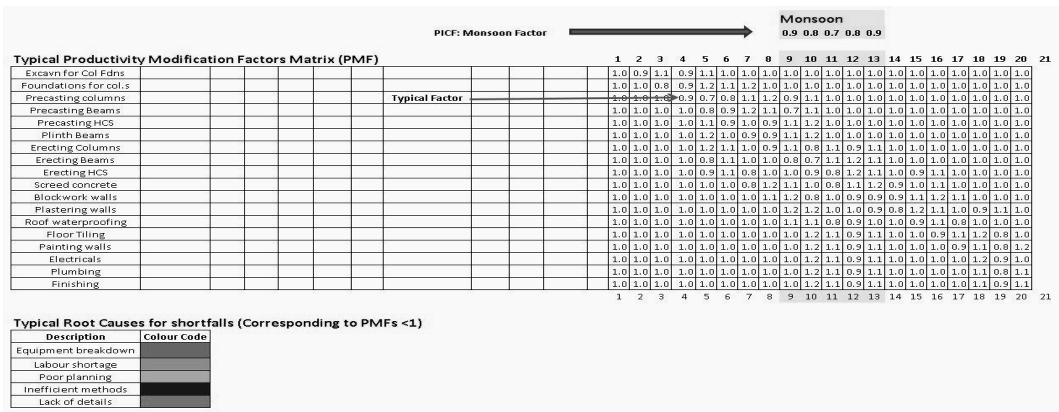
This Simulation exercise has been designed to teach the basic processes of LPS to the beginners in Lean Construction Management. This open system simulation employs the well-known and popular Microsoft Excel spreadsheets as the base. It unfolds the Lean planning systems and concepts such as Look Ahead Plan, PPC Analysis, Root Cause Analysis, etc over the construction duration in a series of connected spreadsheets. It can help in teaching initial planning as well as planning updates to remediate production losses due to various factors. It has been kept simple, by design, to enable easy adaptations to a variety of problems, for training as well as for real-life cases. It has built-in automated graphics for depicting PPC trends as well as Root Cause Analysis. Further developments are ongoing mainly by deploying more Excel macros to infuse greater flexibility for tackling larger real-life cases. With its open domain architecture, users can freely make adaptations for varying contexts.

WORKING OF COLPLASSE

BASICS

An Initial Sheet (Figure 1) lists out the various basic data required for the simulation. This includes the list of activities and for each activity the quantities of work to be done, number of crews available, and average productivity. It is possible to introduce a Period of Inclement Conditions (such as monsoon) by specifying the serial numbers of the weeks when such conditions prevail, which reduce the productivity of all activities performed in such periods. One can also introduce probabilistically-evolved Productivity Modification

Factors for each of the work weeks, which increase or decrease the quantity of work performed during that week for the specified activities (due to productivity improvement measures or better planning put in place, or due to unforeseen problems or unresolved constraints, respectively). It is possible to assign specific Root Causes (from the available library of typical causes) which cause such reduction in productivity. Contractual milestones can be specified by stipulating the serial numbers of the weeks for completion of key activities. Number of working days per week and number of working hours per day can also be changed. The simulation has as many intermediate spreadsheets as the number of work weeks, for the work plans. The Final Sheet, at the end of the various work weeks, contains the results of analysis of the execution parameters, compiled automatically during the play-out of the various weeks.



Typical Productivity Modification Factors Matrix (PMF)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Excavn for Col Fdns	1.0	0.9	1.1	0.9	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Foundations for col.s	1.0	1.0	0.8	0.9	1.2	1.1	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Precasting columns	1.0	1.0	1.0	0.9	0.7	0.8	1.1	1.2	0.9	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Precasting Beams	1.0	1.0	1.0	1.0	0.8	0.9	1.2	1.1	0.7	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Precasting HCS	1.0	1.0	1.0	1.0	1.1	0.9	1.0	0.9	1.1	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Plinth Beams	1.0	1.0	1.0	1.0	1.2	1.0	0.9	0.9	1.1	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Erecting Columns	1.0	1.0	1.0	1.0	1.2	1.1	1.0	0.9	1.1	0.8	1.1	0.9	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Erecting Beams	1.0	1.0	1.0	1.0	0.8	1.1	1.0	1.0	0.8	0.7	1.1	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Erecting HCS	1.0	1.0	1.0	1.0	0.9	1.1	0.8	1.0	1.0	0.9	0.8	1.2	1.1	1.0	0.9	1.1	1.0	1.0	1.0	1.0	
Screed concrete	1.0	1.0	1.0	1.0	1.0	1.0	0.8	1.2	1.1	1.0	0.8	1.1	1.2	0.9	1.0	1.1	1.0	1.0	1.0	1.0	
Blockwork walls	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.2	0.8	1.0	0.9	0.9	0.9	1.1	1.2	1.1	1.0	1.0	1.0	
Plastering walls	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.2	1.0	1.0	0.9	0.8	1.2	1.1	1.0	0.9	1.1	1.0	
Roof waterproofing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	0.8	0.9	1.0	1.0	0.9	1.1	0.8	1.0	1.0	1.0	
Floor Tiling	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.1	1.0	1.0	0.9	1.1	1.2	0.8	1.0	
Painting walls	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.1	1.0	1.0	1.0	0.9	1.1	0.8	1.2	
Electricals	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.1	1.0	1.0	1.0	1.0	1.2	0.9	1.0	
Plumbing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.1	1.0	1.0	1.0	1.0	1.1	0.8	1.1	
Finishing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.1	0.9	1.1	1.0	1.0	1.0	1.0	1.1	0.9	1.1	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Typical Root Causes for shortfalls (Corresponding to PMFs <1)

Description	Colour Code
Equipment breakdown	
Labour shortage	
Poor planning	
Inefficient methods	
Lack of details	

Figure 1: Screen shot of Initial Sheet

Each intermediate worksheet (Figure 2) or work plan covering one week of work depicts a four-week rolling Look Ahead Plan (LAP) as well as the progress in the Current Week (First of the four weeks). Each sheet lists out all the activities of work, the balance quantity of work to be performed for each activity as at the beginning of the Current Week, the basic productivity value assumed for each activity and the number of work teams provided. The actual work performed for any activity in the Current week, which is derived from the above data, is further modified according to Productivity Modification Factors which depend upon the external factors prevailing in the Current Week as well as on any exceptional situations occurring in this week. This progression is carried forward week after week until project completion.

No of Buildings = 50 | PPC Check

S No	Work Item	Qty / Bldg			Total Qty		Productivity			No of Cre	No of day	Typ Qty/ wee	Qty Completed till	Qty Balance	Quantity planned each week				Likely Constraints	Action Plan	Expected Quaniti	PMF	MF	Modified Qty	Actual Qty	PPC 1 / 0	Root Cause
		Nos	Vol	UoM		UoM	Qty	UOM		(8 hr day)	(6 days)/			3	4	5	6			Week NO:						
	No of Running Week													3	4	5	6			3						
1	Excavation	8	20	CuM	**400**	Nos	2.5	hrs/Ftg/crew	6	21	115	0	170	115	115	115	55			**115**	1.2	1	138	138	1	A
2	Foundations	8	3	CuM	**400**	Nos	3	hrs/Ftg/crew	7	21	112	0	0		112	112	112			**0**				0	NA	
3	Precast Columns	8	3	CuM	**400**	Nos	1	hr/no/crew	2	25	96	0	0			96	96			**0**				0	NA	
4	Precasting	8	1.5	CuM	**400**	Nos	1	hr/no/crew	2	25	96	0	0				96			**0**				0	NA	
5	Precasting HCS	4	1	CuM	**200**	Nos	1	hr/no/crew	2	13	96	0	0							**0**				0	NA	
6	Plinth Beams	8	0.4	CuM	**400**	Nos	1.5	hr/no/crew	3	25	96	0	0							**0**				0	NA	
7	Erecting Columns	8	8	Nos	**400**	Nos	1	hr/no/crew	2	25	96	0	0							**0**				0	NA	
8	Erecting Beams	8	8	Nos	**400**	Nos	1	hr/no/crew	2	25	96	0	0							**0**				0	NA	
9	Erecting HCS	4	4	Nos	**200**	Nos	1	hr/no/crew	1	25	48	0	0							**0**				0	NA	
10	Screed concrete		20	SqM	**1000**	SqM	5	sqm/hr/crew	1	25	240	0	0							**0**				0	NA	
11	Blockwork walls		72	SqM	**3600**	SqM	10	sqm/hr/crew	2	23	960	0	0							**0**				0	NA	
12	Plastering walls		120	SqM	**6000**	SqM	15	sqm/hr/crew	2	25	1440	0	0							**0**				0	NA	
13	Waterproofing		20	SqM	**1000**	SqM	10	sqm/hr/crew	1	13	480	0	0							**0**				0	NA	
14	Floor Tiling		20	SqM	**1000**	SqM	8	sqm/hr/crew	1	16	384	0	0							**0**				0	NA	
15	Painting walls		120	SqM	**6000**	SqM	8	sqm/hr/crew	5	19	1920	0	0							**0**				0	NA	
16	Electricals		1	LS	**50**	LS	4	hr/no/crew	2	13	24	0	0							**0**				0	NA	
17	Plumbing		1	LS	**50**	LS	4	hr/no/crew	2	13	24	0	0							**0**				0	NA	
18	Finishing		1	LS	**50**	LS	2	hr/no/crew	1	13	24	0	0							**0**				0	NA	

Create Next LAP

... | Project Data | Basic Data Sheet | Phase Schedule | LAP 1 | LAP 2 | LAP 3

Figure 2: Screen shot of typical Running Sheet for the example problem.

Initially, a Milestone Schedule and Phase Schedules have to be prepared, forming the basis for the LAPs. The Expected Quantity planned for any week for any activity can be adjusted by changing the number of crews assigned to suit completion of milestones as per the current Phase Schedule, which should again be in conformity with the overall Milestone Schedule drawn up initially.

GLOSSARY OF KEYWORDS

LAP - Look-Ahead Plan, typically covering 4 weeks

Current Week - Serial Number of the first of the 4 weeks in the current LAP

PICF - Period of Inclement Conditions Factor (for instance, due to monsoon)

PMF - Productivity Modification Factor (<1 if there are problems for execution of that activity during that week because ofconstraints; can also be >1 iffavourable conditions prevail))

RC - Root Cause responsible leading to PMF being less than 1

No. of Hours worked/week = Standard hours per day x no. of days/ week (= 6x8= 48 hours in this example)

Balance Quantity = Quantity remaining to be executed as of the beginning of the Current Week for any activity

Possible Quantity = Productivity x No. of Crews x No. of hours worked per week

Expected Quantity = Quantity assigned to the first of the 4 weeks in the LAP

Modified Quantity = Expected Quantity x PICF x PMF

Actual Quantity = Modified Quantity or Balance Quantity, whichever is less.

Score for Activity = Equal to 1 if Actual Quantity >= Expected Quantity, Else =0

PPC for Current week = No. of "1"s for Activity Scores / Total no. of Activities executed during current Week x100

WORK QUANTITY MODIFICATION FACTORS

The Initial or the basic Spreadsheet lists all the activities required for the construction work along with the quantities of work for each activity, number of crews envisaged and the average productivity of work for each activity, all of which can be used to determine the number of weeks required for completion of each activity. The Possible Quantity of work which can be done in a week for any activity is the product of the Productivity, the number of crews and the number of hours worked per week. For meeting intermediate milestones, the Possible Quantities can be adjusted by modifying the number of crews. For purposes of this simulation, the planner does not have any control over the basic productivity data; the average productivity specified initially gets modified by the factor due to Inclement Conditions and the Productivity Modification Factor which can decrease or increase the productivity.

A concept of a Period of Inclement Conditions (PIC) has been specified covering a few weeks in between during which climatic or social or economic conditions which hamper good construction progress could prevail. For instance, in the example problem which covers 20 weeks and 18 activities, monsoon conditions prevail over five specified weeks. The fall in production due to reduction in working hours during such a period is simulated by a PIC Factor (PICF) which is less than 1, which reduces the Possible Quantity of work calculated as mentioned above. In the example problem during the five weeks of monsoon PICF is specified as 0.9, 0.8, 0.7,0.8 and 0.9 for the five weeks, to simulate progressively deepening and easing monsoon conditions over the five weeks.

The potential problems which may arise due to various glitches such as equipment breakdown, wrong methods, bad planning, etc are taken care of by assigning a Productivity Modification Factor (PMF). The PMF numbers are assigned by the random number generation algorithm of Excel. They are in the range of 0.7 to 1.2 in this example problem, thus decreasing the productivity sometimes (when less than 1.0) and increasing it (when greater than 1.0) at some other times. This range is set in the Initial Sheet and is modifiable. The final quantity of work executed would then be equal to the original Possible Quantity as worked out earlier multiplied by PICF and PMF. For each application of PMF less than 1, a corresponding Root Cause (RC) (generated or picked from a library of Root Causes) would be assigned for the affected activity, for the users to get a flavour of what all things can go wrong during execution. A pie chart which shows the relative prevalence of the various Root Causes at any given time is built up automatically, week after week.

THE STRUCTURE OF SPREADSHEETS

There are essentially three spreadsheet systems in this tool: Basic Data, Running Plans and Analysis Sheet. Basic Data given in the Initial Sheet comprises the list of various items of work and their respective quantities as well as typical productivities for execution, etc. The PICF matrix and RC library would be found here. Initially depending on the milestones specified, the Planner has to develop Phase Schedules (typically 1 to 3 phases for this example, which has five milestones) covering all the activities and conforming to the set Milestones.

Fig. 2 shows a typical Running Sheet for an example problem, covering various work items right from excavation for foundations to finishing work. The respective quantities for the various work items involved are given in the Initial Sheet. It also gives the expected productivities (inverse of productivity in some cases) for the various work items and number of crews available for each work. It also indicates the weekly schedule template, overall milestones, and scope of work for the three Phases involved and monsoon months. Milestones are specified for Completion of excavations and foundations, Completion of all pre-casting, Completion of all concreting work, and Completion of all finishing except services (electrical, plumbing) and Final Completion.

The Running Plan is a spreadsheet for the Current Week and is also a Look-Ahead Plan (LAP) covering four weeks starting with the Current Week, with all the activities listed along with their original quantities as well as the Balance Quantity as of the beginning of the Current Week. There will be as many Running Plan sheets as the number of work weeks. For each week the Balance Work quantity for each activity will be automatically taken as the Balance Quantity of the previous week less the actual quantity executed during the previous week. In each Running Plan, the Planner has to assign quantities for the 4 weeks of the LAP to the activities which need to be executed in this four- week period as per the relevant Phase Schedule and duly considering the prevailing PICF. However, these quantities will have to be less than or equal to the Possible Quantity, which is derived from productivity, number of crews and number of working days per week. If more quantity of work is desired to be executed, then the number of crews will have to be increased. The Expected (Current Week) Quantities will then be automatically assigned from the first week of the four-week LAP. Then once the Current Week number is entered in the designated Cell, the relevant PMFs will appear automatically for the activities which are being executed in the Current week, having been generated in a random fashion but within the overall specified range given in the Initial Sheet (0.7 to 1.2 in this example). The Modified Quantity column will show the above-mentioned Expected Quantity duly modified by PICF and PMF. Since the PMF can sometimes be more than 1.0, the Modified Quantity may come out to be more than the Balance Quantity and in such a case the Actual Quantity column will show the lesser of Modified Quantity or Balance Quantity. If the Actual Quantity is greater than or equal to the Expected Quantity, then PPC for that activity will be automatically shown as 1; else it will be shown as 0. If PICF is <1 then the Root Cause Type column will indicate a RC Type Number taken from the Root Cause library, corresponding to the specified PICF. In another variation, the RC can be picked out from the library of potential RCs.

Once all the relevant activities are operated upon as above, the weekly PPC will be automatically calculated and the PPC Chart shown graphically at the bottom (Figure 3) will be automatically updated including the Current Week's data. Similarly, the Root Causes Pie Chart shown will also get automatically updated considering the Current Week's data. Columns are also provided to indicate Constraints and Acton Plans to solve the Constraints for the various activities in the LAP to give a realistic flavour during training.

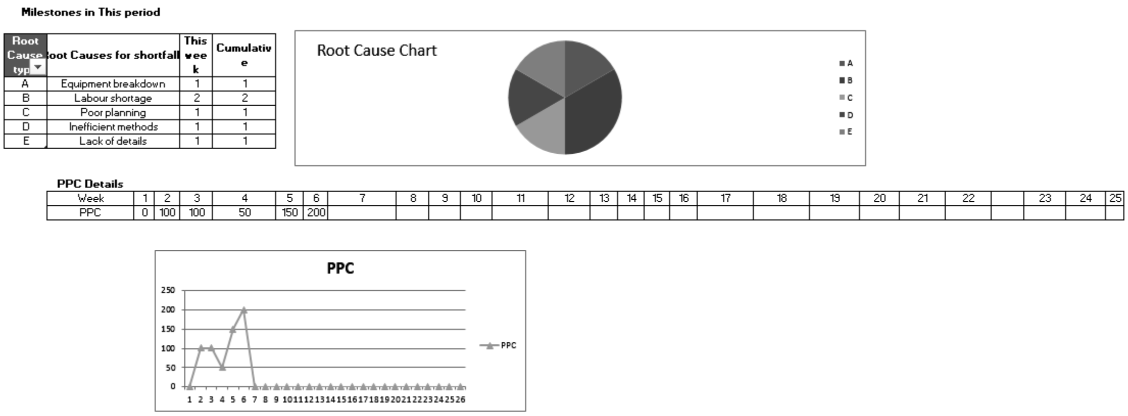


Figure 3: Screen shot of automated Root Causes Pie Chart and PPC chart

Thereafter the Current Running Sheet is copied using macros to a fresh sheet and renamed for the next week's serial number. The above procedure is then repeated again and again until the completion of all activities is reached.

Then the Analysis sheet at the end of the Excel file will be automatically updated compiling the data from all the work weeks and will show the following: the overall PPC variation chart, overall average PPC, the overall Root Causes Pie Chart and the variation in the number of crews deployed in all the weeks for the various activities (as a measure of cost). The quantities executed for the various items in the various weeks as well as the PICF and PMF for the various weeks are also shown in a compiled form.

USING COLPLASSE

In a classroom exercise, each learner can have one copy on his laptop/ computer and run the simulation over the duration of the project. Either the example project (given with fully developed data along with the software) can be used or the instructor can develop a new project model. The various users will get different scenarios because of the randomness of the PMFs and may choose a different number of crews at different times. The Final Sheet compiles the project history and different attempts can be compared for their efficiencies of execution. Using the sum of the products of the number of crews deployed and their standard productivities over the weeks as the base maximum possible output, the actual quantity executed will indicate the efficiency of operations. If the exercise is played out in a group assigning various roles to different people, the identification of the Constraints and their resolution can be done in a collaborative manner, exemplifying the Last Planner process.

Another Method of playing out the Simulation

- Representatives are required for the 6 major trades to interact together: Foundations (excavation, foundations & plinth beams), Concrete Structures (pre-casting & erection, screed concrete), Walls (block work, plastering & painting), Finishing (Waterproofing, tiling, and overall finishing), Electricals, and Plumbing.

- One overall Planning Manager for coordination and one Project Manager for overall management will also be identified. The Planning Manager will prepare all the Schedules and Charts, based on inputs from all concerned.
- The Team will first prepare (together in a Big Room exercise) Phase Schedules for the three phases [Phase I - Excavation, foundations & pre-casting; Phase II - Basic Structure; Phase III- Finishing (plastering, painting, waterproofing, tiling, services, completion], compatible with the stipulated Milestones, by using a Pull system.
- Then they will prepare together LAPs (Look Ahead Plans) for 4 weeks at a time by Pull system, duly considering the Monsoon period. The likely constraints and action plans will also be identified. The Monsoon season has been identified and during this season there will be a reduction in productivity and a Monsoon Factor (PICF<1) is given for each Monsoon week to reduce the Possible Quantity of work which can be done. PMFs with varying values will also be specified for the various weeks and should be duly taken into account. The number of crews can be increased in weeks when additional production is desired to meet specified milestones.
- Finally, the actual completion period should be compared with the theoretical completion period. The Root Cause Analysis should also be compiled and discussed. The variation in number of crews will give an idea of the costs involved.

Alternatively, the instructor can demonstrate a typical execution to a class with the excel sheets projected on a screen for all to see.

In further versions to be developed for actual usage, project practitioners may be able to use COLPLASSE for actual LAPs and keeping track of weekly progress.

LIMITATIONS AND POSSIBLE FUTURE WORK

An attempt has been made to reduce complexity without sacrificing authenticity for this Simulation. In the current phase of development, COLPLASSE can be used mainly for the simpler problems; daily planning has to be done off-line and integrated with weekly plan; constraints listing and resolution have to be done off-line and integrated. It is also slightly tedious to operate over several weeks for simulation projects as each time the Running Plan spreadsheet has to be copied over from the previous Week (though done automatically using a macro) and modified for the Current Week as required. However, for actual projects when only one Running Plan will be active at any given time for the Current Week it may not be a constraint. In the next phase of development, more Excel sheet macros can be used to simulate more processes. It should also be possible to expand the number of weeks for the LAPs from 4 to 8 weeks.

DISCUSSION AND CONCLUSIONS

An example problem covering 20 work weeks and 18 activities has been given along with all required basic data. Students and trainees can practice with the example problem to get a good feel of the LPS process. Actual practitioners can also input data from their projects and run COLPLASSE week after week to automate the templates for easy operations. The data for the example problem as well as screenshots of typical worksheets are given in Fig.s 1 and 2.

The COLPLASSE simulation would be quite useful for beginners of Lean practices to understand the basic procedures of actual LPS implementation and provide them with templates for monitoring LPS implementation. For the serious practitioners, COLPLASSE can provide a simulation tool for evaluating different methods of executing a project. The simulation tool has invoked good interest from Lean practitioners in India to whom this was exposed. It is hoped that the larger Lean community will also find it to be of good interest. COLPLASSE would be freely available for downloading from a specified domain for open usage, while duly acknowledging the Developers.

Further research is proposed to be done using this simulation with various groups to evaluate its capabilities for helping nascent practitioners to use LPS. The results of such research will be presented in a future conference.

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THE EVOLUTION OF LEAN CONSTRUCTION EDUCATION (PART 1 OF 2): AT US-BASED UNIVERSITIES

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ABSTRACT

Effectively transferring lean knowledge and skills to owners, architects, engineers, and constructors (OAEC) requires behavioral changes within an industry that has been legitimately criticized for entrenched practices and low productivity. Documenting how successful that knowledge transfer is taking place can be helpful to those wishing to efficiently introduce lean into their own OAEC organizations.

Lean educational efforts within academic settings have been brought to light through earlier publications. This research identifies the content of lean construction courses from five US-based universities to add to the seven previously documented. Tabulated results revealed that: (a) the content of lean curricula is evolving as grading formats, types of readings, and numbers and types of simulations have grown; and (b) lean curricula as defined by the Associated General Contractors (AGC) lean certification program is starting to permeate academic coursework. This may be a testament that AGC lean certification is providing some advantage in career placement for students.

Investigation of the evolution of lean education within academia helps us better understand a driver of change as students enter the OAEC industry following graduation. The intent of this paper is to document this moment in time, as well as to raise a question about the potential impact of curriculum standardization on future continuous improvement initiatives with respect to lean construction philosophy, methods, and tools, in the OAEC industry.

KEYWORDS

Lean construction education, lean in academia, US-based universities, lean certification

INTRODUCTION

Lean construction pioneer, consultant, and educator Hal Macomberclaims very few contractors, trade partners, architects or engineering firms are truly lean because most are

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operating from only partial experience. Like the ancient Indian parable of the five blind men touching only part of an elephant where each one erroneously comes to believe the animal has the shape and form of a snake (trunk), rope (tail), tree-trunk (leg), fan (ears), spear (tusk), or wall (side), few companies grasp the fuller picture of lean(Schmaltz 2003; Hal Macomber, *Personal Communication*, November 22, 2017).

While there are many definitions of lean, this paper defines lean as *reducing waste and adding value using continuous improvement in a culture of respect* (Rybkowski and Forbes 2016).This description suggests there are at least four critical conceptual parts to the lean "elephant" (e.g. waste, value, continuous improvement, and respect); if any one of the four components is missing, an organization arguably cannot truly be considered lean.

Understanding the full size and shape of the lean animal therefore demands that lean education be both broad and deep. Being able to exercise lean thought means not only nurturing an understanding of lean concepts and principles, but also developing an ability to generate new processes while applying existing ones. Educational specialists reference the importance of teachers engaging students at all levels of the Bloom's Taxonomy pyramid (Bloom et al. 1956; Figure 1).While remembering/recalling information is certainly foundational to the educational process, it is not sufficient; more advanced forms of learning such as applying, analyzing, and creating are also necessary.

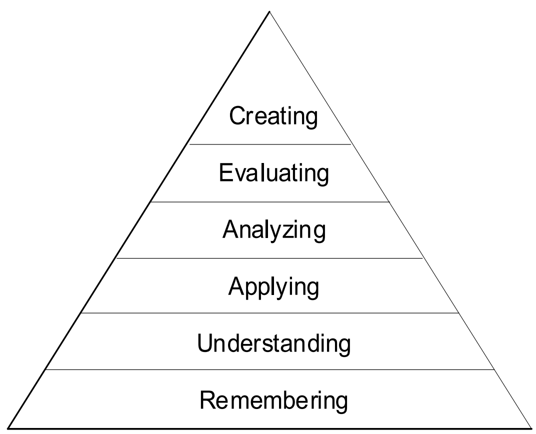

Figure 1: Bloom's taxonomy

To illustrate lean principles to students and effectively engage them at multiple levels, lean pioneer Greg Howell early on began experimenting with serious games and simulations (Tsao and Howell 2015). Serious games are distinguished from simple "gaming" in that the primary aim is educational—i.e.to *learn* through entertainment rather than to be purely entertained (Wouters et al. 2007). Serious games facilitate participant learning through trial and error without risking interference with actual practice. Organizations wishing to inculcate lean thinking use serious games and simulations to teach concepts such as lean processes, supply chain management, sustainable production, logistics, capacity planning, etc. (Pourabdollahian et al. 2012).

Psychologist Csikszentmihalyi described *flow* as the state in which an individual is deeply immersed in an activity, resulting in sense of contentment with little awareness of the passage of time (Csikszentmihalyi 2002). Like scientific experiments, serious games often include a control group, and sequentially modify a single variable that leads to measureable improvements—all while engaging participants in an enjoyable state of play. The most successful simulations immerse players in a state of flow while imparting the lessons intended to be conveyed.

Academics, consultants, and industry practitioners use serious games and simulations, but they are not a panacea. Like all scientific experiments, they must be validated. *Internal validation* means an experiment measures that which researchers believe it is measuring, and *external validation* means the behavioral outcomes predicted by experimental results are applicable to conditions external to that experiment (Jackson 2012).

In addition to internal and external validation, participants must be able to make a cognitive connection between the lean principles illustrated and ways those principles can be applied to actual construction projects. Neeraj et al. (2016) attempted to forge a connection between lean simulations and their onsite manifestations by linking the principles the simulations illustrate to published project case studies.

While serious games are regarded as a hallmark of lean education, no known course on lean consists solely of simulations. Instead serious games are typically embedded into a *structured framework*, offering a deep dive into specific concepts at strategic moments.

Some examples of lean course frameworks include:

- *Factory Physics* and its application to construction (Hopp and Spearman 2001);
- Eleven (11) principles from *Technical Report #72*(Koskela 1992);
- Fourteen (14) principles from *The Toyota Way*(Liker 2003; Figure 2);
- *Lean history and theory* from manufacturing to construction(Taylor 1947; Spriegel & Myers 1953; Gilbreth & Gilbreth 1963; Ohno 1988; Deming [Dawson-Pick 2004]; Liker 2003; Koskela 1992; Ballard 2000; etc.
- *Modern Construction* text (Forbes and Ahmed 2011); and
- Course modules from the Associated General Contractors (AGC 2017).

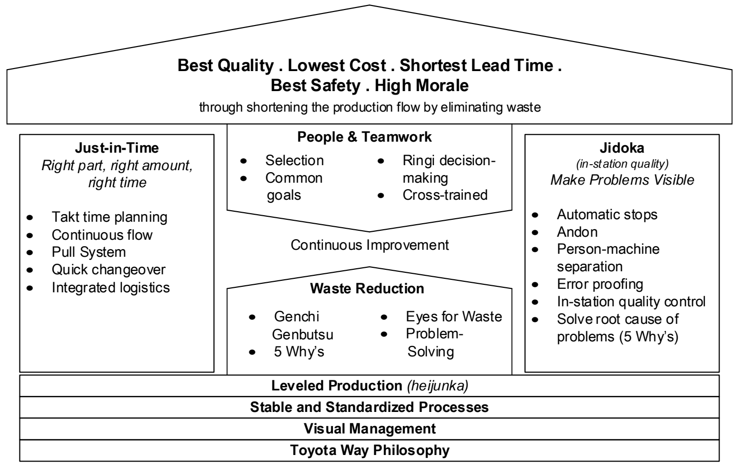

Figure 2: The Toyota Production System as represented in Liker (2003), Figure 3-3, p. 33

THE NEED FOR LEAN: SETTING THE STAGE

One challenge unique to teaching lean at universities that is not shared by those presenting the material to industry representatives and practitioners, is the importance of first establishing the *need* for lean. To students who have yet to work on an actual construction site, lean principles often represent obvious common sense. When one of the co-authors of this paper started teaching lean to a mixed group of undergraduates and graduate students, various methods were used to heighten awareness of the challenges typically faced during project delivery. For example, teams of students were assigned to interview fourteen representative stakeholders about specific challenges the stakeholders faced during their workday. Stakeholders included building owners, architects, structural engineers, mechanical engineers, contractors, specialty contractors, permitting agents, inspectors, vendors, financiers, insurers, attorneys, bonding agencies, and union hall representatives. Students typically expressed surprise about difficulties the practitioners shared during their conversations. These practitioner "deltas" would eventually form the basis for development of the students' final projects—the invention, testing, and reporting of unique and innovative lean simulations designed to address specific challenges mentioned during the stakeholder interviews (Bhaidani et al. 2016; Bhatt et al. 2016; Rybkowski and Kahler 2014; Rybkowski et al. 2011; Rybkowski et al. 2012; Rybkowski et al. 2016).

Similarly, early in a course, students need to be convinced that lean philosophy, methods, and tools offer the potential to solve an organization's problems. Two exercises that help set the stage include: (1) Deming's Red Bead Experiment (Lean Simulations 2017a), and the (2) Repairman Exercise (Mossman 2013; Seddon 2017). In the former, a facilitator assumes the role of a manager who demands her "employees" (audience volunteers) randomly dip a dimpled paddle into a bin of red and white beads while avoiding red beads, where red beads represent an organization's problems. Proverbial sticks and carrots are offered to motivate employees, including threats of firing (the former) and imaginary trips to Hawaii (the latter). Despite their best efforts, players are unable to satisfy their manager's demands because there are significantly more red than white beads in the bin. The purpose of Deming's exercise is to illustrate that the problem of poor performance often rests not with employees, but with a system that makes it impossible for even the most diligent to succeed.

Similarly, during the Repairman Exercise, a facilitator invites her audience to brainstorm all the reasons a house-call repairman may be unable to meet his manager's target average of eight calls per day. The facilitator captures these on a displayed flip chart or computer projection, and, after listing at least ten to twenty possibilities (e.g. traffic, homeowner not in, tools not on truck, bad weather, etc.), s/he invites participants to successively revisit each item on the list and ask: "Is this the fault of the individual repairman or the system?" Inevitably 80 to 90% of the fault lies with the system; yet the repairman is the one who is most often blamed. Blaming the worker for a problem not of his or her own making is not only a recipe for poor morale, it also does not solve the problem. In other words, the intent of both Deming's Red Bead Experiment and the Repairman Game is to set the stage for what is to follow. Once they engage in stakeholder interviews and play either or both of these games, participants tend to become more receptive to learning lean philosophy, methods, and tools.

UNIVERSITY-BASED LEAN EDUCATION

In 2013, Tsao et al. published an inventory of academic lean construction syllabi at seven universities, including an overview of course characteristics, grading metrics, readings assigned (both required and optional) and simulations played. Tsao's articles describe the strategies used by various faculty members, as well as instructions for a number of the most popular simulations (Tsao and Howell 2015; Tsao et al. 2012; Tsao et al. 2013; Tsao et al. 2014). In Table 1, Tsao et al.'s (2013) inventory has been extended to include the lean construction course content of five additional universities. To prepare the expanded table, the co-authors of this paper contacted US-based faculty members they knew were teaching lean, and requested referrals to find additional faculty members they had not previously known. The faculty were invited to fill in a spreadsheet with existing categories and add to these categories as needed.

It is clear from Table 1 that of the 12 universities surveyed, the most frequently played simulations include the Parade of Trades (all 12); the Lego® Airplane Game (or its lower cost variants—the Cup Game, Light Fixture Game, or Make-A-Card) (all 12); and Silent Squares (7 out of 12). From Table 1 it is also clear that of the 12 universities surveyed, the standard required reading diet of most lean construction courses in academia include IGLC papers (9 out of 12), journal papers (7 out of 12), Koskela (1992; 6 out of 12), and Liker (2003; 6 out of 12). The two most commonly played simulations indicate that faculty consider the following concepts critical to Lean thought: reduction of variability (illustrated by Parade of Trades); and materials management, pull, one-piece flow, and balancing workflow (demonstrated by Lego® Airplane Game and/or its variants). Silent Squares is the third most commonly played simulation. This may be due to the fact that it is an easier simulation to set up and faculty regard the demonstration of optimizing the whole over the parts as a critical Lean principle to cover with students. The observation that a majority of Lean faculty require students to read IGLC articles and journal papers, and half of the Lean faculty assign Koskela (1992) and Liker (2003) suggests that they consider these works to be seminal to the understanding of Lean thought. Also of note is that additional material has been added to Table 1 with respect to "Grading," "Readings," and "Simulations," reflecting the continuous improvement of lean construction thought and lean teaching.

Interestingly, Joe Levens' course at Pittsburg State University in Pittsburg, KS, represents a significant departure from previous university courses on Lean Construction because it follows the standard Associated General Contractors' (AGC's) textbook on lean construction and—with the exception of the optional web-based audio book by Paul Akers (2014)—the course is not supplemented with additional required readings. One primary aim of the course is to prepare students to sit for the AGC certificate examination after completing the course, if they so choose. Enrolled Pittsburg State University students and industry representatives alike take the course together in the same university classroom. The site of the course is fluid as well; Pittsburg State students are equally permitted to earn university credit by sitting in the AGC course when offered in Wichita, KS, especially when Levens is serving as local AGC lean course instructor (Joe Levens, *Personal Communication*, November 21, 2017).

ACADEMIC COURSE FRAMEWORKS

Several university faculty commented via e-mail on the conceptual frameworks they employed. The following was communicated by Tariq Adelhamid of Michigan State University: "The conceptual framework I use for the course has always been structured around the premise that Lean Construction is a set of principles and methods that significantly and continuously change what and how we build. I am very keen on emphasizing that Lean Construction has been incorrectly assumed to be related only to the construction phase of a project, while Lean Construction is really Lean in the construction industry, with all of the industry's different providers (owners, architects, engineers, constructors, suppliers, regulators, etc.) considered benefactors of what it has to offer" (Tariq Abdelhamid, *Personal Communication*, January 5, 2018). This comment vividly reflects many of the challenges associated with teaching a university course of Lean—i.e. (1) the reality that the discipline is constantly evolving, as evidenced by the ever-expanding Table 1, and (2) the fact that to maximize success, a culture of lean must permeate not only that of the contractor, but also that of the associated stakeholders as well. The need to "spread lean" to all players has posed to be a significant challenge, and understanding this helps explain the reason why the Associated General Contractors chose to start to develop and standardize an otherwise ever-changing, continuously improving, body of knowledge. This also helps explain why pioneering legal attorneys such as Will Lichtig, took it upon themselves to investigate and write some of the earliest relational contracts for construction, such as the IFOA (Integrated Form of Agreement), and participate in the drafting of Integrated Projected Delivery contracts for the AIA, and Consensus Docs for the AGC. It also explains why Tariq Abdelhamid introduces students to relational contracts as part of his Lean Construction course at Michigan State University. It can be argued that, because the force of law sides with written contracts and many lean projects are now operating under Lean-IPD contracts (or similar), the prognosis for survival of lean construction is greater than earlier, voluntary (i.e. not legally enforceable) collaborative OAEC efforts such as "partnering."

CONCLUSION

Lean construction education—both at universities and in practice—is arguably rooted in lean production theories. The aim of this paper has been to capture a snapshot, through sampling, of university course material that is evolving to include additional readings and simulations. A number of industry practices have been influenced by lean theory developed by academics, as is explored in Part II—a companion article to this paper. An inventory of university curricula suggest there is observable growth with respect to grading, assigned readings, and simulations played. Also, at the time of publication of the Tsao et al. (2013) paper, the Associated General Contractors Lean certification course was still under development. Four years later, not only is the AGC course well-developed and offered to practitioners throughout the US, we are observing its first emergence as a bonafide offering at universities. We observe that graduating students seeking to enhance their credentials in a competitive job market through recognized certifications are increasingly requesting coursework that can do this. Although development of the AGC course and its offering at universities can be viewed as a positive sign that lean construction is "going mainstream" (it is now possible to rapidly grow a workforce of multiple stakeholders who understand lean),a very real concern also arises: i.e. How might standardization of curricula affect the *continuous improvement* process in lean thought itself, which is so fundamental to lean?

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Table 1: Overview of five introductory university-level courses on Lean Construction. Extension is to seven courses published in the original table by Tsao et al. (2013; grey portion, left). Note “Additional” horizontal sections: “Grading,” “Readings,” and “Simulations.”

OVERVIEW	**U. Cincinnati**	**Arizona State**	**San Diego St.**	**S. Illinois U.**	**Amer. U. Beir.**	**Ill. Inst. Tech.**	**Texas A&M**	**N Carolina St**	**Virginia Tech**	**Colorado St**	**Michigan St**	**Pittsburg St**
Instructor	Tsao	Mitropoulos	Alves	Azambuja	Hamzeh	Menches	Rybkowski	Liu	Muir	Senior	Abdelhamid	Levens
Undergrad/Grad	Both	Graduate	Graduate	Undergrad	Both	Grad	Both	Grad	Undergrad	Grad	Grad	Both
Required/Elective	Both	Required	Required	Elective	Elective	Required	Elective	Elective	Elective	Elective	Elective	Elective
Enrollment	10-26	8 to 24	8 to 23	10 to 25	20 to 22	40	10 to 25	20 to 30	10 to 25	8	10	10 to 15
Semester/Quarter	Quarter	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester	Semester
Weeks	10 of 10	8 of 16	15 of 15	16 of 16	16 of 16	16 of 16	16 of 16	15	15	16	15	16 of 16
Started	2005	2004	2009	2010	2011	2012	2011	2008	2018 (antic.)	1999	2001	2016
Ended	2008	2010	Continuing	Continuing	Continuing	Continuing	Continuing	Continuing	New	Continuing	Continuing	Continuing
Night/Day	Day	Night	Night	Day	Day	Night	Day	Day	Day	Evening	Evening	Day
Guest lectures	1 to 2	0	5	0	1 to 2	0	2-3	1	2-3	3-4	1-2	None
GRADING												
Assignments	X	X	X	X	X	X	X	X	X	X	X	X
Contribution	X	X	X	X	X	X	X	NA	X	X	X	X
Discussion forums					X			NA			X	
Exams	X	X	X	X	X	X	X	X	X	X	X	
Field trip	Toyota						Toyota	X	X		X	LCI Kansas Cty
Reflection papers	X				X			X	X	X	X	
Simulations	X	X	X	X	X		X	X	X	X	X	X
Team projects	X	X	X	X	X	X	X	X	X	X	X	X
Additional:												
Video presentation										X		
READINGS												
Ballard 2000							Required	Required	Required	Required	Optional	
Factory Physics			Recommend								Optional	
Gilbreths 1963							Required				Optional	
Goldratt 1992	Required	Required					Ch 13 req'd	Required		Required	Optional	
IGLC papers		Required	Required	Required	Required		Required	Required	Required	Required	Required	
Journal papers				Required	Required		Required	Required	Required	Required	Required	
Koskela 1992	Required	Required	Required				Required	Required		Required	Optional	
LCI white papers			Required					Required	Required		Optional	
Liker 2003	Required	Required	Recommend	Required	Required	Required	Required				Optional	
Oglesby 1989		Required						Required		Required	Required	
Taylor 1947							Required			Required	Optional	
Womack at al.1990	Required	Required				Recommend		Required			Optional	
Additional:												
AGC Textbook											Optional	Required
Aker, 2nd ed.											Optional	Optional
Forbes & Ahmed 2010											Required	
Martinez 1996											Required	
Schmaltz 2017											Required	
SIMULATIONS												
5S Game							X				X	
Airplane Game	X		X	X	X		X	X	X		X	
Cocktail Napkin							X					
Cups Game		X				X						
Delta Design	X										X	
Deming's Red-Bead							X			X	X	
Helium Stick	X				X			X				
Leapcon				X		X					X	
Magic Tarp	X											
Maroon-White					variant		X				X	
Origami Game	X											
Parade Game	X	X	X	X	X	X	X	X	X	X	X	X
Radioactive Popcorn				X								
Silent Squares			X	X	X	X		X	X		X	
TVD Game							X				X	
Win As Much As…	X				X	X				X	X	
Additional:												
Ball Game											X	X
DPR Block Tower									X			X
Gemba Walk									X			
Last Planner (AGC)											X	
Leadership Styles											X	X
Lego Hotel/Tower											X	X
Light Fixtures										X	X	
Make-a-Card											variant	X
Marshmallow Challng											X	
NASA Survive/ Moon											variant	X
No./Task Switching											X	
Oops								X				
Original Dice Game											X	
Prison Door Case											X	
Repairman												
Villego								X			X	X

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THE EVOLUTION OF LEAN CONSTRUCTION EDUCATION (PART 2 OF 2): AT US-BASED COMPANIES

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ABSTRACT

The benefits of lean projects such as reduced schedules and budgets are well documented; construction organizations accomplish lean project delivery through the practices of project teams, yet the backgrounds of many participants have relatively little involvement with lean methodology due to its relative newness. Many participants in the lean movement such as members of the Lean Construction Institute (LCI) attribute project success to the training that is typically conducted to create an awareness and capability among participants and align the team with the priorities of the project. A study of leading firms was undertaken to examine this linkage by reviewing how training is provided for project teams, including the work force. A cross-section of established construction firms, design firms, and consultants were surveyed to determine the best practices that are currently in use. These organizations are all members of LCI or the Associated General Contractors (AGC).

Many important lessons were learned, including: the successful approaches taken by AGC to provide industry training; the best practices of the companies surveyed; and future opportunities for improvement in lean training at the industry level. Notably, some of the approaches used in academia such as simulations, were used, but some companies were developing their own training, emphasizing leadership over tools.

KEYWORDS

Lean construction education, Lean Construction Institute, Associated General Contractors, CM-lean certificate, leadership.

INTRODUCTION

The purpose of this study was to review the evolution of Lean Construction education with US-based, Owner, Architect, Engineering, and Construction (OAEC) stakeholders. The following sections provide case study examples of lean educational initiatives

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offered within industry by LCI and AGC as well as strategies used by lean company champions and independent lean consultants.

The underperformance of the construction industry is well documented (Koskela 1992 and2000; Teicholz 2001; Eastman et al. 2008, and the McKinsey Global Institute 2017). In particular, most recently the McKinsey study identified a growth rate of 1% annually in the construction industry during a recent 20-year period of study compared with 2.8% for the total world economy and 3.6%for manufacturing.

Lean construction emerged as a response to frustration with low construction productivity, errors, delays, cost overruns and safety. However, a survey from a 2003 report by McGraw Hill revealed that major challenges to implementing lean on a job site included: (1) lack of lean knowledge, (2) lack of sufficient support, (3) perception that lean is too complex, (4) employee resistance, and (5) lack of industry support (McGraw Hill 2003). Despite these challenges, the OAEC industry has steadily work on lean implementation, and a decade later, practitioners have noted that the benefits of lean implementation include improved safety, higher customer satisfaction, high quality construction, reduced schedules, reduced costs, greater profitability, and better risk management (McGraw Hill Construction 2013).

METHODOLOGY

A modified Delphi approach was utilized, drawing on the expertise of executives, lean champions and trainers from several OAEC organizations that are known for their leadership in lean construction projects. Fourteen (14) individuals were contacted (as subject matter experts) both by email and/or conference calls to identify the strategies used by OAEC stakeholder companies to impart lean practices to employees, To establish a common frame of reference, open-ended questions were asked about their organizations' mission/corporate philosophy, lean journey, their personal lean background, training approach, lean implementation tools, and how they address the barriers to lean implementation.

OUTCOMES

While the above questions did not apply equally to all respondents, summaries of their responses are included below, as appropriate.

LEAN CONSTRUCTION INSTITUTE (LCI)

The Lean Construction Institute (LCI) was founded by Greg Howell and Glenn Ballard in 1997 "as a way to develop and disseminate new knowledge regarding the management of work in projects" (LCI 2017a). LCI offers a variety of educational resources, including organizing the LCI Congress which rotates to different cities on an annual basis. LCI provides educational resources to 31 Communities of Practice throughout the US, and hosts Internet-accessible webinars, lean coffees, and happy hours. It publishes and distributes educational books and lean simulations, including the Make-a-Card-Game (that is, a variation of the Lego Airplane Game), the Parade of Trades (Tommelein et al. 1999), and Silent Squares (LCI 2017b). LCI also publishes the *Lean Construction*

Journal (LCJ). Since 2003, LCJ articles have made peer-reviewed experimental results and case studies from academics and practitioners freely available (LCJ 2017).

According to Executive Director Dan Heinemeier, although LCI has chosen not to develop its own certification program, it partners with AGC, which offers a lean certification program. LCI's Education Programs Director Kristin Hill stated that the LCI approach to Lean Construction education is to enhance awareness through its annual LCI Congress and Design Forum events. Based on recommendations from LCI's Education Committee, a number of learning modules were rolled out locally (up to 5); they are face-to-face and very interactive. They include a number of simulations in the "Introduction to Lean" class, the Parade of Trades and the "Make a Card" Game. There is also a Big Room simulation and a Target Value Delivery (TVD) module that simulates interactions within a project team as they go through a project and seek to lower costs.

LCI's corporate membership includes approximately 35 to 40 owner member companies, including Proctor and Gamble, Intel, and Universal Health Systems (UHS). Four or five representatives sit on the LCI Board. LCI provides incentives to member companies such as a) having a complimentary "Introduction to lean" presentation, or b) Attendance of one (1) employee at the Annual Congress. Thus, owners have begun to wield some influence in the development of LCI's priorities – which is greatly desirable for increasing construction industry demand for the application of lean principles. According to Heinemeier, one measure of LCI's success is its expansion from fewer than 100 member companies in 2013 to over 200 in 2017, and growth from approximately 800 LCI Congress attendees in 2014 to over 1500 attendees in 2017. Almost two-thirds of Congress participants also attend lean training courses while there (Dan Heinemeier and Kristin Hill, *Personal Communication*, Nov. 7, 2017; Konchar and Mahshum 2017).

ASSOCIATED GENERAL CONTRACTORS (AGC)

Effective lean implementation requires collaboration by multiple project stakeholders who understand the principles, practices, and spirit of Lean Construction. Recognizing the enormity of the educational task vis-à-vis the OAEC stakeholder community, former AGC president Chuck Greco engaged Tariq Abdelhamid of Enovio Consulting from 2009 until 2013 under a research contract with Michigan State University to develop a standardized lean construction education program. Abdelhamid's initial four unitshave since expanded to comprise an interactive 50-*minute Lean 101: Foundations of Lean Construction* web-based introduction and a 35-hour in-seat modular educational program.

Approximately118 lean construction specialists throughout the US teach the seven units. The units are delivered in a bricks-and-mortar (versus on-line) setting. Although each instructor presents the material in a slightly different way, he or she aligns the course with specialized AGC textbooks and also administers the same simulations. For example, lean consultant Colin Milberg is one of the instructors who regularly delivers the course for the Boston-area AGC. While he sometimes presents the material as a weeklong block, he prefers to teach on Fridays with "off-weeks" in between. Typically, Milberg consolidates Units 1 & 2 and 3 & 4 into two separate full-days, whereas Units 5, 6, and 7 are offered as "standalone" days. During Units 1 & 2, participants encounter the concepts of flow, variation and bottlenecks. In Units 3 & 4, they are introduced to pull planning and Last Planner®. In the remaining units, Milberg introduces the principles of visual management, transparency, supply chain management, cross-docking, A3s, target value design, root cause analysis, the lean triangle, co-location, kanban, Choosing by Advantages (CBA; Suhr 1999), Plan-Do-Study-Act, etc. Participants play additional simulations including the 5S Numbers Game (Superteams 2016) and the Marshmallow Challenge (Wujec 2012) (Colin Milberg, *Personal Communication,* November 20, 2017).

After completing all seven modules, students can take a four-hour, 150-question multiple-choice test. Upon passing, they are awarded a certificate. According to AGC's Curriculum Development Director, Warren Kiesel, 600 people earned the credential between the program's inception in Oct2015, and Nov2017. At the 2017 LCI Congress, all 35-seated courses were completely sold out. It is clear to Kiesel that as soon as AGC offered the lean certificate credential, the program took off – "People want to take the course as fast as they can. "He also notes that construction activity in the US is back to pre-downturn levels but is being accomplished with 13% fewer workers in 2017. He thinks this increased productivity may be related to an emphasis on BIM and prefabrication. Lean project adoption seems greatest among Owner organizations—such as hospitals —who have to live with the finished facilities. "Spec" builders seem less interested; they apply heavy price pressure in the acquisition of design and construction services. Their market may be less sensitive to the improved functionality and quality that lean projects typically offer (Warren Kiesel, *Personal Communication*, Nov.14, 2017).

LEAN COMPANY CHAMPIONS

Example 1: General Contractor: J.E. Dunn

Many companies like JE Dunn have developed their own lean champions to guide their organization's lean journeys. Rebecca Snelling joined JE Dunn in 2012 after working as a lean consultant with lean construction pioneers Hal Macomber and John Draper, bringing the company substantial savings on several projects. Snelling said the company decided to engage her on a permanent basis instead of a project-by-project basis. Five years later, Snelling has grown her lean division staff to 10 employees. She says JE Dunn is not using AGC training at this time since they offer their own tailored form of instruction.

Snelling said she typically introduces Lean to employees by facilitating the Lego™ Airplane Game, the Parade of Trades, and Silent Squares. On a typical project, every member of the project team, including trades, is provided with a one-day training class that focuses on lean thinking and the specific tools that a project will use. Separately from that, all employees (project and non-project) go through a one-day lean training that is focused on lean principles and tools that they can apply to their own work. With regard to support, Rebecca's team typically helps a project team with lean facilitation at project inception. Rather than teaching pull planning using the DPR blocks game or Villego® (Villego 2017)for example, Snelling demonstrates the process to a superintendent or project manager (PM) on an actual project in three ways: first, by facilitating a pull plan in front of a superintendent or PM; second, by co-facilitating a pull plan with the same superintendent or PM; and third, by observing the superintendent or PM administer a pull plan on his or her own. Snelling then provides feedback in a plus-delta format.

The team has a variety of skills on tap; some are knowledgeable about IPD, and others about the Last Planner System (LPS). They are dispatched to different project locations; two members help to provide content on procedures for the company. The team comprises people of different backgrounds; some used to be project managers, or superintendents; while others have prior experience in manufacturing. Snelling has taught participants to teach lean to others. In Rebecca's words, "These people do not grow on trees." During hiring, she said she looks for rising stars who are both humble and curious.(Rebecca Snelling, *Personal Communication*, November 7, 2017).

***Example 2:* General Contractor: DPR Construction**

DPR Construction has been active in shaping lean thought through the pioneering involvement of Dean Reed and his interaction with Stanford and UC Berkeley during Lean Construction's formative years. East Coast Leader of Lean and Project Executive, Chris Dierks, is a strong believer in workshops and focuses participants on what it means to have a lean mindset. Projects start with teaching and learning and Chris plans these activities to best match the dynamics of a project by varying the duration and agenda; a project with a smaller overall duration may need only one short workshop, while others may work best with multiple half-day or full day workshops. There is much emphasis on having team members getting to know each other. DPR's commitment to lean is evidenced by having these activities whether or not the owner asks for a project to be lean. The curriculum typically includes Silent Squares, the Airplane Game, and the DPR Pull Planning Exercise.

DPR stresses establishing Conditions of Satisfaction (CoS), and defining value; owners' representatives are almost always included, as are the key trade partners. The process is sometimes leveraged by having a knowledgeable trade partner lead portions of the training; different people are used to lead Gembawalks, present the Last Planner System, etc. while being active participants in projects. "Go and See" projects are considered to be important; special recognition is given to successful project teams and the company creates a platform to transfer knowledge to other project teams.

DPR's employee lean training involves simulations including the Lego® Airplane Game, Silent Squares, and the DPR Pull-Planning Game (Visionary Products 2008; LCI 2017b; King 2011; Tsao et al. 2014). Interestingly, although they encourage their employees to take the AGC lean course and occasionally teach local classes, DPR has departed from focusing on tools and has instead turned its attention to an emphasis on leadership, exposing its employees to a nine-week program called "Lean Leadership" where the largest focus is on building teams. Cory Hackler the "West Coast Leader of Lean" and Erika Byse guide 20 to 30 people at a time with two to three courses being offered simultaneously. Students are asked to build individual radar charts to plot personal strengths, as well as areas in which they can improve. They are then encouraged to find someone who scores highly in an area in which they feel they need to improve, in order to learn from that individual. The success of the program is borne out by the fact that 220 people are waiting to take the course. In post-course evaluations, 100% of the attendees have recommended the course to others.

With regard to performance metrics, DPR is studying past projects to determine which ones are the most relevant. Hackler and Byse concur that DPR is intensifying its focus on the "respect for people" part of the definition of lean construction (Erika Byse, Chris Dierks, Cory Hackler, and Dean Reed, *Personal Communication*, Nov. 21, 2017).

Example 3: General Contractor: Linbeck Group, LLC

Linbeck Group based in Texas is one of the earliest general contractors to experiment with lean construction. According to Stewart Trapino, in 1968Leo Linbeck Jr. responded to a client's urgent request to reduce cost and schedule. He fortuitously uncovered many of the principles that now are associated with the IPD approach: early involvement, collaboration, openness concerning cost, target costing as a method (vs. value engineering), and a commitment to providing the best value (Stewart Trapino, *Email Communication*, January 4, 2018).Then in 1998, Leo Linbeck III formally introduced lean as a management system to the company, having met Greg Howell and Glenn Ballard while completing his MBA at Stanford. The Lean Construction Institute worked with Linbeck to implement the Last Planner™ System of Production Control (LPS) on a project for Rice University--a move which led to LPS being used on every Linbeck project until 2012. However, because of the perceived complexity of LPS, Linbeck's management struggled to convince its employees to fully implement it. It was at this time the company's management developed its "Lean Boards" system as a way to simplify LPS. The boards were inexpensive, could be packed up in a suitcase, and provided a platform to support pull planning, daily huddles, PPC tracking, and accountability.

In a 2014 company meeting, Paul Akers encouraged employees to read his book *2-Second Lean* (Akers 2014) and use their cell phones to create "before and after" videos recommending opportunities for improvement on site. The company hosts a spoof of the Academy Awards at their annual meeting and presents video winners with small "head" statues in lieu of the Oscar statuette. The videos are posted on the company website for others to see (https://www.linbeck.com/lean), and new employees are asked to watch the videos so work improvements can be adopted and standardized. Also, all employees are encouraged to complete the AGC Lean education program and demonstrate they have mastered Lean Boards, make and share at least one lean video, and teach one or more AGC lean units(Stewart Trapino, *Personal Communication*, January 4, 2018).

Project manager and company lean champions Sean Sachtelbenand David Noonan say lean is deeply embedded in the Linbeck culture. They put great emphasis on combatting the eight wastes of lean (the eighth defined as "unused employee genius") and Sachtelben and Noonan carrya list of the eight wastes on a pocket card as a constant strategic reminder. The two tools they use most often include: (1) pull planning, and (2) Lean board tracking. All Linbeck projects are pull-planned and involve posting a master (milestone) schedule, phase schedule, two week-lookahead plan, and weekly work plan. Lean board tracking charts are posted to a white board on casters instead of a job trailer wall so it is made readily available wherever workers are engaged at any point in time.

Sachtelben and Noonan said they stress to employees that lean is *simple*. For example, as project managers, they move the dumpster and locate portable toilets to areas that are convenient for their workers, reducing the waste of unnecessary movement. They store tools in easy-to-find gang boxes so "$25/hourworkers don't repeatedly waste20 minutes searching for equipment." Since many construction activities are repetitive, small continuous improvements lead to substantial savings. Sachtelben also said Linbeck has a number of project managers who rotate as lean champions. They travel to one another's site locations (i.e. Houston, Dallas, etc.), socialize and exchange "ideas that work".(Sean Sachtelben and David Noonan, *Personal Communication*, November 28, 2017).

Example 4: Architecture firm Boulder Associates

Several architects have begun experimenting with the application of lean construction methods to design thinking. According to Todd Henderson, a principal at Boulder Associates, Romano Nickerson, also a principal, began experimenting with applying the Last Planner® to design. Nickerson was an early advocate of lean who sought to remove waste from his own work. For Henderson, a turning point came when Nickerson shared a graph of staff working hours with his colleagues; three-quarters of the staff were accustomed to working on Saturdays and Sundays. Following the application of the Last Planner®, workflows steadied and staff found they were then able to spend weekends away from the office. The method spread laterally at a grass roots level via staff members assigned to multiple projects who then "mentored up" to other managers. Company directors recognized the positives in lean thinking and adopted the "Work Plan"—Boulder's lean initiative. Despite the 2009 recession, and a downsizing of nearly one-fourth of their staff, Boulder Associates doubled their profits.

Henderson explained that as an office, they have read and discussed Liker's *The Toyota Way* (2003) about six times. In truth, they are finding it difficult to sustain lean processes, and do observe themselves backsliding at times. As a design firm, Henderson admits they are discovering that Agile and Scrum, which are heavily practiced by the software design industry, may be a better fit for the "loopy" iterative process of architectural design than the Last Planner® System. The LPS seems better suited for the more linear processes used by general contractors, although there is some disagreement about this. (Todd Henderson, *Personal Communication*, November 11, 2017).

LEAN CONSULTANTS

Hal Macomber is an example of a lean construction pioneer who has offered a solid foundation for next-generation lean consultants, including the likes of Rebecca Snelling (now at JE Dunn), Colin Milberg (now founder of ASKM Associates), and Cynthia Tsao (now a lean coach, educator, and researcher at Consigli Construction Co, Inc.). Macomber has made critical contributions in the development of lean practices that have now become mainstream. They include Study Action Teams (SATs), as well as several ideas seminal to lean construction, including Reliable Promises as part of language action theory. He also co-authored with Greg Howell the "Five Big Ideas" for corporate pioneer Sutter Health in the early 2000s as they embarked on a major construction program and took a leap of faith with the then emerging lean methodology. The ideas were embodied in an Integrated Form of Agreement (IFOA) and ultimately in AGC's Consensus Docs. Hal's contributions also include the "Good 5 Why" process. Hespent time in Japan in the mid-1980s as part of a program with the Japan Union of Scientists and Engineers (JUSE) that exposed him to total quality and time-based management. Although he since consulted for various technical industries, Macomber ultimately chose to focus on construction, and the 2017 Macomber and Davey book, *The Pocket Sensei*, reflects the Japanese influence.

What is especially interesting about Macomber's recent work however, is that instead of being interested in lean tools, he is most concerned with *kata*—a practice involving personal reflection which leads to continuous improvement. Reflection means an individual observes what he or she is learning, and because of this, continuous improvement becomes automatic, almost involuntary. For example, if a kata-enlightened staff at Toyota spies a stray paperclip on the floor, he will pick it up without being told; if a diploma in an employee's office is misaligned, another employee will straighten it without asking. Macomber argues that few companies now claiming to be lean actually are because most are missing a type of automatic, "muscle-memory" form of continuous improvement which is key to a true organization-wide lean culture. If his observation is correct, kata may help resolve the difficulty expressed by several companies of maintaining lean within their organizations long-term. In fact, kata may serve as the interstitial glue that holds together the parts of the elephant we call lean (Hal Macomber, *Personal Communication*, November 22, 2017).

OWNER ORGANIZATIONS

James Pease is a Regional Manager with Sutter Healthcare in Northern California. Heleads a team of 7 Project Managers who manage approximately 100 projects valued at $350M in the greater Sacramento Area. Sutter's mission is to enhance the well-being of people in the communities served through a not-for-profit commitment to compassion and excellence in healthcare services. .

Sutter's lean journey started as a need to meet a California Senate Bill that required the replacement of most of their hospitals starting in the late 1990's. Having limited success with earlier projects, Sutter looked for new approaches to deliver an estimated $7 billion program in the early 2000's and was led by its construction attorney Will Lichtig to seek guidance from Greg Howell and Glenn Ballard. Dave Pixley, the Director of Construction, embraced lean construction and saw significant success with the initial project implementations. Subsequently, all projects have been lean-based, including design and construction work. One provider, Herrero Builders, through Paulo Napolitano created a Lean training program for its partners and clients on an IPD project.

Building on these successes, Sutter appointed a director of Lean Integrated Project Delivery – Digby Christian. He leads a 5-day Lean and IPD training for all PMs and project controllers. Sutter has developed in-house resources for IPD best practices; Last Planner and Target Value Design concepts are usually taught through LCI meetings or conferences. Sutter also often hires consultants to get new project teams started.

The simulations used include the DPR Block Game, Parade of Trades, and Villego. One day per month is reserved for staff training although it is primarily process-driven.
Last Planner training and education are done at the start of projects - including the design and construction partners. Trade partners are also selected based on these abilities. The

majority of the training is hands-on at the project level. Christian's training is held once for each Project Manager and a sequel to that program is being developed.

With regard to implementation barriers, projects tend towards chaos and it takes work to keep them organized. Overall, the dedication to lean from the internal construction administration structure has proven to be successful in creating a lean culture, and in engaging the services of providers who are highly capable... With this support from the administration, including Dig by Christian and TanosLampsas, James Pease believes it is unlikely that project team members - both internal and external will backslide to traditional behaviors. (James Pease – Personal Communication – February, 2018)

CONCLUSION

This paper describes LC teaching approaches in the OAEC community, including LCI, AGC, design firms, construction organizations, and training consultants; it complements Part 1 of the series that focuses on academia.

The results of this new study with lean construction leaders in the U.S. provide valuable lessons for the construction industry in improving lean deployment. The findings suggest that many OAEC stakeholders view a knowledge of lean as providing a competitive advantage, and are trying to deploy lean training as rapidly as possible. Interest in lean construction and IPD has accelerated in recent years with even greater interest in the training that is provided at LCI conferences. Construction professionals have been actively seeking the AGC's CM-Lean credential. The AGC program mirrors the simulation approach used in academia with foundational concepts such as visual management, transparency, supply chain management, and root-cause analysis.

Construction organizations have been adopting the model of internal "lean champions" as exemplified by DPR Construction, JE Dunn Construction, and Linbeck Construction. Lean deployment is far from uniform and is constantly evolving, from having structured training programs in some cases, to simply promoting waste reduction as an internal culture. While lean consulting firms offer training that contains many of the tools encountered in academic programs, companies such as DPR have begun to emphasize the role of leadership in the lean transformation. Design firms such as Boulder Associates have many successful lean projects to their credit. However, in the spirit of continuous improvement for design projects they are gravitating towards a more advantageous scrum/agile methodology. Owner organizations such as Sutter Healthcare attribute the success of their projects to their commitment to lean and active participation and leadership in deploying the lean methodology through their project teams.

Given the wide variety of approaches used by companies in training members of the project team, a number of questions arrive: How do individual methods stack up against a cost/benefit analysis? How should the training be adjusted to match the needs of a specific project? How does "just in time" training compare in effectiveness with routine training? It would be useful to develop an inventory of the tools/techniques used by industry practitioners as was done in Part 1of this two-part paper.

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A RELOOK AT PLAN RELIABILITY MEASUREMENTS IN LEAN CONSTRUCTION AND NEW METRICS FROM DIGITIZED PRACTICAL IMPLEMENTATION

Thi Qui Nguyen [1] and Sharath Sridhar Waikar [2]

ABSTRACT

Lean construction is increasingly being adopted in many countries as a means to improve construction project performance and productivity. Measuring the various improvements towards achieving the outcomes of reliability, preparedness, commitment and collaborative culture is crucial for a sustained successful practical implementation of Lean. Among various Lean techniques and tools, the Last Planner System (LPS) method has been widely used in construction projects for its simplicity and applicability to the construction environment. With LPS, the plan reliability is measured by Percent Plan Complete (PPC). The PPC as a single metric has been found to be insufficient in providing actionable information in understanding the root cause of challenges faced in different projects nor in improving the reliability nor in getting valid commitment of key project parties. It is also ineffective to symbolize as the metric to represent the preparedness, capacity or performance of the different sub-contractors. This paper aims to provide an in-depth review of PPC and other reliability measurements and their advantages and shortfalls for practical implementation. It reviews the symbolic representation of PPC to improvement through the application of Lean methods in construction from a planning and management perspective. From these analysis, this paper introduces a framework for practical implementation of Lean construction. It also proposes new metrics to supplement PPC to accurately represent plan reliability for better understanding of the root causes. The proposed indices are validated using data obtained from the digital application of Lean construction processes using Lean PlanDo. Lean PlanDo is digital tool embedded with Lean principles for construction planning and management based on LPS with a key emphasis on Value Stream Mapping (VSM) and constraint management. The proposed indices will provide the project teams with practical measurements and to build upon their understanding of Lean, measure the effectiveness of planning and the application of Lean methods in the project.

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KEYWORDS

Lean construction, percent plan complete (PPC), construction productivity, digital construction, data analysis, reliable planning, valid commitment

INTRODUCTION

Construction productivity has been flat over several decades while other labour-intensive industries are experiencing improved productivity. Poor planning, lack of commitment and blame-game culture have led to weaker control over construction processes. These have compounded the problem of project delays, wasted time, defects and reworks.

Lean construction has been promoted as an effective approach for improving productivity in construction (Aziz, et al., 2013) through better project planning and control. It is the application of lean thinking into construction projects, and essentially focuses on maximizing the performance and value for the customer and minimizing waste. In general, lean construction make projects easier to manage, safer, completed sooner, and cost less and of better quality.

Reliable planning is vital for achieving a successful project performance (Laufer, et al., 1993). Master and phase scheduling defines the scope of work and provides the long-term vision of the entire project from which project managers can make suitable strategy decisions. Lookahead and weekly planning on the other hand provide detailed action plans to the site team for commitment and execution. At any time of the project, construction plans at both macro (master- and phase planning) and micro (lookahead- and weekly planning) should be dynamically integrated with the current project conditions so that they be executed on site. While there exist different metrics to measure the plan reliability at different level, they are found missing this dynamic nature, and thus fail to capture the true reliability.

Last Planner System (LPS) (Ballard, 1994) is one of the most common Lean methods being adopted in the construction industry. This approach emphasizes on micro planning and aims to improve the workflow reliability of the construction plan and reduce the negative impacts caused by variability. Although the key input to this planning system is the master schedule, its dynamicity is not integrated. This missing element would lead the team to outdated and or unachievable project targets, and the related reliability KPIs may not truly describe the plan reliability picture. In addition, the main reliability measurement of the LPS is the Percent Plan Complete (PPC) which focuses only on very micro planning level and overlooks the importance of macro planning.

This paper is to provide a review the existing metrics of planning reliability and how they are interpreted in practical applications. It also presents the execution framework for practical adoption of Lean concepts and the LPS which is currently been used in the Singapore construction industry. This framework is implemented in Lean PlanDo – a digital tool for Lean construction project planning and management. New plan reliability indices are also proposed and subsequently illustrated through a simulated case study.

LAST PLANNER SYSTEM (LPS) AND ITS RELATED PLAN RELIABLITY MEASUREMENT

OVERVIEW OF LPS

The Last Planner System is one of the most common Lean techniques which has been demonstrated to be a very useful approach for the planning and control of construction processes (Aziz, et al., 2013). It comprises of two main processes: Lookahead planning elaborating project milestones into action plans, and weekly work planning describing the weekly execution plan. These processes provide a better control on both construction workflow and production unit.

The sequence of last planner process (illustrated in Figure 1) consists four main steps: (1) master and phase scheduling defining the scope of work and milestones – what SHOULD be done to achieve the project targets; (2) lookahead planning elaborating project targets into work sequences (tasks) and constraints that need to be cleared before execution – what CAN be done; (3) Weekly work plan determine what will be executed by the team – WILL do; and (4) DID – what was achieved.

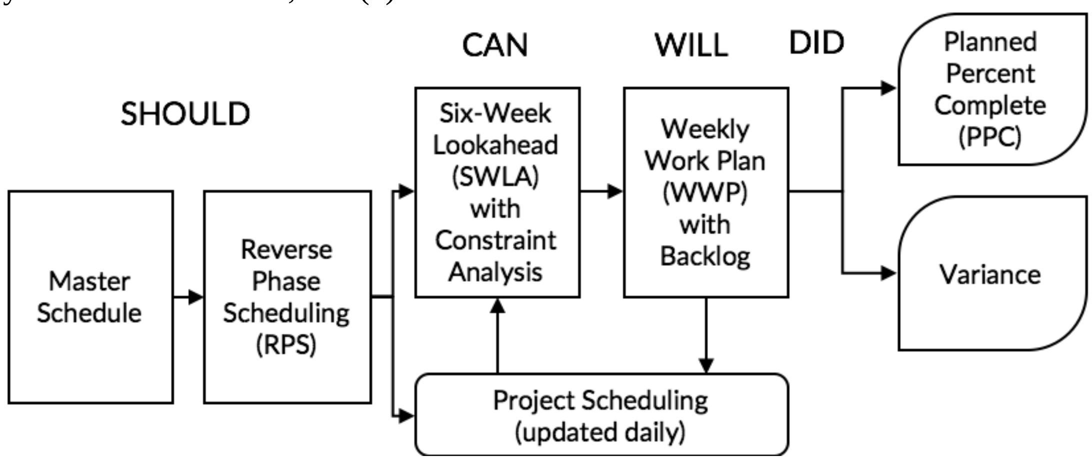

Figure 1: Planning sequence of the last planner process (Aziz, et al., 2013).

One of the fundamentals of the LPS is reliable promises or commitments through reducing workflow uncertainty and variation so that only tasks that are well defined, sounded with right sizing will be allocated for execution. This shielding process also helps improve the reliability of planning and boost up productivity (Hamzeh, et al., 2015).

PLAN RELIABILITY MEASUREMENTS

Different metrics have been developed to represent the reliability of planning at different phases and are summarized in

Table 1 from macro to micro planning levels.

It can be found from the summary that the PPC, TA and TMR indices are mainly focus on short-term planning reliability and yet lack the description for long-term planning targets in the master and phase schedules. In addition, since the calculation of PPC are mainly based on the number of tasks completed versus committed and disregards the task sizes, it does not provide sufficient information for the site team on sizing their capacity to fit the targeted progress which has been defined in the long-term plans. It is also widely recommended by LCI that higher PPC is preferable and projects should target a PPC range of 75% to 90% for good performance (Emdanat, et al., 2016). However, data obtained from practical implementation show that aiming only increasing PPC through reducing the number of commitments will not improve project performance, yet the team capacity should be increased according the long-term plan requirements. In other words, focusing only on short-term reliability and especially PPC may mislead the project team from long-term milestones.

CL and PRCO metrics are solutions to link short- and long-term planning targets. However, the dynamic nature of long-term plans is not considered, which may lead to outdated targets to be considered in the calculations. In addition, the metrics are built at activity level and thus missing a link to enhance the execution.

Table 1: Summary of plan reliability metrics

Plan reliability	Metric and Author	Description	Calculation
Master/Phase plan	Commitment Level (Emdanat, et al., 2016)	Percent of the total committed required activities of the total required activities (when its Late Start date falls within the work planning window time) on a work plan when a new work plan is created.	CL = Required WILL / SHOULD
Lookahead plan	Tasks Anticipated (Hamzeh, et al., 2012)	Percent of tasks on a work plan that were anticipated in the previous plan 2 weeks earlier	TA = WILL / CAN
	Tasks Made Ready (Hamzeh, et al., 2012)	Percent of completed tasks in a given work plan that were anticipated in a prior work plan	TMR = DID / CAN
Weekly work plan	Percent Plan Complete (Ballard, 2000)	Percent of completed commitments to the total commitments	PPC = DID / WILL

	Percent Required Completed or Ongoing (Emdanat, et al., 2016)	Percent of the required activities that are completed on or before their promised completion dates	PRCO = (Required to be Done + Ongoing On Track) / Required Will

FRAMEWORK FOR LEAN CONSTRUCTION PROJECT PLANNING AND MANAGEMENT

This section presents an execution framework for project planning and management using Lean construction techniques called Lean PlanDo (LPD). The kernel value of LPD centres at its ability to marry strategic long-term planning (CPM) with Lean construction techniques (LPS and Value Stream Mapping) and constraint-based planning. The planning and controlling cycle is described in Figure 2.

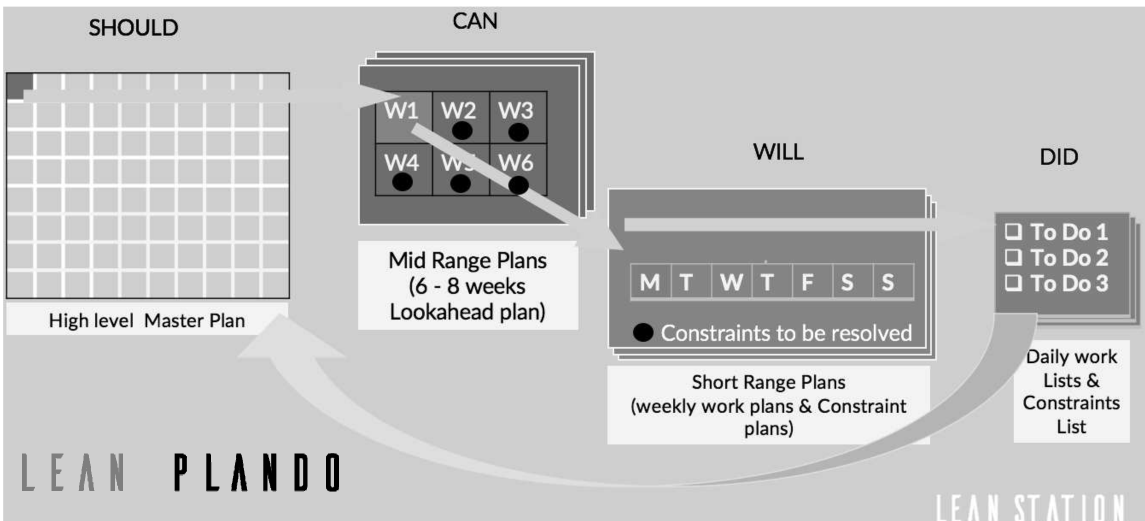

Figure 2: Lean construction project planning and management framework (LPD)

Inheriting LPS features, the planning workflow of LPD also starts from a high-level master plan indicating project scopes and milestones. Lookahead plans are sized at 6 or 8 weeks and created in a weekly basis, which allow the project team plan out the required construction plans with proper task sizes and sequences for value-added works. Essential non-value-added works are considered as constraints which hinder the construction works are also identified and assigned for accountable parties. Subsequently, the weekly work plans provide detailed information on the works (tasks) to be executed and constraints need to be handled to make future works ready. The weekly plans are then broken down into daily To-do list for monitoring and updating in a daily basis. The daily progress and status for both construction works and constraints are integrated back into the lookahead and master plans, providing accurate real-time information about the project. The week-on-week planning and controlling cycle is presented in Figure 3.

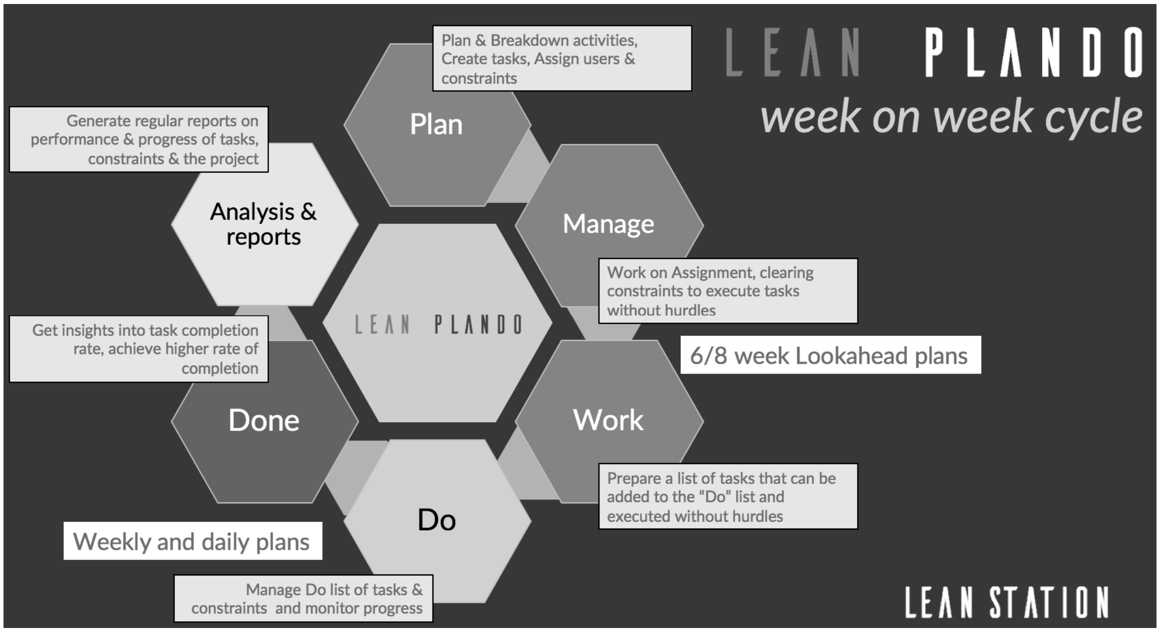

Figure 3: Week-on-week planning and controlling cycle

With this bi-directional planning and controlling framework, the master plan is always updated with latest project data and thus provides better guidance for the project team. Long-term plans now can be dynamically revised and adjusted to the site and project situations. Essentially, it provides a direct link throughout SHOULD – CAN – WILL – DID plans in one single system, and allows for improved plan reliability metrics.

LPD has been widely adopted in Singapore as one of the leading Lean construction tools in the industry. The typical organization of a LPD team comprises of three main teams:

(1) Planning team: in-charge of lookahead planning for both construction works and milestones for constraint management. It involves experienced team members with both planning and practical execution knowledge.
(2) Coordination team: in-charge of constraint management. They are responsible for clearing constraints and make everything ready so that the related construction works can be started as plan.
(3) Site team: in charge of site work and project monitoring. This team with the cooperation of supervisors and the execution team (subcontractors) is to make sure the construction to be conducted and update site progress daily.

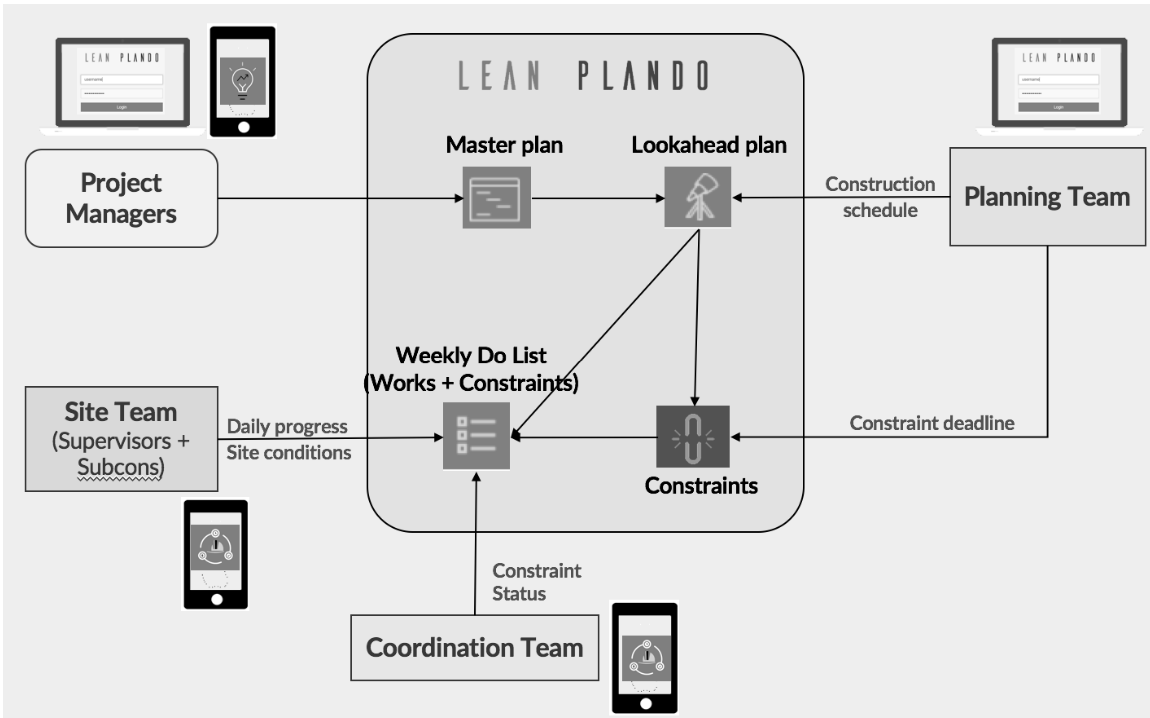

Figure 4: Information flow and team involvement in LPD

PLAN RELIABILITY METRICS

The above framework provides the consistent link between long-term and short-term plans. This integration also allows for improvements of the existing plan reliability metrics. The reliability of any plan is determined by various factors including the ability/knowledge to identify and resolve crucial constraints, the readiness of the site and site team, and capacity and dynamic performance of the site team to keep the commitment. Moreover, one of the key differences between construction and production systems is that the amount of work need to be done is not fixed but changes over weeks according to the target milestones (which can be seen through the progress S curve). Thus, a weekly performance index should incorporate required capacity or task size information. A closer look on all these factors is necessary to better illustrate plan reliability. In this context, for any given plan (in a weekly basis), the following reliability metrics should be visualized:

(1) Constraint resolution level (CAN vs SHOULD): The percent of task that can be done (constraint-free) in compared with tasks that should be done to achieve the milestones required by the master plan. The difference between CAN and SHOULD demonstrate the ability of identifying and resolving the recognized constraints.

(2) Site readiness level (WILL vs CAN): The percent of tasks that the team will take up against the total number of tasks that can be done. This metric represents the readiness level of the project team including site condition and site team.

(3) **Commitment level or PPC (DID vs WILL)**: The percent of tasks that are done against the committed tasks. The difference between DID and WILL can express the lack of capacity from the execution team or unanticipated constraints that hinder the site works.

(4) **Capacity level or normalized PPC (normalized DID vs normalized WILL)**: The percent of task units that are done against the committed task units. This difference describes the quantum of capacity shortage to execute the committed amount.

(5) **Overall plan reliability (DID vs SHOULD)**: The overall reliability level of the dynamic plan strategy is presented as the percent of tasks that are done and tasks that should be done. The difference between DID and SHOULD presents the gap between what is achieved and what is planned, and thus the reliability of the plan. This gap can be linked to all the delay reasons that affected in the past weeks for better understanding of the root causes of plan variations, from which improvements can be implemented in the future planning cycles.

The interpretation of the proposed metrics is presented in the illustrative example presented in the next section.

ILLUSTRATIVE EXAMPLE

A simplified drain construction project is used to illustrate the application of the proposed framework and reliability metrics. The master program of this project is created using Microsoft project (Figure 5) and imported into Lean PlanDo. The project is run under simulation mode for illustration purpose. Case study of actual project data will be presented in the presentation once this is approved by the data owners.

Each activity in the master plan is then elaborated into a series of tasks. Crucial constraints are added identified and added to the system for management. Under the simulation mode, this project is completed after 6 weeks, and delayed by 2 days. Weekly data of the proposed metrics are presented in Figure 6.

Task Name	Duratio	Start	Finish
New drains	**35 days**	**Tue 13/3/18**	**Sat 21/4/18**
Mobilization	2 days	Tue 13/3/18	Wed 14/3/18
East drain	**20 days**	**Thu 15/3/18**	**Fri 6/4/18**
Segment E1	10 days	Thu 15/3/18	Mon 26/3/18
Segment E2	12 days	Mon 19/3/18	Sat 31/3/18
Segment E3	12 days	Thu 22/3/18	Wed 4/4/18
East drain cover and touch up	2 days	Thu 5/4/18	Fri 6/4/18
West drain	**33 days**	**Thu 15/3/18**	**Sat 21/4/18**
Segment W1	12 days	Thu 15/3/18	Wed 28/3/18
Segment W2	14 days	Mon 19/3/18	Tue 3/4/18
Segment W3	16 days	Thu 22/3/18	Mon 9/4/18
West drain cover and touch up	2 days	Tue 10/4/18	Wed 11/4/18
Inspection	1 day	Thu 12/4/18	Thu 12/4/18
Rectification	7 days	Fri 13/4/18	Fri 20/4/18
Handover	1 day	Sat 21/4/18	Sat 21/4/18

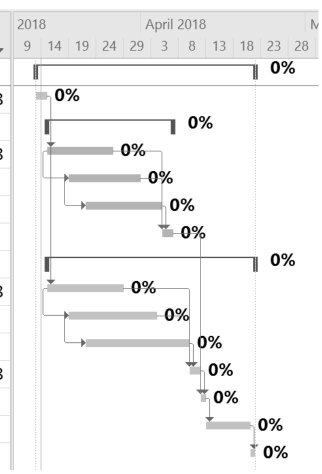

Figure 5: Master plan of drain construction project

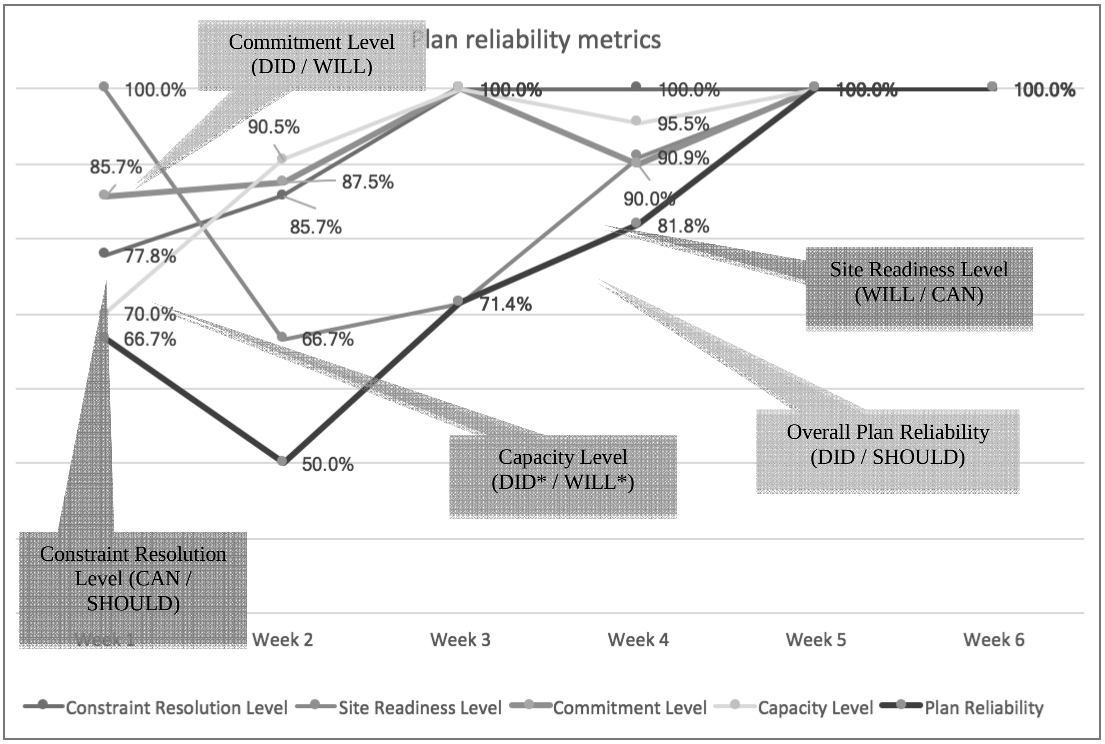

Figure 6: Plan reliability metrics

- In week 1, the site is 100% ready to take up all do-able work, but the committed level (PPC) is achieved at 85.7%. The capacity level is at 77.8% indicating manpower shortage issue. The overall plan reliability is at 66.7% as there is a big gap between SHOULD and DID.
- In week 2, as the team aims to enhance PPC, they committed only what they think they can do and increases their capacity, and thus the Site readiness level is very low (66.7%) and thus the overall plan reliability is very low at 50%.
- In week 3, the team continue to commit work with their capacity, keeping the site readiness level is also low at 71.4%, but they manage to achieve 100% PPC. However, the plan reliability is still at 71.4%.
- In the remaining weeks, as all constraints are resolved properly in advance (constraint resolution level is 100%), and the team has met the required capacity, PPC is increased and thus plan reliability also increases.

CONCLUSION

Reliable planning is crucial for good project performance. Planning should be dynamically done at both long-term and short-term levels with real-time consideration of site situation. The existing plan reliability metrics are found to have two drawbacks: focusing only on short-term plan, and/or basing on a static master plan. They therefore may not present the in-depth understanding of the Lean process and root causes of delays. This paper presents a framework for Lean construction project planning and management which incorporates CPM, LPS and VSM methods. Lean PlanDo enables the direct link between long-term and short-term plans and due its nature of a cloud-based platform, it allows for real-time collaboration and actionable decision making.

The binding between long- and short-term plans into one single data set allows for the development of new reliable metrics: Constraint Resolution Level (CAN vs SHOULD), Site Readiness Level (WILL vs CAN), Commitment Level (or PPC) (DID vs WILL) and Plan Reliability (DID vs SHOULD). The Capacity Level (normalized PPC based on task size) is also introduced to represent the capacity of the team. The new metrics will effectively describe the effectiveness of Lean process and the overall plan reliability in a dynamic nature. They provide better understanding of the root causes of delays and assist teams with continual learning and improvement in people intensive construction projects.

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DIGITIZATION FOR CUSTOMER DELIGHT IN READY MIX CONCRETE BUSINESS IN INDIA

Anup Mathew [1] & Mehernosh Pooniwala[2]

ABSTRACT

The concrete industry in India is subjected to challenges such as aggressive work schedules, space constraints and requirement of concrete with high strength and quality which has created an increasing awareness of Ready Mix Concrete (RMC) due to its many advantages. However, RMC Industry has been always being plagued by issues such as ensuring proper understanding of customer requirements, tracking of product delivery during transit from manufacturing plant to site, unceasing follow ups, and planning error free concrete pours. Improper handling of these issues leads to losses in man-hour, time and quality and cause customer dissatisfaction. In this age of digitization, a leading RMC company felt the need to formulate a customer service oriented mobile based application (App) for addressing customer concerns. In order to make the App relevant with real-time updates, the organisation mapped customer issues. This paper elaborates the journey for the development of RMC App and explains how it serves as a virtual assistant to enhance the customer experience by easy tracking and real-time product updates right from the concrete booking to delivery at project sites. The approach for App development based on Lean principles is brought out in the paper, covering strong orientation for customer value creation, innovative approach for operational efficiency and waste minimization by continuous improvement etc.

KEYWORDS

Lean Construction, Collaboration, Continuous Improvement, Digitization, customer value creation.

INTRODUCTION

In a developing country like India, Construction plays a significant role in the overall national development and the sector accounts for second highest inflow of (FDI) approximately 8% which generates employment more than 35 million people. The Indian construction industry is valued at over USD 126 Billion. (makeindia.com Report 2017). During the last decade, the business infrastructure has become digital with increased interconnections among products, processes, and services (Bhardwaj A 2013). Information technology matters to business success because it directly affects the mechanisms through which they create and capture value to earn a profit: IT is

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thus integral to a firm's business-level strategy. IT both enhances the firm's current (ordinary) capabilities and enables new (dynamic) capabilities, including the flexibility to focus on rapidly changing opportunities (Dr Nevich PL, Croson DC 2013).

Results suggest that firms whose digital business models remain viable in a world of "freemium" will be those that take a strategic rather than techno-centric view of social media, that integrate social media into the consumption and purchase experience rather than using it merely as a substitute for offline soft marketing (Oestreicher-Singer, Gal and Zalmanson, Lior,2012).

Grover V, Kohli R (2013) feels that digital business strategies (DBS) offer significant opportunities for firms to enhance competitiveness. Unlike the large proprietary systems of the 1980s, today's "micro-applications" allow firms to create and reconfigure digital capabilities to appropriate short-term competitive advantage. In the quest to provide value to customers through digitization such applications can be efficiently deployed.

Current construction practices are unable to eliminate "causes of waste" efficiently due to limited use of information technology (IT) in the construction industry. There is truly a need of digital technology to address and manage the "causes of waste" in an integrated manner to achieve project success in terms of cost, time and satisfaction to clients (Jyoti Singh,2015).
Based on the above research it is evident that there is an urgent need in today's world for organisations to leverage IT and use digitization for better operational efficiency, customer service and creation of lean processes for product delivery to ultimately achieve the business goals of ensuring customer value with profitability.

WHY THE ORGANISATION FELT THE NEED OF THE RMC APP

The organisation felt that in addition to focussing on the financial parameters it needs to improve the customer experience by addressing relevant issues and identifying focus areas for improvement. Internal and External Third-Party Feedback Mechanisms were deployed to analyse stakeholder pain areas and highlight possible areas of improvement. Detailed analysis of customer grievances and issues faced right from Order Booking to Delivery across its entire production lifecycle were mapped. Feedback was taken in the year 2016-2017 by a reputed third party for RMC customers from Mumbai and Pune Region a batch size of 105 companies were considered and personal interview of 139 customers were taken. Findings are as follows: -

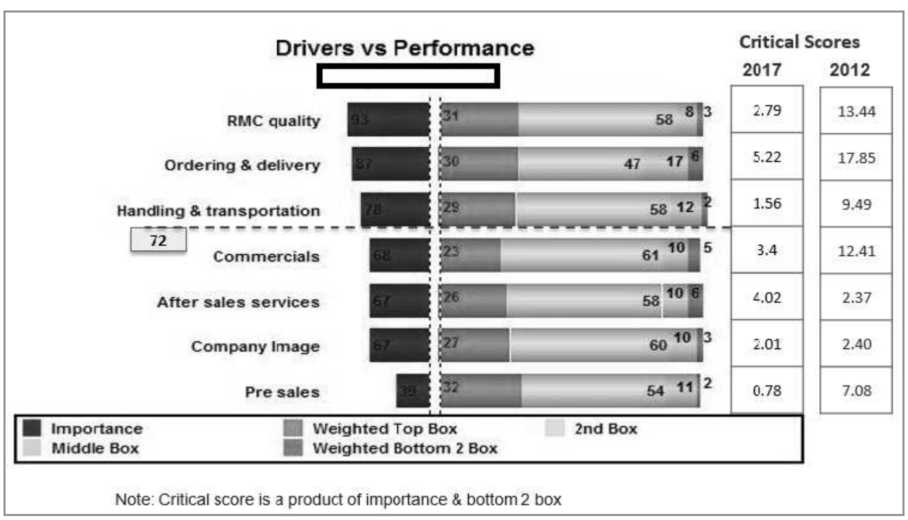

Figure 1- Feedback survey to give insights on Company's performance in a 5-year time frame (on critical parameters)

Figure 1

Third Party feedback indicating the need for the organisation to focus on Product Order & Delivery processes by attention to: -

1. Commercials
2. Post Sales Service
3. Company Image
4. Pre- Sales Service

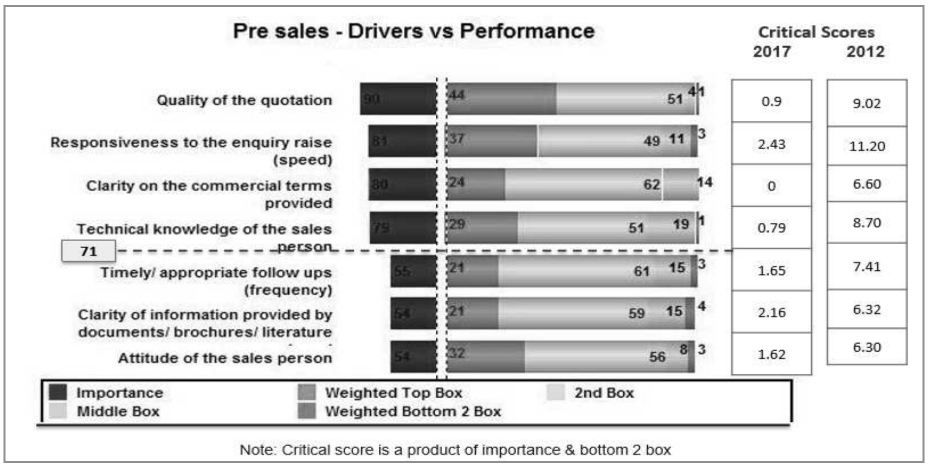

Figure 2-Feedback Survey indicating Focus areas for improvement initiatives in Order Handling and Communication (below score=71)

Figure 2

Feedback indicates need of the organisation to improve on the following parameters

1. Feedback on product delivery
2. Clarity of Information
3. Sales response/personnel

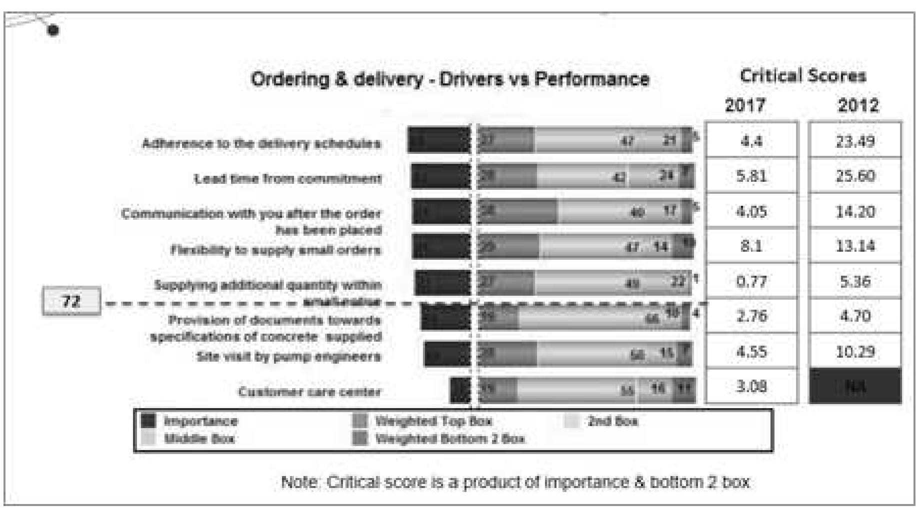

Figure 3-Feedback Survey indicating focus areas for improvement in Ordering & Delivery (below score-72)

Figure 3

Feedback indicates need of the organisation to improve on the following parameters

1. Documentation on product delivery
2. Technical Support
3. Customer Care responsiveness

Based on the above Feedback mechanisms deployed, stakeholder needs and expectations are summarized below:

CUSTOMER ISSUES:

Cumbersome booking process

Non- adherence to committed delivery timelines

Multiple telephone calls for Transit Mixer(TM) follow-up

Non- availability of detailed metrics of order i.e. dispatched and pending loads to all relevant teams

No real-time status updates available.

SUPPLIER ISSUES:

High wastages in concrete supplied due to improper communication received pertaining to the Concrete Grade, Quantity, Time etc.

Multiple requirements and multiple calls from single project involved in Order Booking often resulting in confusion and wastage.

Lack of a platform to update production teams for all orders taken across all plants.

Handling irritated customers / order loss due to delay in deliveries.

Lack of real time tracking of TMs causing trust and transparency issues.

Lower productivity of TMs due to low cycle time.

Delayed payments because lack of information and communication to end users from Accounts team.

DEVELOPMENT OF THE RMC APP

In this age of digitization, India has seen an increase in the use of smartphones for ease of business and related transactions to improve operational efficiency, better communication management across multiple stakeholders to minimize time and maximize value to all in the supply chain. App usage is the preferred option to simplify routine work in today’s tech savvy world. But the main advantage of mobile App usage is that there is no need for formal training required for effective usage and this saves a lot of the organizations and stakeholder’s time and effort. Hence, the company decided to leverage technology to enhance customer experience by providing a hand held virtual assistant for the Concrete Supply business. The company collaborated with their internal IT team to develop a customer friendly Mobile App which would address customer concerns and reduce wastages in time and material by creating a platform for effective communication management across all stakeholders.

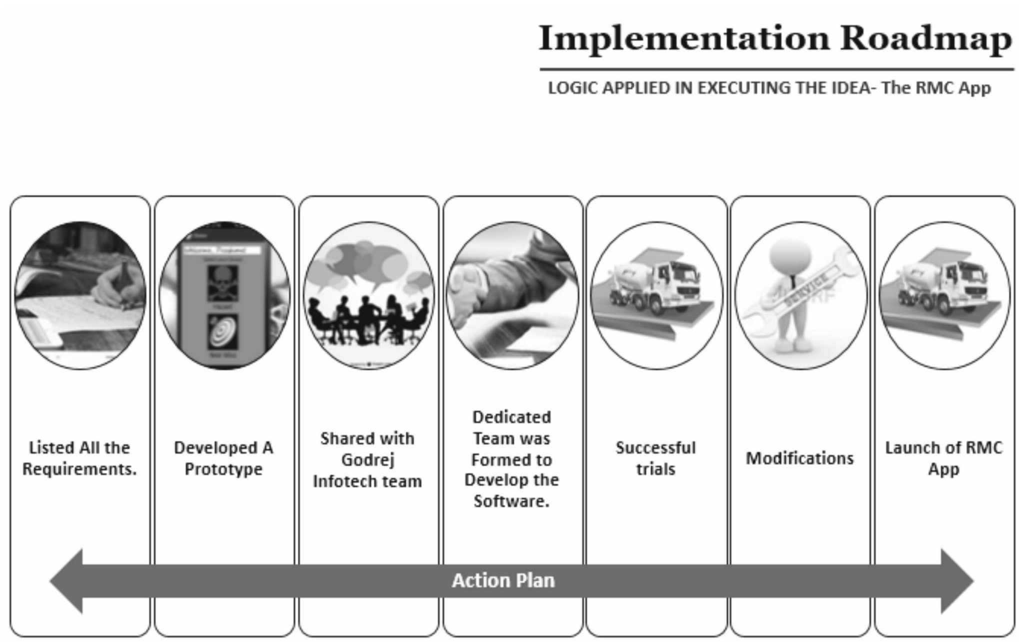

Figure 4-Stages of RMC App Development

STAGES IN RMC APP DEVELOPMENT
(From concept up to its implementation, commercial development, and deployment)

1) MANAGEMENT OF CUSTOMER NEEDS AND EXPECTATIONS:

The key features based on customer and supplier needs and expectations which the App would address were listed:
Real time updates to customer since RMC is a live product and having shelf life of only 3 hours
Tracking of delivery trucks.
Ease of order booking and confirmation to customer
Outstanding details and alerts
Product information

2) **IDEA GENERATION**

A Lean App team was formed comprising of various internal stakeholders such as Production, Planning, Finance, Safety, IT to create a platform to collaborate for faster turnaround and to optimisation of resource expertise and knowledge.

3) **CONCEPT DEFINITION**

Various possible mobile app models were evolved from the efforts of the Lean App team and after feedback from Top Management and consensus from the entire team the best model for development was chosen.

4) **PLANNING AND DESIGN**

Planning and Design of the App involved creating a Lean charter with all stakeholders with target milestones. These milestones were monitored and controlled to ensure timely delivery and launch of the App.

5) **MOBILE APP DEVELOPMENT**

Development of the mobile App was done as per the organisations requirement by the IT team and several trials runs of initial versions were taken. To mitigate this and improve the effectiveness of vehicular tracking system by GPS, it was decided to install the GPS system within the Transit Mixers(TM). A contractual commitment with Map My India which is a service application and technology provider for offering satellite imagery, street and other maps via GPS helped tracking the real-time location of the TMs during the pour.

6) **TEST AND EVALUATION OF APP**

Beta version was released and shared with selected customers to take their inputs. Testing and evaluation of mobile App was handled by the Customer Care team.

7) **MOBILE APP LAUNCH POST TESTING**

A Web Portal which serves a backend of the Mobile App provided able support to the RMC App. Initial testing was done within the internal team comprising of Production team, Finance team, and drivers. As the GPS of the TM was tracked with reference to the mobile position of the driver it led to certain issues such as faulty location and no errors in real time data.
Indicated below are Figures which help understand the features of the App and how it addresses customer issues and enables ease of communication among stakeholders.

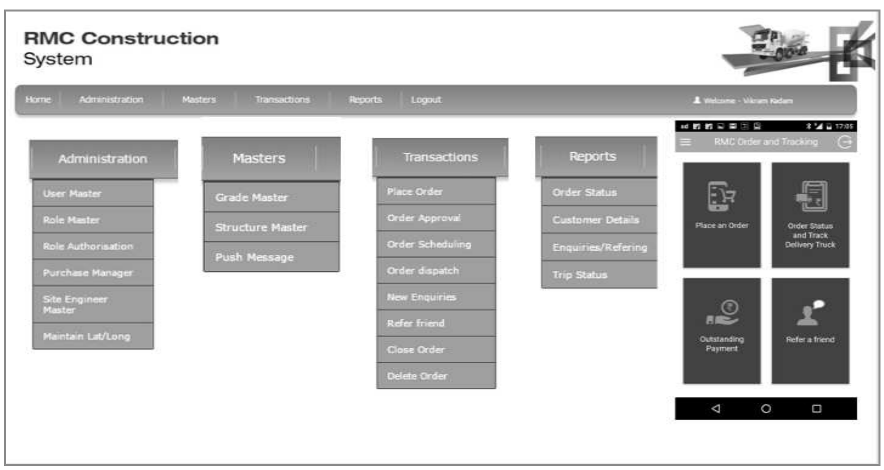

Figure 5 – Mobile Application and Backend System (Screenshot shots indicating easy App interface to meet customer needs

Figure 5: This figure portrays the Web Portal backend for the RMC Mobile App (all the orders, reports of all customer etc are shown on the Web Portal)

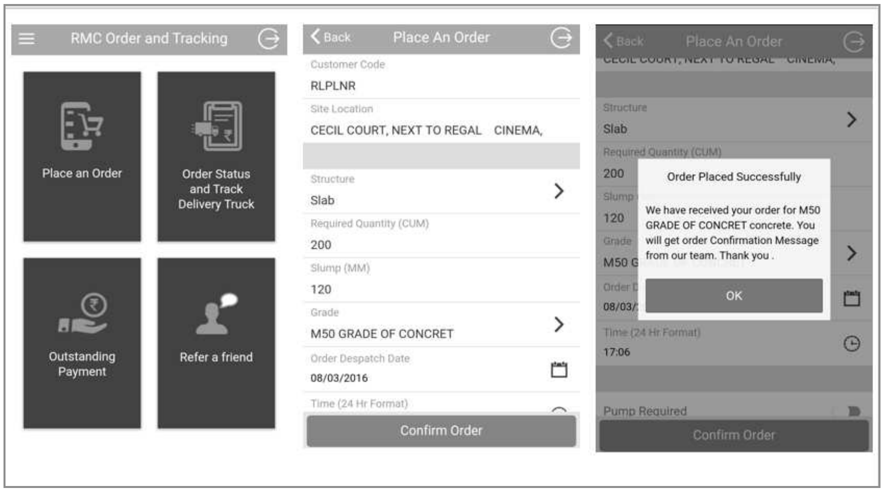

Figure 6- Some features –Payment Status and Refer a Friend

Figure 6
These Screenshots portray the screen wherein we can: -

1. Place an order
2. Check the outstanding balance
3. Order Status
4. Referral page in the App.
5. Booked order details

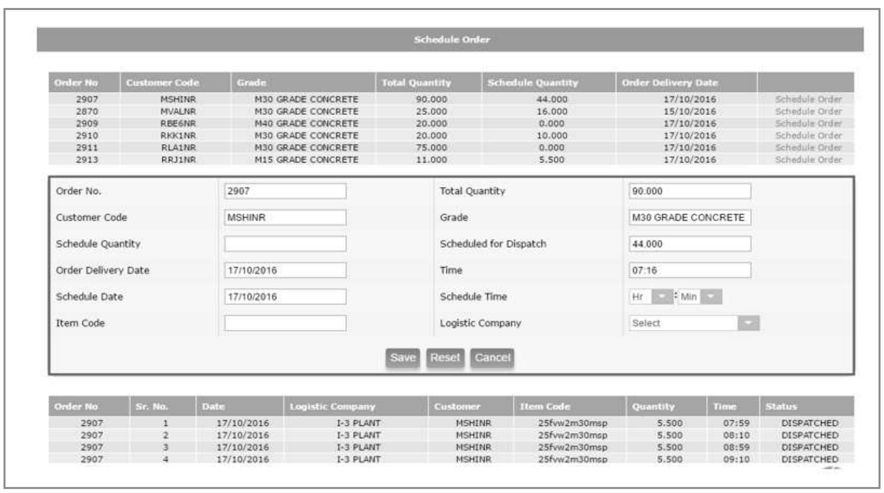

Figure 7-App provides Consolidated Product Order details

Figure 7
This figure potrays the screenshot of

1. Customer Order Number
2. Unique Customer Code
3. Total Ordered Quantity
4. Scheduled Quantity
5. Order Delivery Date & time

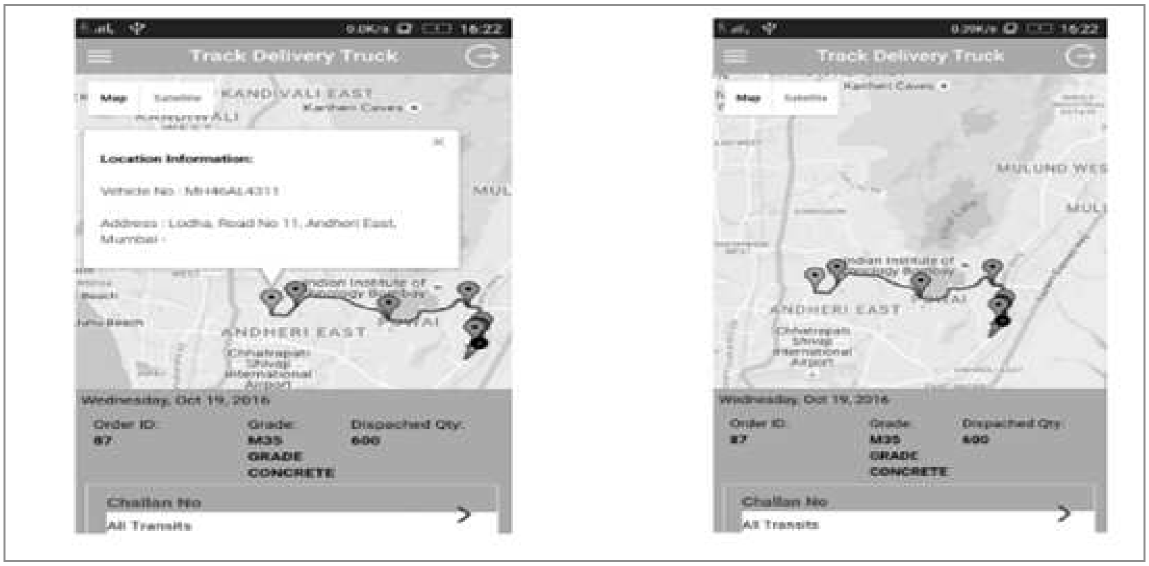

Figure 8- Live Tracking feature of the Transit Mixer

RESULTS:

(a) CUSTOMER RELATED RESULTS:

1. Online Order Booking and Live Updates eliminate the need for calling the RMC Sales Team, the Customer Care and rigorous follow up hence saving time and better communication.
2. Real Time Order Tracking for effective site planning by customer.
3. Quick Confirmation after booking of order with flash message and Unique Order ID.
4. Increased transparency and improved customer experience.
5. Consolidated information available on Payments/Orders for a project site.

(b) SUPPLIER RELATED RESULTS:

1. Waste Reduction: Morale boost in Concrete Production teams due to reduced wastages in time, cost and increased productivity due to reduction in non-value adding work
2. Increased Safety: Due to availability of TMs-data on speeding, overheating of engine, mileage and productivity available.
3. Improved Distribution and Logistics: App acts as a seamless mobile app to address most Logistic issues like the turnaround time of a transit mixer, how much time the empty vehicle will take to come to plant to increase the operational efficiency
4. Ready-Mix Concrete Supply Chain process due to its ability to notify RMC truckers of delivery instructions, location based tracking of trucks.
5. Systemic view of Information for better decision making.: The solution integrates organisation's BAAN ERP in premise for exchange of master configuration data and transactions from mobile app orders, delivery and invoices thereby providing operational data that will help improve processes and aid decision making.
6. Improved Truck Turnaround Time(TTT).

RESULTS POST IMPLEMENTATION OF THE LEANBASED MOBILE APP: -

OTHER BENEFITS:

1. Improved Customer Satisfaction since all their needs were addressed
2. Error Reduction
3. Targeted Advertising
4. Improved Order Handling
5. New Customers
6. Company Database Building
7. Customer Retention
8. Additional Sales Opportunities
9. More responsive customer service centre

FEEDBACK FROM STAKEHOLDERS & RESULTS:

Post the App launch and successful usage, the following feedback was received from top 15 ustomers on a scale of 1-5.

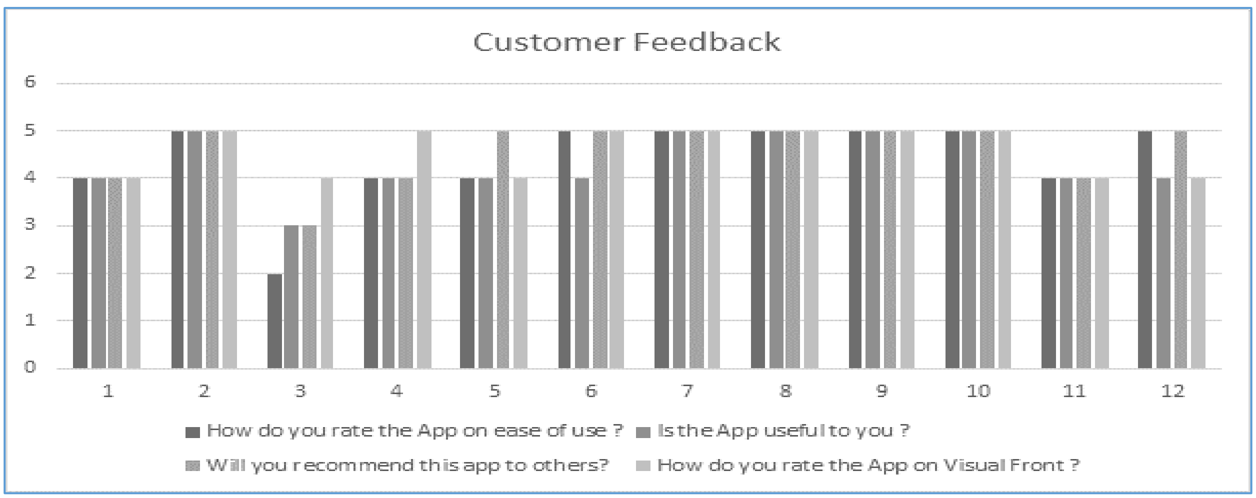

Figure 9 -Graph Indicating Customer Feedback for the Mobile Application

Customer Feedback post launch and usage indicates:

- Most customers have found the App to be user friendly.
- Most customers felt that it is very useful and has met their needs and expectations.
- Customers strongly feel that this App will help RMC players in the market to ensure better communication, product delivery and customer satisfaction thus creating a competitive advantage.
- The visual interface has been appreciated but there can be further scope of adding better features for speed of data retrieval etc.

FEEDBACK OF THE CUSTOMERS: - CUSTOMER SPEAK:

Customer A

· Transit Mixer are updated with real time status so better site planning is possible.

Customer B

· It minimises the gap of communication between dispatch and consumer, easy to operate.

Customer C

· Overall good, my team can manage order through a virtual hand-held assistant during concrete pours

Customer D

· Excellent app, can see all my outstanding dues and clear them on time.

LEAN WAY FORWARD AND PROPOSED INITIATIVES FOR RMC APP CONTINUOUS IMPROVEMENT:

1. Editing of the Live Order.
2. Introduction of Quality Features.
3. Inbuilt Feedback Mechanism.
4. Additional Text (SMS) alerts.
5. SMS will be sent to customer on completion of Order through Web portal to collect feedback.
6. Improvements in Web portal like "Scheduled time of Dispatch" and "Pour Duration"
7. Customer access for editing Order.

CONCLUSION

Digitization helps to a large extent to address customer and supplier issues in a service industry such as "Ready Mix Concrete "where multiple stakeholders need to be given product related real type updates and communication management poses challenges.

In today's technology driven era, adopting digitization to improve customer satisfaction and to make the organisation "Lean "in terms of process optimisation, waste minimization is the need of the hour.

Continuous improvement based on periodic Stakeholder feedback for digital Apps is a must so that new needs are converted into digital features and to prevent the App from becoming obsolete.

For the service providing organisation, digitization helps creating a real-time database for getting insights on production, delivery, product quality, customer issues and helps analyse and use trends to get a competitive advantage and enhance brand image.

Smooth process flow can be enabled by Digital Apps across the supply chain which translates into efficient production systems, improved morale in teams, profitability and customer satisfaction .

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AD HOC DATA ANALYTICS AND BUSINESS INTELLIGENCE SERVICE FRAMEWORK FOR CONSTRUCTION PROJECTS

Frank L. Wang[1], Leonardo Rischmoller[2], Dean Reed[3], and Atul Khanzode[4]

ABSTRACT

This paper presents a framework of an ad-hoc data analytic and Business Intelligence service tailored to a construction project. Mandates of delivering integrated information solutions and effective reporting are commonly required nowadays in large capital projects. Due to the nature of construction projects with schedule and budget constraints, poorly defined business problems prohibited the team to deploy full scale data analytic and Business Intelligence (BI) services on site. On the other hand, the increasingly complex data coming from multiple applications and organizations on projects requires more powerful data integration tools and techniques. The proposed framework outlines an agile and ad hoc best practice for job site data analytics and effective reporting based on a real use case from a large pharmaceutical project. Processes in the framework include data alignment, Level of Detail (LoD) data articulation and analytical model establishment. It also illustrates how to resolve complex data analytic challenges for unforeseen cost disputes and how to deliver solutions within a short period of time.

KEYWORDS

Integration, waste, customization, complex, Integrated Information, Data Analytics

INTRODUCTION

If design information is inadequate, materials are missing, or prerequisite work is incomplete, the assigned work will cost more, take more time, or be done incorrectly, if at all (Ballard & Howell 1998). Due to the nature of construction projects schedule and budget constraints have been identified by several authors (Alarcon & Ashley 1999;

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Gonzalez et al. 2006; Rischmoller 2006). These problems are aggravated by poorly defined business problems that include: the lack of customer requirements captured by the design team or available during the design, suitable capability of the production system, and construction requirements satisfaction; which are four of the five value generation principles proposed by Koskela (2000) and deepened by Rischmoller. The lack of these principles, as well as the loss of value expressed as ignorance of client requirements, bureaucracy and paper work, information not available, poor interdisciplinary coordination and rework (Rischmoller et al. 2006) are Lean Construction related problems identified in the case study presented in this paper.

A solution to the above-mentioned problems is presented, based on a solid conceptualization of the owner's requirements that led to outlining a data strategy supporting the development of a data model for analytics that helped to overcome miscommunication, misalignment, and lose of trust among the owner, general contractor and steel subcontractor, increasing value and reducing waste in the project.

Integrating information allows project teams to operate from single sources of truth, i.e., a single document containing current and accurate information on which to act (Fischer et al 2014). This eliminates the common industry practice where participating companies expect employees to create documents for their own use rather than share them across a project team. This wastes precious time and opens the door to misunderstanding because information is inaccurate and inconsistent (Flager et al. 2009).

PROBLEM AND CHALLENGE

The owner team of a new life sciences laboratory building wanted a thorough review of the change order for significant modifications to the structural steel frame they had requested. Originally, the work was authorized without review in the interests of time so that steel members could be modified in the shop during scheduled fabrication. While a majority of the modifications were made in time, other steel had to be reworked during erection of the steel frame.

The steel fabricator was contracted lump sum and submitted a summary level description of changes along with the price. The entire change consisted of 69 individual change orders, called "Extra Work Estimation (EWE)." Causality of each EWE was documented in a "*Driver.*" A driver could be either:

1) An updated drawing set or bulletin: 11 sets of drawings were listed.

2) Recorded RFI with attachments: 128 RFIs were associated with the changes.

The change orders were later rejected by the owner's project controls group that had been established later in the project. The general contractor asked the project manager for the steel fabricator to provide more documentation, which he did. The steel project manager provided fabrication control reports called Bills-of-Material (BoM) from the Manufacturing Information System (MIS), shop drawings showing changes and a color-coded erection plan showing the location of the changed steel for each EWE. The owner project controls team was still not satisfied and refused to approve the changes. They wanted to see the material fabrication data together with shop and labor hours relative to change order requests and authorizations to proceed.

Each BoM contained approximately 3,000 line-items including parts, cuts, welds and joints. The steel fabricator expressed concern when asked to provide detailed labor hours and BoM that were not an obligation under their original Lump Sum contract. The granularity of data was misaligned between the owner, GC and the subcontractor when the request for additional documentation was made.

On the owner side, without a structured layout and guided data navigation method, the owner's project controls staff was overwhelmed by piles of submitted documents. They also started analysing submitted data based on an incomplete understanding of the steel fabrication process, which created more ambiguity. On the other hand, the GC and steel fabricator considered that they had complied with owner's requirements and fulfilled the contractual obligation. This miscommunication and misalignment caused the parties to lose trust and threatened to jeopardize the long-term relationship between the client, GC and subcontractor (Phelps 2012). It also increased the possibility of unnecessary fee erosion to both GC and steel fabricator. Guaranteed Maximum Price (GMP) negotiations had broken down. At that point, the owner's Director of Project Engineering asked the project manager and controls team, the structural engineer, fabricator, and general contractor project managers to meet one last time to find a way through the impasse. The GC managers asked the owner project controls managers to describe the data they needed to determine that the owner was being charged a fair price. An urgent mandate was assigned to the GC and steel fabricator to provide an intuitive reporting mechanism so an outside auditor working with the owner's project control team could easily comprehend overall cost and impact. All parties agreed to give the GC and steel fabricator one week to see what they could produce.

The problem became a data analysis challenge given the nature, amount and complexity of data (Jin & Levitt 1996).

Table 1: Source documents and data to be analyzed

Document	QTY	Description
EWE summaries and invoices	69	• Material Cost – Additive/Subtract steel tonnage and cost • Labor Hours Cost - Shop/Field man hours and cost, Field Cost - Additional field work cost • Sub-Tier Costs - Equipment rental, detailing service, freight delivery cost, • Other Costs - Fees, taxes and other costs
Bill-of-Material per EWE	3000x69 lines (approx.)	• All parts, joints, welds, etc.
RFI	128	
Drawing Sets/ Bulletins	11	

SOLUTION

The GC responded quickly with actions to turn around the rising distrust and resolve the dispute.

1) Invite industry lean experts and senior think-leaders to the job, interviewing all parties, analysing the current process, strategizing and facilitating team communication with the owner (Koskela et al. 2016).

2) Brought onboard a data analysis solution architect to meet with owner's project controls team, understand the overall scope and intent, analyse the data, and deliver an acceptable solution (Dave et al. 2008).

SOLUTION DEVELOPMENT AND DATA ANALYSIS FOR JOB SITE

Unlike normal software development, facility owners are often unable to provide detailed specifications or existing examples of an anticipated solution. Conceptualizing complex business problems into deliverables is a known challenge, analogous to a design process. In fact, the solution shown in this paper is no exception. It was a design problem, or arguably a design task with a data driven deliverable.

In conventional development and delivery processes, the conceptualization process is broken down into steps for a chain of specialists, e.g., business analyst, data analyst, developer, etc. However, this model does not suit a construction project very well due to a few impediments, which are:

1) Lack of agreement on scope and information. A typical lost-in-translation challenge often occurring during scope and requirement gathering where the project team cannot successfully communicate and provide the right amount of information

from the business to support solution development, causing scope creep or over/under development.

2) Time constraint. The given time for project team to deliver a solution is often very limited and does not allow for a conventional non-agile approach. For example, a week was given to deliver the final solution in this particular case.

3) High level of customization. Problems in hand often are specific to the project due to special reporting requirements from the owner. A certain customization is always needed, and a top-down corporate solution cannot fully resolve the problem.

A better approach learned from the past is to engage a solution architect who has both analytic and development skills to facilitate and advise on delivery of the solution. Such a solution architect must be able to: 1, capture the owner's intention; 2, digest the owner's intention into a solution design; 3, lead implementation of the solution inclusively on time; and 4, enable the scaling up of such a solution for other issues and to other projects later on. The delivered solution should not only fulfill the owner's expectation, but also prevent misuse that could lead to further disputes and undermine trust among parties.

REQUIREMENT AND SCOPE CONCEPTUALIZATION

After a single scope meeting with the owner team, the solution architect was able to translate the owner's high-level guidance into the following *"Design"* criteria.

1) Multi-directional navigation. The owner demanded flexible navigation methods; for example: 1, navigating data from Change Orders (EWE) to correlated drivers and vice versa; and 2, see costs in different aggregated levels such as detailed unit price per part for both reused and scraped and labor cost breakdown at the shop and field level.

2) Correlation and finding insight. Enable correlation of all EWEs relative to a particular driver and visa versa, e.g., find all EWEs that are correlated to the "GMP drawing set."

3) Trending by time. The owner wanted to understand progression and magnitude of change orders throughout the project timeline; that is, make change orders visual as they evolved through time in both count and amount.

4) Data accuracy and transparency. The owner wanted to understand and visualize how cost and tonnage summed up from the BoM level to the final cost per EWE.

METHODS AND ACTIONS

The solution architect outlined a data strategy and step-by-step processes after conceptualizing the owner's requirement into design criteria.

Articulate Missing and Derivable Fields

1) Shop versus Field classification. Submitted BoMs did not obtain a distinct classifier for shop versus field per steel part. Such classification was needed and derivable from several existing fields within the BoM.

2) Scrap versus reuse classification. Submitted BoMs did not include a distinct classifier for reused or scraped steel per part. Such classification was derivable from several existing fields with certain logic.

3) Unit Price for each part. Submitted BoMs did not include a unit price on a per-part level. Each part needed to be associated with a unit price in order to aggregate cost to an assembly, type, and entire change order level.

Data granularity and LoD (Level-of-Detail)

Proper data granularity for reporting is normally driven by owner's requirements and contractual obligations. In this particular case, the granularity was readjusted from a summary level down to the BoM level. Because classifications of Shop/Field and additive/subtractive information resided in the detail BoM level, the team needed to readjust reporting data granularity to a proper level that accommodates these classifications. With the adjusted data LoD, the team not only could fulfill the owner's requirement on reporting, but also was able to provide additional insights. For example, the team could explore many intermediate levels of aggregations from the same data, and gain insight such as:

1) Summarize by type of part, e.g. channel shapes (C) or angles (L).

2) Summarize by assembly level.

3) Summarize by Extra Work Estimation (EWE).

4) Summarize by all 69 EWEs together.

There were also consequences when readjusting data granularity and collection processes in the middle of the project, especially to a more detailed level. These were:

1) Inability to reproduce data from the past – a system may not preserve a transaction log so retrieving historical data therefore is impossible.

2) Discontinuity on existing trending.

The requirement to breakdown Shop Labor Hours (SLH) into a per-part level was a good example to illustrate the problem of adjusting granularity to a more detailed level. The labor hours were collected and reported at the EWE summary level prior to the owner's new mandates. By adjusting the data granularity to the BoM level, the subcontractor could not easily provide shop hours associated with each line item from the BoM. The subcontractor may have had the standard SLH and material cost for cost-control internally but faced a tedious data process to ensure the total invoiced amount aligned with the breakdown at a per-part level.

As a summary, an appropriate data strategy, consisting of 1, the right data granularity and 2, establishing a collection process, should be planned ahead by future project team as part of an execution plan early as possible. A good data strategy (Pasquire 2012) could avoid possible discontinuity in trending and provide tolerance to granularity change.

Data Model for Analytics

An analytic data model was created to transform raw data into consumable forms for connected reporting systems. The data model design complied with a typical data warehouse approach of articulating data into dimensions and facts. Dimensions allowed the analyst to create filters that partitioned data across all datasets, i.e., facts. Dimensions were driven from owner's requirements for example:

1) Extra Work Estimation (EWE) Number: a sequential number of individual change orders.

2) Shop/Field: Shop versus Field.

3) Drivers: Drawing Sets or RFI.

Data preparation and cleansing

Like all typical projects of data scientists and analysts, the majority of work went into data preparation and a cleansing process. The analyst needed to process multiple versions of EWE summaries into a single dataset while also preserving all levels of cost hierarchy from the submitted summaries. An EWE number was added to the BoM to correlate two data sets as the joining key. The analyst was able to accomplish processing all EWE summaries and BoM files in two workdays by utilizing superior business analysis tools.

Reporting and Dashboard Design

A robust dashboard was created by following the four "Design Criteria" listed above. A navigation panel was created to fulfil the multi-directional navigation request, shown in Figure 1 and Figure 2. The analyst was also able to create side filters allowing users to slice and dice the data for more specific focus and insight.

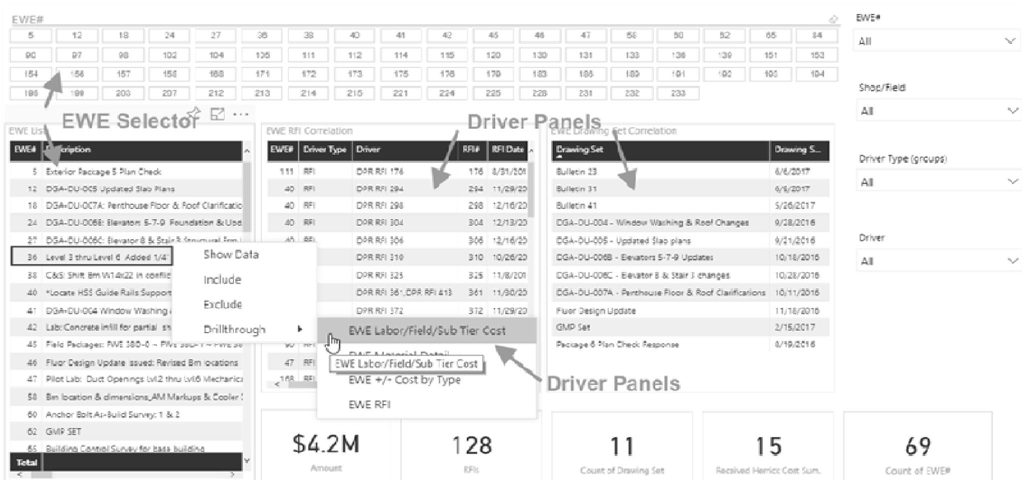

Figure 1: Navigation Panel

From the navigation panel, users were able to drill down to detail summary such as the BoM or Cost Hierarchy from selected EWE(s), and also collapse cost in hierarchy and materials by type, shown in Figure 3. Time trending charts, shown in Figure 4, were also created to illustrate EWEs in both the count and amount throughout the project history.

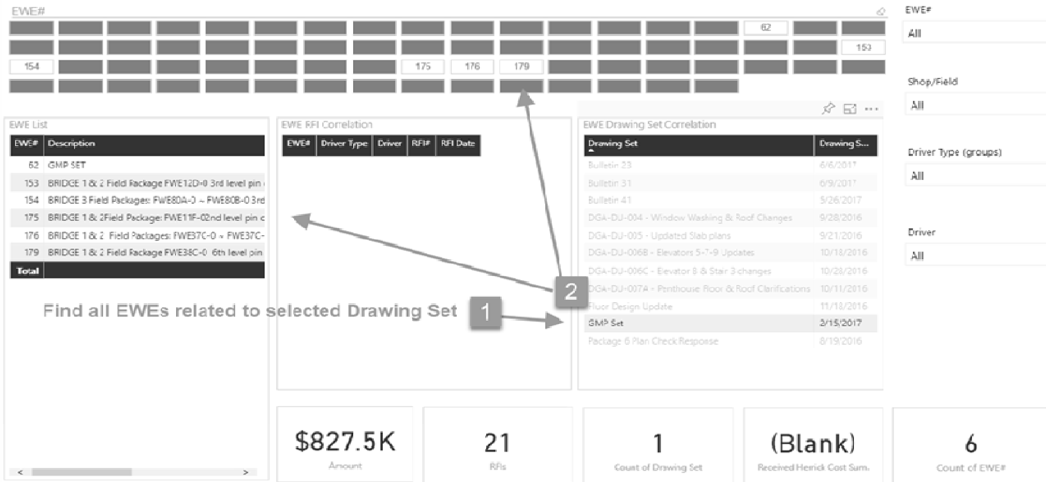

Figure 2: Finding correlation from selected Drawing Sets to related EWEs

Figure 3: Alternative Navigation – Finding correlation from selected Drawing Sets to related EWEs

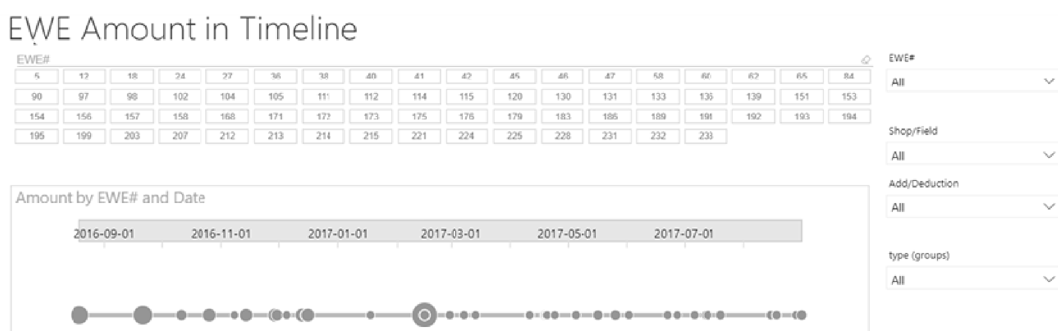

Figure 4: Browsing EWE amount over time showing the volume and amount

SUMMARY

Working together, the team delivered a full solution within a week, including gathering business requirements, designing outcome visuals, aligning and collecting raw data, establishing the analytic model, and data transformation and cleaning, On the business side, the owner's project controls team was able to verify that the fabricator and GC had properly accounted for all of the modified steel and priced the changes fairly, including credits for scrapped steel. Respect for good intentions and competence increased among the individual managers. The GC managers realized that things would have gone much faster if they had had asked the owner project control managers what they needed to see earlier rather than provide what they thought was sufficient.

The above framework presents an ad-hoc solution tailored for unforeseen and unexpected, one-time, data analytic challenge that frequently occurs during construction. It was a more agile and possibly cost-effective approach compared to full scale enterprise level data analytic solution. The framework was part of a data democratization effort from the GC IT corporate services, enabling data self-services for people to perform data analysis right on projects, that combines data science advances with value adding and waste reduction Lean principles. Future work based on this study includes continuously enhancing the framework into a formal curriculum along with proper tooling, and training for greater dissemination.

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USING TECHNOLOGY TO ACHIEVE LEAN OBJECTIVES

P.R. Surendhra Babu[1] and N. Hayath Babu[2]

ABSTRACT

The construction industry is facing increased challenges and becoming more and more complex due to number of factors. Whether it is constructing a Building, Infrastructure or Industrial plant, the challenges remain there in every type of the project. This results in delays, waste, overruns and claims. So we need to develop new ways of doing things to manage the construction process. Adopting lean manufacturing principles in construction industry is an effective approach to bring improvements in design, procurement and construction to reap benefits and add value to the project. Using Technology is critical in the advancement of Lean Construction. This paper aims to discuss the need of Lean for our construction business and how technology is used within our organisation to achieve lean principles.

KEYWORDS

Lean construction, BIM, Leveraging Technology, Augmented Reality, Value additions

INTRODUCTION

Our organization is involved in constructing mega projects from concept to commissioning which include a variety of complex arenas:

- Buildings & Factories: Airports, Hospitals, Commercial & Residential Buildings
- Transportation Infrastructure: Roads, Runways, Elevated Corridors and Railways
- Heavy Civil Infrastructure: Metros, Ports and Power plants (Hydro & Nuclear)
- Power Transmission & Distribution
- Water supply and Treatment plants
- Metallurgical and Material Handling plants

In order to overcome the production and profitability challenges, the organization is continuously improving its design, procurement and construction processes and adopting the various technologies that support to achieve Lean Principles. This paper highlights

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some key technologies which can help construction organizations to achieve good Value addition through the adoption of Lean Principles.

Some of the platforms that are implemented to achieve Lean Principles include:

- Using 3D models and visualization techniques to improve planning and communication.
- 4D planning to improve workflow, look-ahead scheduling, identifying the processes that deliver customer value and eliminate activities that do not add value, Just-in-time (JIT) deliveries.
- 5D BIM for value management techniques.
- Pre-fabrication.
- Integrating the supply chain through collaborative practices.
- Improve accuracy and efficiency through Lidar, Laser Scanning, AR/VR/MR, RFID and Equipment gateways.

TECHNOLOGIES IMPLEMENTED

The organisation is continuously exploring the potential applicability and benefit of using Technologies to achieve Lean Principles. The design teams are using BIM to support Lean Construction. They produce data rich 3D models which contain all the spatial, geographic and geometry information. A comprehensive and verified model improves construction efficiency considerably and also enhances effective operational management. It is always ensured that the final purpose of any model is clearly defined and developed to provide the greatest benefits.

Building or Infrastructure projects require many different design elements, often designed by multiple parties that must be integrated to form the final design. Models obtained from various sources are validated to confirm that they have been developed to support the asset's future operation and maintenance. In addition these models are updated from multiple sources to a common standard platform, and integrated. The working methodology ensures that these models are integrated with accuracy and transparency and all clashes or conflicts are resolved.

Technology such as AR/VR/MR is being used within the construction projects to improve visualization and identify errors / omissions quickly and correctly. Wearables enable collaboration between the office and sites to happen. Using models on this platform facilitates collaborative working and leads to better decision making.

The error due to working on incorrect version and sharing the right information on time across the project was one of the challenges in some of the projects. Cloud based common data environment was implemented for this purpose. Every team involved in the project was able to access the same latest data anywhere and anytime. Using digital tools on the cloud platform has taken collaboration to a different level. Now it is possible for the design, project, safety, quality and planning teams to work in tandem and updating data is seamless and on time. This also enabled synergetic project management and informed accurate decision making.

Completing the project on time and within budget is always a challenge for planners. To make a realistic schedule, it is important to take care of all the risks which can affect the construction of a project. The inter-departmental coordination is highly essential. Each department should give its input in the preparation of the schedule. So 4D planning was introduced in the projects. The planners simulate the various construction tasks to be completed and create models known as 4D BIM that accurately represent the planned sequences of construction. The sequences can be reviewed to explore options and choose the solution that will provide the desired result both in terms of constructability as well as programme. This allows construction timelines to be planned effectively by coordinating the activities of different trades across all areas of the construction and by optimizing procurement lead times. 4D BIM modelling is also a key tool to forecast and address problems, using different methodologies much before they occur on site. Using the 4D aspects of BIM, project managers can now vividly see the schedule of each sub activity, analyse the what if scenarios and also plan JIT.

BIM based approach is also used for estimating, applying material take-offs and costing through the project design phases. 5D BIM uses a BIM model directly for cost estimation in such a way that any change in the design can be reflected in the cost immediately. This enables architects, contractors, and engineers to work collaboratively on a live model and make more informed decisions by comparing multiple cost estimates with the project's target cost thus achieving timely delivery, cost efficiency and quality. Quantity take off from models is done by the QS and contracts team to get an accurate assessment of planned vs actual.

Precast technology has proved to be an ideal choice for Lean Construction which facilitates planning and control, maximize value and minimize waste throughout the construction process. The building process is very efficient and safe in a centralized and controlled environment. Building systems that have been pre-assembled can be rapidly installed, requiring less rework than traditional methods. Prefabrication from a coordinated model assures project team members that building elements will be fabricated and installed accurately.

The other challenges include possibility of effectively implementing technology such as laser scanning and LiDAR that collects three dimensional point cloud data of the asset and convert this physical data of an object into a digital file (3D Point Cloud) allowing an extremely accurate survey details and record of the built environment. This will help the project team to produce a model of existing conditions rapidly and accurately.

Equipment gateways are being used for the fleet of construction machinery. This enabled the teams to efficiently monitor fuel consumption, equipment downtime and health of the machine. This data is accessible through cloud and the dashboards can be viewed, assessed and actioned by the management teams anytime remotely. RFID tags are used in construction sites for monitoring the activities of workmen and to ensure that they are efficiently deployed and redeployed where necessary. This has significantly reduced the idling time of labour.

CASE STUDY - DESIGN AND CONSTRUCTION OF FORD GLOBAL TECHNOLOGY AND BUSINESS CENTRE.

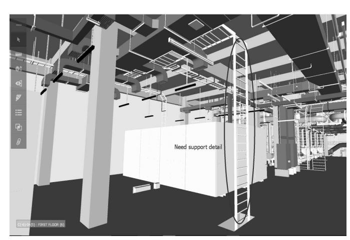
ABOUT THE PROJECT

Location: Sholinganallur, Chennai
Plot Area: 28.5 Acres
Built up area: 26, 33,130 sq.ft
Start Date: 07-09-2016
Target Completion: 06-10-2018

WHAT WAS DONE

- A Project BIM strategy was developed to support design and construction and encourage collaboration and communication.
- Also developed interactive 3D models of all disciplines and shared with team for better collaboration.
- The 3D models were delivered to act as a 'single source of truth' and facilitated the use of 4D planning and 5D estimation.
- Mobile devices and Cloud collaboration were implemented.
- HoloLens was used to improve visualisation, collaboration and better communication.

BENEFITS ACHIEVED



- Figure 1: On-Site BIM review meet Figure 2: Design RFI through BIM
- Facilitated clear communication within project teams by sharing 3D models to Construction team, enabling them to visualize the design intent clearly before

executing the work. This encouraged better collaboration between the design and construction teams and reduced the number of RFIs.

- Raising the design RFI by marking up on the 3D models enabled the design team to clearly understand the issue at site and resolve them immediately, rather than the traditional chain of communication.
- Colour coded status on 3D model enabled the team to identify the critical areas easily and helped the project control team to take necessary actions at a faster pace.
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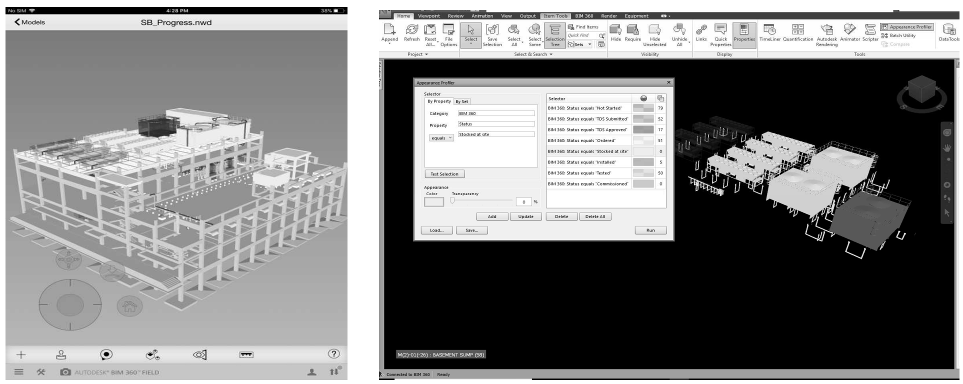


Figure 3 & 4: Colour coded 3D BIM

- Use of 3D models on mobile devices improved visualization for site personnel and they were able to propose easy/ alternate methodologies for construction resulting in lesser duration and costs.
- Availability of Project documents tagged to 3D models on Mobile devices enabled the team to access the data anywhere anytime.

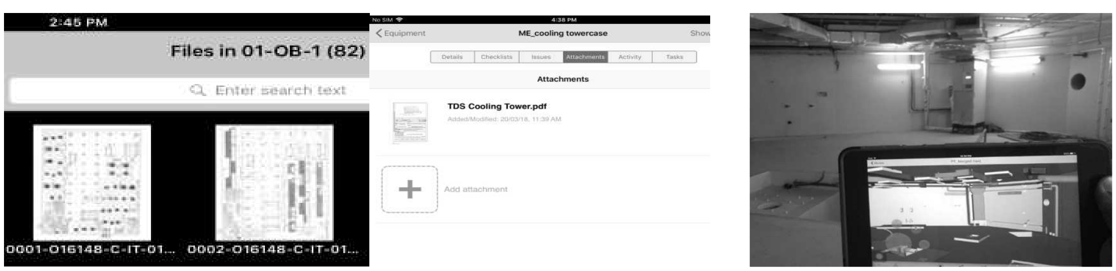


Figure 5: Project documentation on Mobile device, Figure 6: 3D BIM on Mobile device

- The 4D BIM tool enabled the project team to monitor the project in terms of planned vs actual. This facilitated mid-course corrections. Based on the schedule it was possible to extract the relevant quantities and track them on daily/ weekly/ monthly basis.

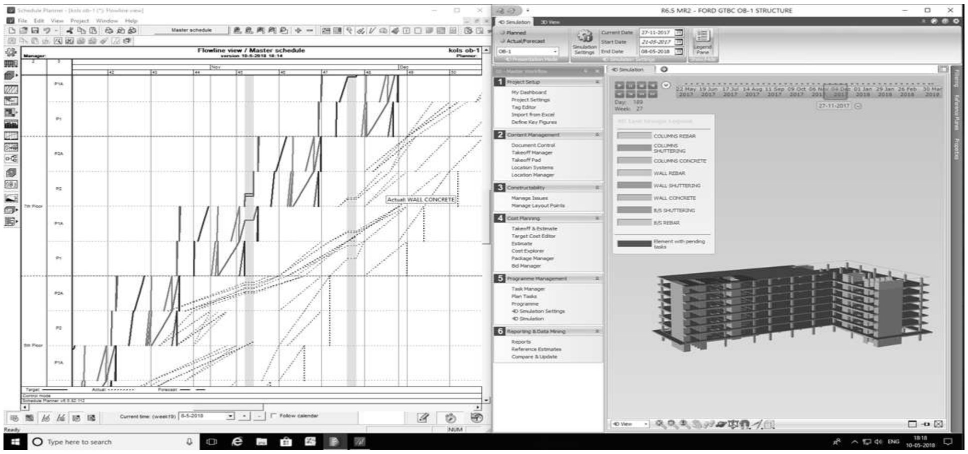


Figure 7: Planned vs Actual

- Quantity take-off through BIM enabled the team to reduce the time required to quantify the complete building, when compared to manual take-off. There was more than three fourths saving in time when BIM is used for quantity take-off.

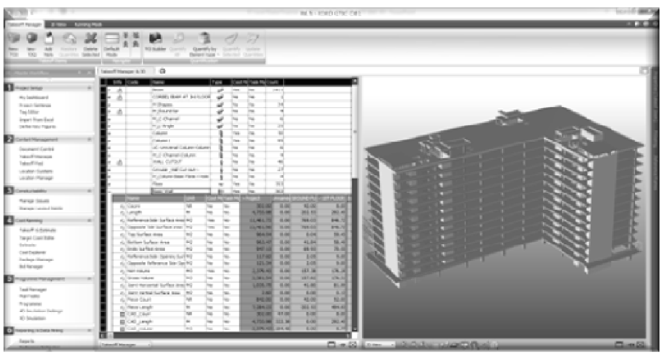


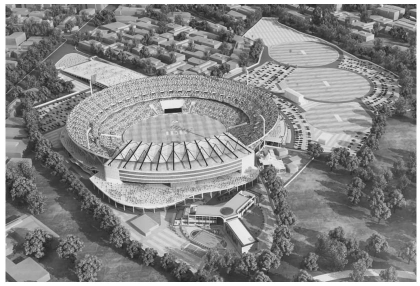
Figure 8: Model based automated Quantity Take Off

- HoloLens were used collaboratively between site and design office. Interaction led to issues being resolved and questions answered within minimal time. The constructability issues and appropriate solutions were proposed by the site team and led to value engineering.



Figure 9 & 10: Wearable Technology for improved Collaboration and Communication

CASE STUDY - SARDAR PATEL CRICKET STADIUM



ABOUT THE PROJECT

Location: Ahmedabad, India
Spectatorship: 110 K (World's largest)
Duration: 24 months
Start Date: 8th Dec, 2016
Target Completion: 7th Dec, 2018

WHAT WAS DONE

- High levels of collaboration and integration ensured amongst all project partners through BIM models.
- Weekly meetings through 3D model for coordination and constructability reviews.
- Availability of 3D BIM on mobile devices used by site engineering for visualisation.
- Planned vs Actual reviewed through 4D BIM.

BENEFITS ACHIEVED:

- The project involved precast construction of complex elements. The 3D models with high level of detailing helped in the visualisation of the critical aspects and junction details. This was used during the review meetings involving the design planning and construction teams. The sequencing of activities could be fine-tuned using the same.

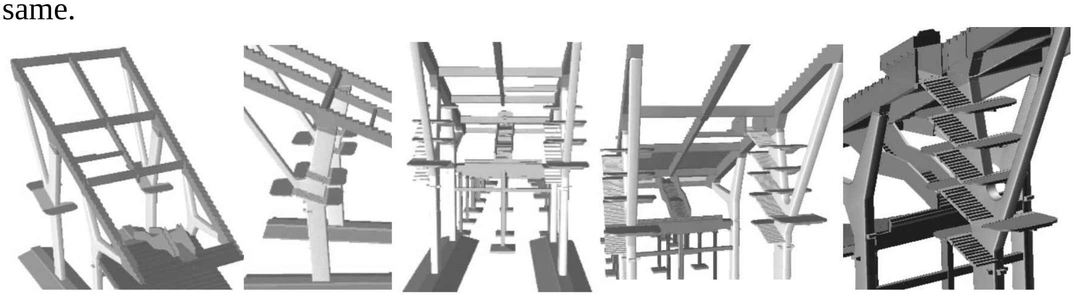


Figure 11: 3D model of Precast Elements

Figure 12: Weekly review meetings

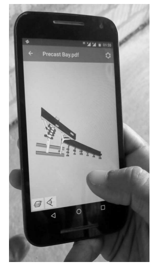


Figure 13: 3D BIM on Mobile Device

- The availability of 3D models on handheld devices enabled the construction team to visualize the critical junctions of the precast elements at site while working on the methodology of critical erection activities.
- Use of 4D enabled the project to be delivered as per the challenging programme by facilitating continuous monitoring and extracted look ahead quantity schedules. These schedules were shared with execution and procurement teams thereby giving advance information about the upcoming activities to be executed and resulted in smooth and better progress.

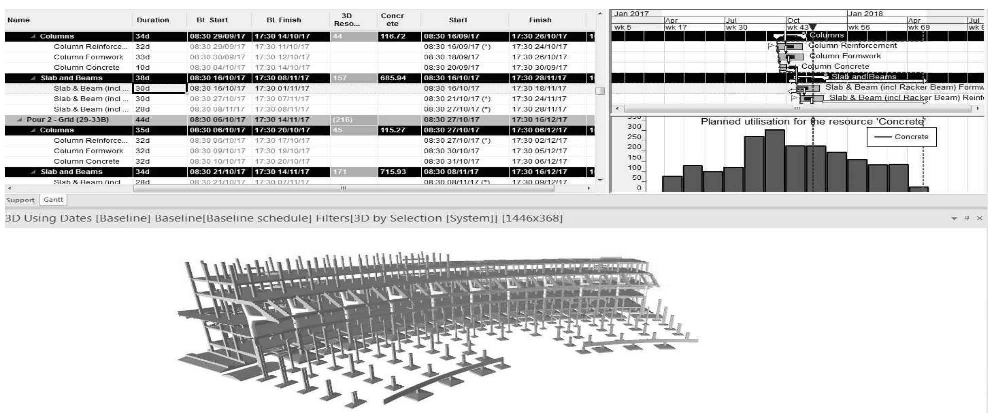


Figure 14: 4D BIM

- 4D BIM enabled the team to compare the baseline and actual progress. This alerted the team to focus on achieving milestone events and come up with solutions either by rescheduling the construction sequence or increase the resources. The multiple options could be simulated to arrive at the optimum solution.

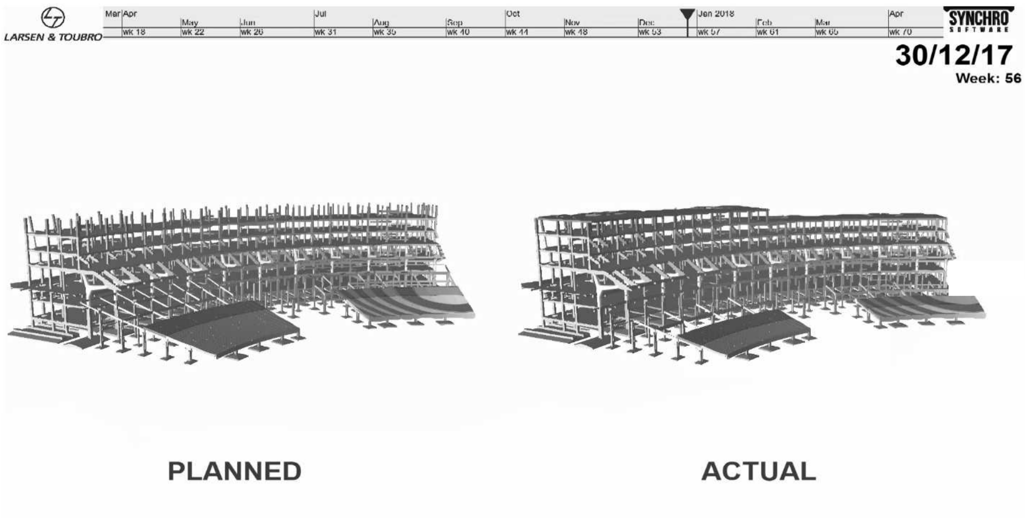


Figure 15: Progress monitoring

CASE STUDY - PROVIDENT SUNWORTH HOUSING

ABOUT THE PROJECT

Location: Venkatpura, Bengaluru
Configuration: 60 Towers
Built up area: 70 Lac sq.ft
Duration: 60 months

WHAT WAS DONE

- Precast system was used against conventional construction system.
- Methods of mould fabrication & yard set up were suitably modified to cater to Indian Construction Industry.
- Maximum utilization of moulds was planned for achieving savings in cost of moulds.

BENEFITS ACHIEVED

- High Quality concrete was produced in a controlled pollution free environment with minimum wastage.

- Reduction in the number of activities resulted in lesser material, labour and costs. High speed and quality was achieved with the deployment of lesser resources.
- Minimum finishing works meant lesser amount of scaffolding and labour deployment.
- Use of BIM tools led to better planning and detailing and tried up with the precast and erection activities

Figure 16: Precast Erection Figure 17: Precast Yard

CONCLUSION

To sum up, construction needs to be Lean and Digitized. The emerging technologies are enablers and if they are harnessed well one could see the industry delivering consistent high quality products on time within estimates. This paper has presented case studies where in multiple principles and technologies were deployed to maximize value and enabled lean construction. The industry will continue and adopt various technologies to add value to the customers.

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GOVERNING FLAT-ROOF CONSTRUCTIONS: A CASE STUDY

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ABSTRACT

A lean construction process depends on reliable procuring and governing of materials. This paper examines the case of flat roof constructions. It is based on an assumption that current practice might lead to a risk of premature roof failures. Within the case of flat roof constructions, we seek to answer the following research questions:

- What are the main threats to the value for the client in the case of flat-roof constructions?
- How does the client govern in order to oversee that requirements are met regarding construction materials- and assembling?

The research was explorative in nature and limited to the Norwegian context; based on a scoping literature study and seven semi-structured in-depth interviews with experienced industry actors. The findings show that in a short-term perspective, the divergence of stakeholder interest and premature roof failures present a great threat to the value of the building. Poor procuring and handling threatens the construction process. It is a source of disputes between the contractor and the client. Furthermore, it constitutes an obstacle in creating long-term value for the client. Flat-roof constructions are particularly exposed. We propose that clients should implement a more structured approach to overseeing that client requirements are met. To ensure a lean project delivery and maximizing value, mitigating unwanted events related to suppliers and materials are crucial.

KEYWORDS

Lean Construction, Value, Waste, Supply chain management, governance, safeguarding problems

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INTRODUCTION

The aim of implementing lean principles and tools is to yield improvement in value for clients, users and producers (Ballard and Howell 2003; Drevland and Lohne 2015; Drevland et al. 2017; Hjelmbrekke et al. 2017). Some of the core principles are outlined in Howell's seminal paper on what lean construction actually entails. The essentials include a clear set of objectives for the project delivery process that aims at capitalising on performance to the best for the customer (Howell 1999). One essential, though often-overlooked, aspect of the project delivery process is supply chain management from a governance perspective. This may be understood as making sure the right materials are available to the on-site workforce, that the materials are of the intended quality and that their implementation is adequate. A delivery process aimed at creating value for the customer may be pulverized on the micro level by unsatisfactory procurement services, sloppy handling, and counterfeit, fraudulent or sub-standard (hereafter; CFSS) building materials. This paper addresses the intersection between governance, supply chain management and building physics.

More specifically, this paper examines the case of flat roof constructions. In Nordic climates, constructing flat roofs are more vulnerable to roofing defects than traditional pitched roofs, and largely avoided on small buildings if sloped, ventilated roofs can be built instead. As such, in Norway, flat roof constructions are mostly limited to large commercial or public buildings. The possibility of high snow loads makes flat roofs somewhat impractical for single-dwelling detached houses, which make up approximately 50% of Norwegian residential buildings (Statistics Norway 2018). However, flat roofs see use on row houses and detached houses in functionalist style. The prevalence of single-dwelling houses in Norway sustains a large industry of local construction companies specializing in building them. Norwegian companies increasingly employing foreign labour, primarily from Eastern Europe, dominate this industry. The roof is usually the most exposed façade of a building, and its protection is crucial to secure the integrity of the rest of the structure. A study by Gullbrekken et al. (2016) revealed that roof defects made up 22 % of all building defects investigated by the SINTEF Building and Infrastructure. Out of these were 19 % on compact roofs and 28 % on terraces.

The research presented is based on the assumption that current management practices during construction lead to an increased risk of using sub-par materials or errors occurring during assembling due to lack of proper workmanship. Governing these challenges is not a trivial task – and at the cornerstone of viable lean construction practices. Within the case of flat roof constructions, we address the following research questions:

- What are the main threats to the value for the client in the case of flat-roof constructions?
- How does the client govern in order to oversee that requirements are met regarding construction materials- and assembling?

METHODOLOGY

The theoretical framework provides a review of academic literature related to flat-roof constructions, project governance- and procurement, CFSS-materials and supply-chain control, particularly within the field of lean construction. The literature review followed an approach as outlined by Denzin and Lincoln (1994), and Blumberg et al. (2011).

A case study approach with the use of interviews as the main source of collecting data was chosen (Blumberg et al. 2011; Yin 2013). The use of semi-structured interviews as prescribed by Creswell and Poth (2017) was considered convenient. An 'interview guide' was developed, covering the topics thought to be relevant for the outlined research purpose. The interview guide was structured according to the research questions. The respondent were encouraged to elaborate on topics beyond the interview guide.

The data collection took place between November 2017 and February 2018. Actors from different parts of the supply-chain were interviewed, focusing on the client perspective. These consisted of representatives from clients, suppliers, as well as one representative respectively from a major insurance company and the Norwegian Directorate for Building Quality. We alternated between executing the interviews face-to-face and over the telephone/Skype. As described by Novick (2008) on the subject of telephone interviews, some researchers are concerned that a lack of physical representation could lead to data loss. These concerns, however, seems to be most valid for research related to fields such as psychology and medicine. On the contrary, telephone interviews could actually allow the respondent to reveal information more freely. All the interviews were recorded using an audio-recorder, a process accepted by all respondents. Transcriptions of the interviews were sent to the respondents respectively for acceptance. No data was used without acceptance of the respondents.

The study is limited to the case of flat-roof constructions. The context of the study was a seemingly growing concern in industry-specific newsprints regarding errors related to flat-roofs. One specific article, written by a supplier, and aimed at clients caught our attention(Icopal 2017). We, therefore, emphasized on the clients, with the purpose of increasing our insight into how clients consider such particular- and critical part of many building projects.

LITERATURE REVIEW

FLAT ROOF CONSTRUCTIONS

The majority of flat roofs are built as compact roofs covered with roofing membranes. Most commonly, the membranes are made using polymer-modified bitumen reinforced with polyester or glass-fibre sheets. Other materials used are based on polyvinylchloride (PVC) or rubber, with the same reinforcement of polyester or glass-fibre (Björk and Gränne 2000). Roof membranes are applied to the underlying surface using gluing, welding, ballasting or mechanical fastening, the latter being most common in Norway. Roofing may consist of one (single-ply) or two (double-ply) layers, welded or glued together. The primary purpose of roofing is to protect the underlying structure from weather damage, with moisture in the form of rainwater posing the greatest risk to the service life of components. Roof membrane application requires particular attention to the transitions between the roof and elements such as parapets, roof edges, drains, or other perforations(SINTEF Byggforsk 2008). The membrane itself will usually be waterproof, but water can leak through a faulty weld joint or transition, causing moisture damages that may not be detected easily. The primary degradation factors for roof membranes are elevated temperatures and UV radiation(Paroli et al. 1993; Rodriguez et al. 1993). To mitigate this, membranes may be covered in a white coating to reflect solar radiation. Other degradation factors include chemicals (in air pollution, salt spray or bird droppings) and mechanical wear (wind, hail or foot traffic).Gullbrekken et al. (2016) conducted research on roof defects in Norway, but with a focus on pitched, ventilated roofs. There appears to be a deficiency of research into the material supply aspect of roof defects.

LEAN GOVERNANCE AND CONSTRUCTION PROCUREMENT

In the perspective of literature on Lean Construction, several papers address governance. Banihashemi and Liu (2012) introduced the term ‘lean governance’. They define ‘lean governance’ as “a specific combination of inter-organization relationships governance mechanisms that emphasizes social mechanisms and promotes valued relationships in the project”. This approach was sought as a means to minimizing disputes and rework among others. The concept of governance is complex, and a plurality of definitions exist. In the following, we use the definition of Winch (2001), having the significant advantage of clear-cut analytic operationalisation: “the process of governance refers to practice on specific transaction sets: the micro analytical level.” Here, the micro analytical level refers to governing the project process.

Alarcon et al. (1999) list a selection of problems detected in Chilean projects related to procurement. These include poorly planned inspections, lack of quality and suppliers failing to meet requirements. On aligning procurement with lean construction, Pekuri et al. (2014)maintain that value loss or uncertainty can be resolved by procurement procedures alone. Stating that procurement also involves procuring a production system, not just a final product, Pasquire et al. (2015) addressed what they referred to as ‘safeguarding problem’ in construction procurement. Defined by Rindfleisch and Heide (1997), a ‘safeguarding problem’ arises when a firm fears that its partner may opportunistically exploit their investment. Furthermore, Pasquire et al. (2015) categorize various safeguarding approaches within construction. They differentiate between ‘conventional approaches’ such as ‘standard forms of contract’ and ‘less prevalent approaches’ such as relational contracting. They emphasise that the industry favours conventional safeguarding approaches focusing on shifting risk, without the regard of the effects. Moreover, the clients’ approach to procurement may lead to unnecessary costs, entrench wasteful processes both within the supply chain and through the project life cycle (Saad et al. 2017). Furthermore, Tillmann et al. (2014)urges that a shift from the “client x supplier” relationship into a “client + supplier” relationship may improve value creation for all parties.

MATERIAL FLOW, VALUE-DRIVEN PURCHASE, AND CONTROL

Mastering the physical flow of materials is of utter importance for succeeding with construction projects. As stated by Agapiou et al. (1998), the supply of materials to the construction site has a significant effect on productivity. Several problems connect with the traditional flow of materials, for example, the practice of purchasing materials just before they are required, or purchasing in large quantities without compliance with actual needs on the constructions site (Agapiou et al. 1998). Childerhouse et al. (2000)argue that the purpose of supply chain management is not only waste reduction and cost cutting, but also customer satisfaction, which is a competitive advantage in itself. According to Alves et al. (2013), little has happened in the industry regarding supplier quality surveillance. These researchers suggest that Lean principles such as acting on root causes of problems, transparency, improving communication between supply chain members and helping suppliers improve could all improve current practice. An important aspect of choosing materials is their enormous potential effects on a building. Beyond their cost, materials have social, economic and environmental effects ranging from indoor environmental quality to waste production (Arroyo et al. 2016).

The academic literature concerning CFSS materials in the construction industry appears sparse, especially concerning roof/roof membrane solutions. The main provider of information on this topic related to the construction industry is the Construction Industry Institute (CII).The CII categorizes counterfeiting after types of products, ranging from Class A that are high-end goods very similar to the original, Class C that are obvious junk and easy to spot as fake, and Class B that are all products in-between(CII 2014; Minchin et al. 2010). Two major concerns arise: First, the possibility that such materials infiltrate the construction projects. Second, the possibility that they affect the process and the building. It creates wasteful activities such as need for rework- and control & inspections, negatively affect the value and the value creation for all parties, and increases the risk of HSE-related problems both during and after construction (Engebø et al. 2017; Engebø et al. 2016; Kjesbu et al. 2017; Kjesbu et al. 2017). These results support the findings of the CII and Naderpajouh,concluding that detection of such materials prevents incidents related to safety and rework as well as associated risks to safety, cost and schedule(CII 2014; Minchin et al. 2010; Naderpajouh et al. 2015).

In sum, the CFSS-phenomena is crucial for mastering project governance and the supply-chain. Lean focus on relationships, shifting from transaction-based procurement to relationship-based procurement are threatened by the fact that some actors seek to exploit their partners concerning CFSS-materials.

RESULTS AND DISCUSSION

THE MAIN THREATS TO FLAT-ROOF CONSTRUCTIONS

Due to the relative complexity of such operations, the assembling of roof constructions is typically carried out by specialist roof-contractors. The risks involved in working on a tall roofs and the importance of securing a watertight roof all reinforce the impression that roofing work is “to be left to professionals”. It was stressed by several of the interviewees that perforations and connections between structures were the most troublesome and vulnerable parts of a flat roof. Leaks are prone to happen where roofs meet walls or parapets. The problem is exacerbated for small or temporary building additions (such as adding a small overhanging roof to shelter baby strollers outside a kindergarten), where little money or time is invested into the project and quality control is all but absent; then again, the consequences of a leak in such cases tend to be accordingly small. In larger projects, faults may also occur. Few problems related to the roofing material itself were reported, but some interviewees noted that extreme climatic conditions might cause failures with roofing solutions that have been proven trustworthy elsewhere. One of the roof suppliers also noted that membranes in roof corners need extra reinforcement due to wind forces, but that this is not always applied.

Several of the interviewees also mentioned user failure as a potential threat to roof integrity. Insufficient snow removal and failure to replace aged membranes before they sprung a leak were repeatedly mentioned. Roof drains mounted on rigid drainpipes may even cause a “tent pole effect”, where the drain itself becomes the only part of the roof that cannot be compressed by snow loads, thus becoming the highest part of the roof instead of the lowest. When the snow melts, the melt will not be drained away, and a donut-shaped pond forms around the drain. Interviewees noted that this is less of a problem if the drain is mounted on a “telescope drainpipe” or in a gutter. In extreme cases, snowmelt may also build up along parapets or walls, potentially exceeding the height at which the roof membrane is folded up along the wall, and then run down on the backside of the fold into the structure below. Potential causes for this are drain blockage, lack of overflow drains, ice build-up, or the fold being insufficiently high in the first place.

Foot traffic across the roof may also potentially damage it, particularly if stones or bits of metal are stuck under the sole of the person’s shoes, as this may penetrate the roof membrane. Natural wear and tear of the roof membrane may be mitigated or exacerbated by material choice, design, and workmanship. For instance, the choice of fastening system is crucial in areas with excessive wind loads, and membranes may have to be reinforced with an extra layer where extra durability is required, such as in corners and traffic zones. Failure to recognize and compensate for climatic or other use conditions may lead to premature defects in otherwise well-built roofs.

OVERSEEING THAT CLIENT REQUIREMENTS ARE MET

In Design/Build projects(as often used by public clients in Norway, specialist contractors are procured as sub-contractors by the main contractor. The procurement is often strictly transaction-based with the lowest price as the key evaluation criteria. Several problems might occur using this delivery model. In extreme cases, fraudulent behaviour is experienced. Such behaviour is exemplified by sub-contractors providing certificates related to a “product A”, but uses “product B” during assembling. Thus, the client assuming he gets “product A” which satisfies his needs, instead “product B” with unknown properties is used. Often, clients have little knowledge, or influence over sub-contractors used in the project. This could result in insufficient control over material choices, or the assembling of flat roof constructions. Moreover, such aspects of building projects are critical for the lasting value of the building. Substandard flat-roofs might result in a variety of problems for the client during the building's lifetime and often cause a need for earlier-than-planned refurbishment of the building.

According to the interviewee from the insurance company, serious actors often fix claims without involving the insurance company. This is in contrast to so-called 'bankruptcy runners', who initiate projects and file for bankruptcy within the year. Under such conditions, the insurance provider is often held responsible for the whole claim. The interviewees emphasised the importance of having favourable construction insurance, a traditional safeguarding approach, in order to mitigate the unwanted risk from unserious actors and dubious workmanship. By creating a setting where every actor is focusing on shifting the risk, disputes will eventually involve a multiparty of actors in the supply-chain. Involving a multiparty of actors creates a wasteful and tedious process resulting in unnecessary costs within the supply-chain and the project.

In the case of flat-roof constructions, problems related to CFSS-materials seem to be discovered by coincidence (for example sparkled by a suspicion by a competitor). In reality, neither the contractor nor the client has the needed resources to control every delivery or the documentation of every material used in a project. As stated by several interviewees, Norwegian clients put an extensive amount of trust into their chosen contractor. The trust seems correlated to the expectation of the final product, i.e. the finished building, with little emphasis on the contractor's execution model. In other words, it seems that clients have little competence, or maybe willingness, to study exactly how the contractor delivers value. When the client chooses a delivery model, they tend to choose models that shift risk and minimize contractual relationship (i.e. one contract with the main contractor). Thus, avoiding concerns with sub-contractors and material choices.

Figure 1. shows an illustration of our findings. There are undoubtedly problems related to flat-roofs, problems that affect the value of the client. Furthermore, due to their complexity, flat-roofs should be viewed as a critical part of the delivery. Clients seem to focus on shifting risk when choosing the delivery model. Thus, when asked about governance during construction they tend to emphasize that the responsibility is with the contractor. Finally, when asked about previous experiences with erroneous roofs, everyone has a narrative to describe. The narrative often resembles that of a Greek tragedy, a construction of suffering and insight.

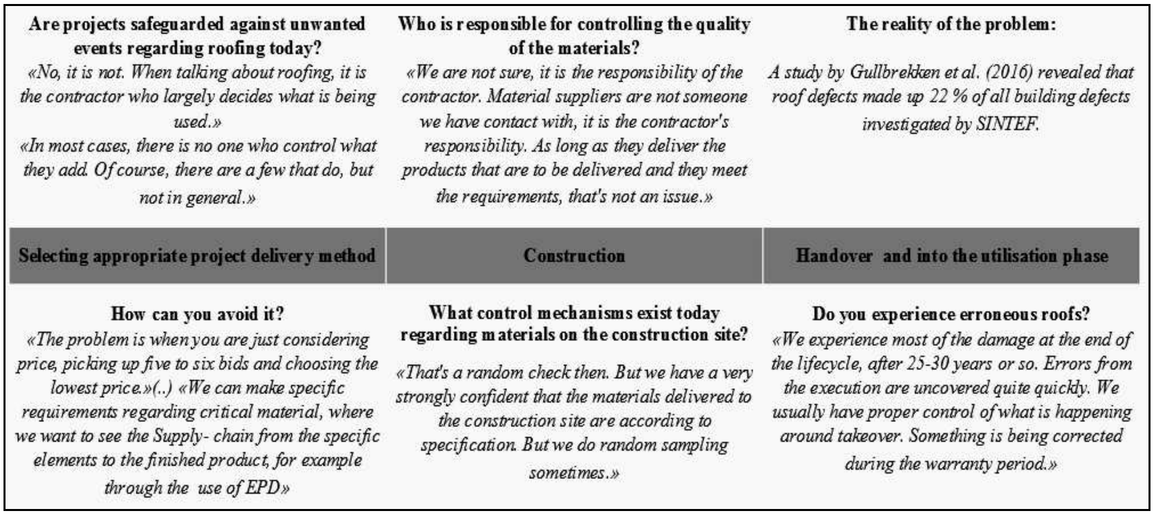

Figure 1: An illustration of some of the findings

A potential long-term solution is, as described by Alves et al. (2013) and Pasquire et al. (2015), to change the focus from just shifting the risk from one another to instead focusing on the root cause of the problem. Thus, focusing on soft elements such as improving communication, transparency and helping sub-contractors improve their own practice.

CONCLUSION

Premature roof failures present a great threat to the value of a roof, especially so if the failure is not discovered and repaired before excessive moisture damage has happened underneath the roof membrane. There can be many causes of failure. According to interviewees, design flaws and construction errors are more common than material faults. Perforations and transitions of the roofing material stand out as the most risky elements on a roof. Additionally, failure to maintain the roof may also cause roof defects. When asked about CFSS-materials in flat-roof constructions, the findings show that neither clients nor suppliers had substantial knowledge or experience with this phenomenon. This is a worrying finding bearing in mind the assortment of consequences described in the literature.

In the context of such complicated constructions as flat-roofs, both the client and the responsible contractors need to be aware of the possible risks. Often specialist contractors procured sub-contractors that have the main responsibility for flat-roof constructions. There seems to be a real prospect that emerging forms of project procurement arrangements such as relational contracting that emphasise on lean principles – such as the focus on people, relationships, and integration – may prove to be more effective in counteracting problems revealed than the conventional methods are. Thus, we propose that clients should implement a more planned approach to overseeing that client requirements are met. To ensure a lean project delivery, mitigating unwanted events related to material choice, design, and workmanship is necessary.

Future research should be directed towards the perspective of the sub-contractors that specialises in constructing flat-roofs. Especially focusing on supply-chain management and the relation between the sub-contractor and the main-contractor and the client. Several of the interviewees suspected that conditions were "less tidy" in the part of the industry focusing on smaller-scale (i.e. single dwelling residential) projects. While the large actors interviewed in this article have greater amounts of data and a better overview of the many requirements of a construction process, interviews with small-scale actors may give a better insight into the smaller and less organized side of the industry – if only on a local level.

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KNOWLEDGE MANAGEMENT AND ITS APPLICATION IN DEVELOPING LEAN CULTURE

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ABSTRACT

Construction projects generate a lot of learning during their lifecycle. However, it is common to see this learning go underutilized in subsequent projects. If an organization learns to control the "waste of knowledge" during the project lifecycle and utilize this knowledge in subsequent projects, it can form a significant competitive advantage for the organization.

Knowledge management (KM) is defined as the process of capturing, managing, and disseminating the knowledge of an organization.

This paper presents our experience of implementing of an award-winning knowledge management system for construction projects and explores how knowledge management activities facilitate and enable to build lean culture within an organization. It shows how our KM system allows for "information pulling" by project team members to get the correct information, to the right people, in the relevant form, at the appropriate time. We show how different facets of KM aid in promoting Lean Principles and through examples from our projects, how Lean Culture can be developed by sharing best practices and learning from past projects.

KEYWORDS

Knowledge management, Lean Culture, Lean Principles, Knowledge Enterprise

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INTRODUCTION

In a highly competitive sector like construction, retention and use of an organization's knowledge assets can offer a significant competitive advantage. Construction projects have potential to be rich sources of knowledge for the organization. Generally, this knowledge is in the form of knowledge of individual project managers, construction managers, engineers, and designers rather than the collective knowledge of the organization. Sharing this knowledge has many benefits. It minimizes the learning process from past projects, reduces the time and cost of problem-solving, and improves the solution quality during the construction phase of a construction project. (Lin and Tserng, 2003).

However, given the scale, complexity, diversity, uniqueness and geographic dispersion of these projects, acquiring this knowledge becomes a challenge. This challenging environment can result in this knowledge going uncaptured. This **'waste of knowledge'** results in organizations 'wasting time and money' during a project’s life cycle to 're-invent the wheel', to do re-work or for failed bids. (Gannon and Banham, 2011)

This paper attempts to show how Afcons’ Knowledge Management system aids in promoting Lean Principles and through examples from our projects, how Lean Culture can be developed by sharing best practices & learning from past projects, identifying & reducing wastes in activities, recognising &respecting people expertise and driving continuous improvement.

KNOWLEDGE MANAGEMENT

Knowledge is commonly categorised in practice and literature as explicit and tacit knowledge (Gannon and Banham, 2011). Explicit knowledge is formal knowledge that can be expressed through language or symbols, whereas tacit knowledge is knowledge known by an individual through experience and internal reflection (Anumba et al.) and distributed throughout an organization. Project knowledge includes explicit information such as project records and documentation and tacit knowledge such problems faced, solutions developed, expert suggestions, innovations and knowledge gained from project successes and failures.

According to Davenport &Prusak (1998) Knowledge Management (KM) is managing the organisation's knowledge by a systematic and sustainable process for capturing, organizing, applying, disseminating and replenishing both the tacit and explicit knowledge of employees to create value and improve the performance of the organizational. According to Gannon and Banham (2011), the challenge with managing Tacit knowledge in a project environment is how to recognize, generate, share and manage the knowledge between team members and then how to transfer this knowledge to the organization.

ABOUT AFCONS

AFCONS Infrastructure Ltd. (Afcons) is the flagship Infrastructure Construction Company of M/s Shapoorji Pallonji Group the second largest Engineering and

Construction group in India, (a group in existence for more than 150 years with businesses in India & 60 other countries). Afcons has experience of over five decades of infrastructure construction in Marine works, Highways / Expressways, Bridges, Railway& Metro works, Barrages, Tunnels, Oil & Gas, LNG Tanks & facilities serving both Government as well as Private Clients. Afcons has completed over 350 Infrastructure projects across 15 countries, including India, Africa, South Asia & Middle East, generating revenue of ₹ 65 billion (~1 Bn USD) in FY 2017-18.

AFCONS LEAN JOURNEY

Afcons' Lean journey began in 2008 as one of the founder members of Institute for Lean Construction Excellence. Under the guidance of the Executive Director – Technical, a team of 3 employees at Head Office anchor Lean Construction initiatives supported by Lean Champions at site. Over the years, several Lean implementation initiatives have been carried out at various projects. The Last Planner System ™ has been studied and adopted. Several Lean tools such 5S, Standardized Work, Visual Management, Value Stream Mapping, Single Minute Exchange of Die etc.have been implemented successfully at different sites. More than 200 employees have been trained in Lean tools and principles through an E-learning module on Lean Construction. An extensive training program (Mission Dhanush) is in place to train each employee at every project on basic Lean tools and principles. Since 2016, adoption of BIM tools has also been initiated at several projects.

AFCONS KM JOURNEY

In 2012, Afcons started its Knowledge Management (KM) journey. KM was launched in three phases, an initial pilot, followed by official launch and finally KM introduction workshops and roll-out at project sites. The next two years were spent launching the Gnosis portal at different sites and building the content. To encourage users to use the Gnosis portal and contribute content, promotional campaigns were carried out. The lessons learned process was developed and initiated in 2014. In 2016, the knowledge organization was revamped and Knowledge Services Group was formed.In 2016& 2017, Afcons' efforts in implementing Knowledge Management System was rewarded with the Global, Asian and Indian MAKE award (Most Admired Knowledge Enterprise) in the IOU (Independent Operating Unit) category. Currently a team of 12 employees anchors the organization's Knowledge Management related initiatives.

KNOWLEDGE MANAGEMENT AT AFCONS

At Afcons, KM process is based on three stage learning approach with designated inputs and favorable outputs. The outcomes of KM are helping constantly in cultivating a Lean culture within the organization. The three stages are as shown in Figure 1

LEARN BEFORE

Knowledge at the right time, right place and right combination is an efficient key to informed decision making. Therefore, before the start of any new project, organizational knowledge needs to be transferred to the project team.

Project team can refer to the lessons learned reports, success stories and project completion reports of past projects which are readily available in KM portal (Gnosis) as a guide in adopting right practices and avoiding mistakes. Knowledge about the process can also be gained through process videos, animations and photographs which are stored in KM portal. Various standard project documents like method statements, Health, Safety, and Environment plan, Quality Approval plan, Inspection and Testing plan, formats, checklists etc. can also be referred from the portal, reducing the time required to prepare the documents and formats.

Kick off workshops are designed to be conducted at new project sites just before the start of execution. The newly assembled project team discusses the execution strategy with Heads of various departments. They also seek to know details of past project learning of similar nature. Experience of the experts is leveraged to fulfill the knowledge requirement of the project team.

The teams in projects can also enhance their domain knowledge by going through the e-Learning courses. The e-Learning courses are designed by taking practical inputs by experience of subject matter experts within the organization. In addition to this, Afcons has developed an extensive network of external experts and consultants, who help in introducing the latest ideas and best practices from across the world.

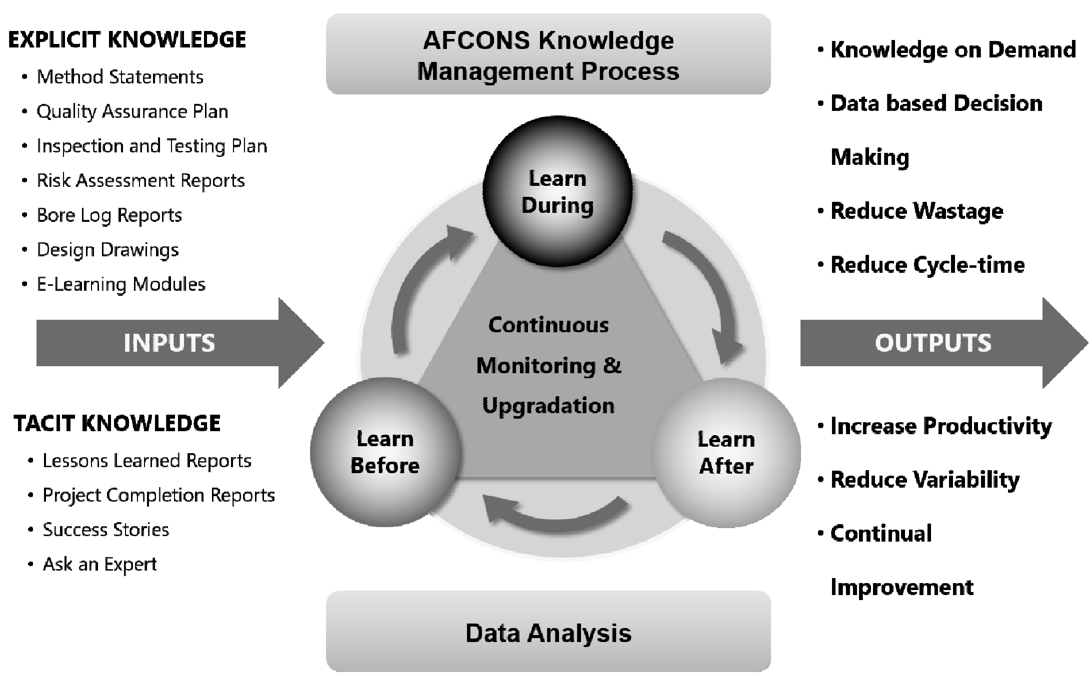

Figure 1: AFCONS Knowledge Management Process

LEARN DURING

Continuous learning and improving the process is very important during the construction project. Afcons KM process makes it possible by providing learning support through Activity Based Classrooms, Classroom at Site, Ask an Expert, Technical Audio Visuals, Process Videos etc. as per the project demands.

Activity Based Classroom (ABC) is conducted just before the start of an activity in which an expert guides the project team through the intricacies of executing the activity. Expert illustrates the lessons learned which are captured from the previous projects and suggests the value engineering that can be done in the execution of the activity. There are even practical demonstrations associated with the ABCs that are performed at the sites. Classroom at Site is a platform where the engineer with the expertise in a specific domain shares his knowledge with the project team. Activity Based Classroom and Classroom at site share lot of similarities with First Run Studies (Howell and Ballard, 1999).

Ask an Expert feature in the KM portal connects the knowledge seeker and expert directly. This feature helps the user in getting the right solution from the expert for any question related to the project. Daily learning is ensured by Q&A platform in KM portal in which a single question related to construction process is updated every day whose answer along with the description is made available next day. KM system also ensures the learning on new technologies and trends by facilitating the external trainings.

The KM team is also involved with small scale studies to help generate awareness about the better operating processes that can be implemented within the organization either by the intervention of technology or streamlining the existing operations. These are published in the form of a technical bulletin quarterly.

Cross transfer of knowledge between projects in real time basis happens through group of experts who visit various projects frequently. The Core Methods and Engineering Group (CMEG) and Budget Task Force (BTF) are two such examples of experts who help cross pollinate knowledge across various projects

LEARN AFTER

Knowledge created within a project life cycle is captured, classified and stored into domain knowledge and process knowledge. Lessons learned sessions are conducted with the objective of capturing lessons and insights for future projects to perform better. The motto is every time we do something; we should be able to do better than the last time. Efforts are taken to identify different situations where these learning can be applied. During the lessons learned session the entire project team gets an insight of the job executed.

Since the project moves forward activity wise, the lessons learned is captured at 60-70% completion of major activities. It is prudent to capture the learnings at this stage, as project team members start getting assigned to other activities/projects as the activity approaches completion. These lessons learned are stored in the form of reports and uploaded in KM portal for use in parallel or new similar projects. The captured lessons learned throughout the lifecycle of the project are consolidated the end of the project.

This in turn churns out a final lesson learned report for the entire project. The major outcomes expected from a lesson learned session are:

- What was expected to happen?
- What were the assumptions?
- What happened?
- What went well and why?
- What did not go well and why?
- What could have been done differently?

The report is further checked and reviewed by experts before upload to the KM portal (Gnosis) for use in future projects. The critical lessons learned points from past projects are disseminated as per the project team's "pull information demand" which increases the acquaintance of the project team with anticipatory circumstances and equips them with the capability to implement the technically and commercially viable solutions. Table 1 brief describes the various KM activities undertaken at Afcons

Table 1: Brief description of KM activities

KM activity	**Description**
Activity Based Classroom	Training session at project site by external facilitator on a critical activity before start of the activity. *Pushed by KM team*
Classroom at Site	Training session at project site by one of the members of the project team, who is experienced in an activity, before start of the activity. *Pulled by the project team*
Ask an Expert	Feature of Gnosis portal to request for help from designated experts on issues, problems or difficulties faced in execution of an activity at project site *Pulled by individual*
Community of Practice	Online community of people with deep expertise and passion for a domain of work *Pulled by individual*
E-learning	Online training module with interactive content *Pulled by individual*
KM Portal (Gnosis)	Online repository of information and project documents

	Pulled by project team, at times pushed by KM team
Kickoff Workshops	Information sharing workshop during the initial stage of the project, to ensure Client expectations are communicated clearly to each project team member *Pushed by KM team*
CMEG, BTF	Team of experts with deep domain knowledge in particular area of work *Pulled by project team*
Lessons Learned	Workshop to capture what went well, what did not go well and lessons for the future *Pushed by KM team*

KM AS AN ENABLER OF LEAN CULTURE

Lean is a comprehensive approach to create value by eliminating waste in an organisation. It incorporates everything from single processes, management, organisational culture and structure. Within Lean, seven types of wastes have been identified: over-production, waiting, transportation, over processing, inventory, defects and motion. 'Waste of knowledge' as another type of waste that can be added to this list.

In Lean, a push system releases work based on demand, whereas a pull system releases work based on system status (Hopp and Spearman 1996). (Ahn et al., 2007) have defined “information pulling” as delivering prerequisite knowledge of the successor activity at the time that project participants are ready for that activity. The key purpose in “information pulling” is to make the information system know when to deliver prerequisite knowledge for a succeeding activity.

Our KM system allows both; content to be pushed to the learner and the learner to pull the content. Content can be pushed to Learner through Activity Based Classrooms, Classroom at Site, and Kick-off workshop. This content is decided based on the type of project, with the aim of ensuring that most project team members are made aware of the critical aspects and activities for the success of the project. Apart from this, the Learner can pull the content through the KM portal (Gnosis), E-learning, Ask an Expert, Project completion reports and Lessons learned. This enables the learner to quickly reinforce or upgrade his skill, find solutions to problems and identify improvements/innovations to improved performance. It ensures that mistakes made in earlier projects are not repeated. Improvements made through lean initiatives can hence be effectively deployed horizontally to ensure transmission throughout the organisation.

Lean does not force change, but rather builds on successful practices and procedures as well as inspires employees themselves to make suggestions for change. Continuous improvement of Lean process requires long-term commitments from top management and employees. Hence building a Lean culture is a key factor in successful implementation of Lean. KM promotes development of a learning organisation and efforts to eliminate waste and improve construction processes will invariably require sharing and transferring knowledge from previous projects and later to transfer the learning from Lean initiatives to new projects.

At its core, Afcons KM system helps to reduce waste that happens due to mistakes being repeated from project to project. At the same time, it allows project team members to connect, explore ideas for improvement and build on previous successes and failures. It enables continuous improvement in how construction activities are performed. Therefore, several lean initiatives at Afcons are aligned with KM activities. Value Stream Mapping is embedded in Activity Based Classrooms. At the same time, Activity Based Classrooms are aligned with First Run Studies ((Howell and Ballard, 1999).Experience and output from Standardised Work and Visual Management are captured on the KM portal for future reference. Experience in using Last Planner System™, especially Constraint Log, Make-Ready and PPC charts are crucial to identify lessons learned.

Lean initiatives and KM system are tightly coupled. On several occasions, promotional campaigns for KM system have identified Lean improvements which project team members have been able to achieve on their own. An effective KM system not only enables development of Lean Culture, but in fact accelerates the pace of adoption.

The pillar of Lean is the adoption of its six principles – value, value stream, flow, pull, perfection, and respect for people. Table 2 describes the facets of our Knowledge Management system that supports and enables various Lean principles.

Table 2: Lean Principles supported by Knowledge Management

Lean Principle	**Lean Enabler**
Respect for People	1. *Classroom at site* and *E-Learning* help users develop themselves professionally 2. *Rewards and recognitions* help to highlight knowledge contributors 3. *GNOSIS portal* offers several features to come up to speed about different areas of construction 4. *Community of people* enables users to connect with others to share thoughts, problems and solutions
Value	1. *Lessons learned* & *Project completion reports*(PCR) demonstrate how the project can enhance value for the customer 2. *Kick-off workshops* help to bring the entire project team on the same table and create awareness regarding customer's requirements 3. *K-capsules* & *success stories* help to share innovations across the organization 4. KM team utilizes *experts (CMEG)* to innovate on methods
Value Stream	1. Users can use *GNOSIS portal* to explore multiple solutions simultaneously for their problems through *PCRs, methods & Ask an Expert* 2. *Kickoff Workshop* and *Activity based Classroom* help to identify and ensure that capabilities to deliver a project are available up-front 3. *Project completion reports* and *method statements* offer insight into the productivity parameters and ways variability in a process can be reduced
Flow& Pull	1. *Community of Practice* and *Ask an Expert* feature allow users to discuss their problems in an open forum and get feedback from experts 2. *Methods and process videos* enable to standardize work procedures and standard operating procedures to increase efficiency 3. *GNOSIS, PCRs, E-Learning* etc. offer knowledge on demand to ensure preparedness before starting a new activity
Perfection	1. *Lessons Learned* from the projects are captured effectively and are easily accessible to users to avoid repeating mistakes 2. *Project completion reports, lessons learned* and other project documents help users identify key risks and effective mitigation measures 3. *Method statements and lessons learned* enable users to identify baseline benchmarks which they can strive to exceed

EXAMPLES

At a metro construction project in eastern India, we had to construct an underground metro station building. The Knowledge Services Group team identified the execution expert from a similar project in south India. The expert prepared a presentation highlighting the learnings they had got from their project experience and the good practices that could be adopted. Post review, the expert was sent to the project to conduct an Activity Based Classroom for training the project team to execute underground station buildings. This ensured that mistakes made in the earlier project were not repeated, and were in fact, proactively avoided.

At a marine wharf project in Western India, piling cycle-time was not being achieved as planned. Hence Value Stream Mapping exercise was conducted to identify how to make value flow and remove wastes. During the exercise, it was observed that defects from liner fabrication yard and reinforcement cage fabrication yard were flowing downstream and impacting piling cycle-time. The checklist for the finished product at both the yards were modified to incorporate the checks for defects and thereafter standardised. The case was also captured as lessons learned for future reference and shared with similar projects.

The Ask an Expert feature on the Gnosis portal is used extensively by the on-going project teams. One such instance is of the Sulphur Handling Facility in Middle East. The project team was facing problem for under water pile cleaning and painting in the splash zone. The experts from head office discussed the problem with the project team and then searched for similar kind of issue on the KM portal. They found a solution in the form of a method statement for similar works from a past project in Mauritius. A cofferdam arrangement scheme for pile painting in splash zone was proposed to the project team which the team executed to complete the activity within the scheduled time. This is an example of how the project team 'pulled information' at the right time to enable them to complete the work as per schedule.

At times, due to criticality of an activity it is necessary to both, "push" as well as "pull" knowledge. An expressway project in northern India, had a time-sensitive and critical bridge over a major river. Delays in fabrication of the launching truss, resulted in the team exploring ways to improve launching cycle-time. The team studied methods for launching at other projects. At the same time, CMEG group of experts conducted an Activity Based Classroom to explore how to improve the cycle-time. The team were able to identify several areas where time could be saved, as well as some improvements through innovations. As a result, the launching cycle-time was reduced by half, to a record time.

CONCLUSION

The application of Lean principles is very challenging in the construction industry. This paper attempted to show how Lean Construction implementation and KM system are linked and inter-connected and how KM can be an enabler for building a Lean Culture. It first introduced the concept of knowledge and KM and then discussed how Afcons implements its knowledge management system. Further it discussed how KM enables

Lean Culture by preventing 'waste of knowledge', satisfying 'information demand' to the right person, at the right time and in the right form and supporting transfer of learning from Lean initiatives to new. Preventing 'waste of knowledge' can form a significant competitive advantage by minimising the learning process from past projects, faster learning curve, reduce the time and cost of problem-solving, improving the solution quality and reducing waste and improving cycle-times. At the end, examples were used to illustrate how KM system helped to deliver value for the project. Development of a Lean Culture is a slow and gradual process and an effective KM system acts a catalyst to accelerate the adoption of Lean principles.

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BUILDING A LEAN CULTURE INTO AN ORGANIZATION

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ABSTRACT

The Indian construction industry is in need for a change; a change that can help its people and organizations discard the conventional project management approach of 'Command and control'; a change that can create better collaboration between project teams and reduce blame games. Lean construction and the Last Planner System™ is a potent and proven solution that offers the change.

This paper suggests/proposes an approach for an organizational lean transformation. The approach is based on real life experience of the authors working with both Owner and Contractor organizations. The approach is based on building experience in lean tools at the site level that can be scaled across projects as a bottoms-up model. This is complemented with a top down approach that builds awareness, empathy, and knowledge at the leadership level. Together, the goal is to build capability and confidence in the organization to adopt and adapt lean into the organization. This paper explains in detail about the program and evolution of it from Indian experience.

The authors will share their experience and their learning making the change in organizations. They will share the successes and the limitations of the approach.

KEYWORDS

Lean construction, Indian Construction, Lean Implementation, Last Planner System, Organisational Culture.

INTRODUCTION

India is in the midst of immense and rapid infrastructure growth (Raghavan, Satyanarayana., 2014) and the construction industry has yet to fully realize the impact of this. While business volumes will grow, other dynamics will enter like increased competition, reduced margins, shortage of labor etc. The large and medium size stakeholders (Clients, PMC's, Contractors) in the Indian construction industry are fast

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realizing that the current project management practices are inadequate to contend with these shifting market dynamics, the rapid pace of works, and still operate profitably. As a result, everybody is on the look-out for systems that can give better control of the projects, improve operational efficiency and profitability so as to compete with (other key) global stakeholders. This paper proposes an approach that an organization aspiring for such change can adapt and adopt for organizational lean transformation for improved operational efficiency.

From the authors' real-life experiences, it was observed that, more than a few organizations have identified lean as the missing ally to operate at better efficiency and profitability. But, given the rapidity and need for speed of change, organizations are trying to do independent isolated pockets of experimentation on lean. For instance, there are more than a few instances of project/site based lean engagements to bring Last Planner System, Kaizen and Value Stream Mapping et.al. There are other instances where the organizations have come-up with HR Learning & Development initiatives for training the top management on Lean and to create awareness amongst the senior personnel. More recently, there have been rapid advancements in construction technology and there are instances where technology also being tried in addition to process changes to bring in better operation efficiency. IT departments are bringing in mobility, 3D parametric modelling solutions, and digitization initiatives under the BIM (building information modelling) initiatives to improve business processes and project operations. Although these isolated attempts on embracing lean into their organizations have yielded some positive impact, we hypothesize that, they are unable to see the transformative impact that they are expecting. This is because, we postulate that they could not formulate a corporate strategy or a holistic approach for organizational lean transformation.

The remainder of the paper is structured as follows. The next section will explain the formulation and basis of the hypothesis. Then we describe two case studies based on experience of working with a couple of Indian companies and use it as the basis to explain the methodology for the proposed approach. In the last section, we will have some discussion describe a possible corporate strategy for the transformation and then conclude with scope for future work.

HYPOTHESIS

Decision makers in the Construction Industry in India are now exposed to lean construction for the past few years. They understand and agree that lean construction would be a vital strategy to improve the performance of construction and create substantial improvements for firms that are adopting it (Ballard and Howell 2003).

The authors' hypothesis is that, isolated attempts can lead to sub-optimal results and probably question the efficacy or applicability of lean. What is needed is, a somewhat of holistic approach/strategy that is long term and comprehensive methodology for incorporating/inculcating lean tools, processes, and complementing technologies along with the culture into the organization; to make it sustainable and yield substantial benefits. There are references from literature that support this hypothesis. For instance, (Leonova, Ballard and Gehbauer, 2017) mentioned that if the success of lean adoption is sub-optimal, then we need a discussion about improved strategies.

METHODOLOGY

The authors have been engaged on lean consulting engagements for projects in India for nearly a decade now. They have experience working across infrastructure (Vaidyanathan et al 2015), residential real estate (Vaidyanathan, Pratap 2015), and commercial real estate projects (Vaidyanathan et al 2016) both with Owners and Contractors. A typical engagement would last atleast a year with the authors acting as lean coaches bringing about the adoption of the Last Planner System, Value Stream Mapping and other such lean tools to transform the culture of managing the projects to be more transparent, collaborative and problem solving based from the conventional project monitoring based on cost-based targets leading to blame game when targets are missed. Metrics and output measured on a couple of the engagements are documented in previously published case studies listed above. Based on their experience and understanding on working on nearly twenty such engagements, the authors are proposing a two-pronged approach to adopting lean at an organization level with complementary process and technology strategy. A Bottom-Up approach of implementing lean tools at the site to build capacity and collaboration between site teams that is complemented by a Top-Down approach that builds awareness to management drive continuous improvement initiatives. The approach is explained with two independent case studies that are elaborated below. The first case study is of an EPC contractor amongst the top ten contractors in India with operations pan India. The second case study is of a real estate developer working on large residential projects in Mumbai region, India.

BOTTOM-UP APPROACH: CAPACITY BUILDING

The intention of the program is to teach and inculcate the basics of lean and lean tools. Tools such as the Last Planner System™ (LPS), Value Stream Mapping (VSM) and work sampling to the site personnel at various sites in a scalable and repeatable manner. Besides teaching the team on lean, the program is aimed at a cultural change amongst the site team. The following is a case study of implementing this for an organization.

The organization, in question, is one of the top ten EPC contractors in India. It has several regional offices spread across India. It has a conventional project monitoring and control set up, driven in theory by the PDCA logic. The planning system is focussed more on the master schedule, target completion schedule and the monthly plan. The execution team is expected to deliver on the monthly plan. The plans are typically difficult to achieve and not owned by the last planners and hence the plans tend to fail. Filling this ground level void of making the plans work in real time is what LPS is meant to achieve.

The organization, drawing from its past experience with implementing lean and LPS (Vaidyanathan, Pratap 2015), decided to implement lean construction principles across a region on a pilot basis and then depending upon the degree of success, scale it to the whole organization in the long term. They hired a lean coach that they had the past experience with to evolve a strategy to achieve the goal. The initial plan was to employ the lean coach in each site for a three-month duration. The objective of the coach was to get the site team to learn and adopt the lean process, specifically LPS for collaborative planning and VSM for productivity enhancement or wastage reduction and to tailor the lean processes and systems to the specific project requirement (if any) for planning and controlling. In short, the purpose was to mentor the team, institutionalize the process and repeat the process. The program was implemented for about five projects over a period of fifteen months with each Project having different deliverables with different set of challenges. The program was rolled-out to three residential township projects, a commercial facility, and to an industrial project.

LPS was designed to improve workflow reliability by continuously aligning what will be done on projects with what should be done through collaborative planning (Ballard and Howell, 1997). From the phase schedule, the site team was to identify the fifth week's (rolling Look ahead Plan) major activities. Then they were to identify the constraints or make ready processes for each of the activities. With that a weekly work plan is created which a list of commitments (WILL do) from the last planners. Daily monitoring and controlling is done on the commitments. Adherence or misses to commitments are measured to calculate percent plan complete (PPC) and failures lead to learnings and taking corrective actions using VSM or other intervention techniques. The achieved production during the week (successes) is tied back to the phase schedule and master schedule to ensure that contractual milestones are not being missed. In this sense, an alignment between planning and execution from top to bottom and bottom to top was created. Production was emphasized over productivity and cycle time was measured as the KPI rather than revenue (or cost) for the organization.

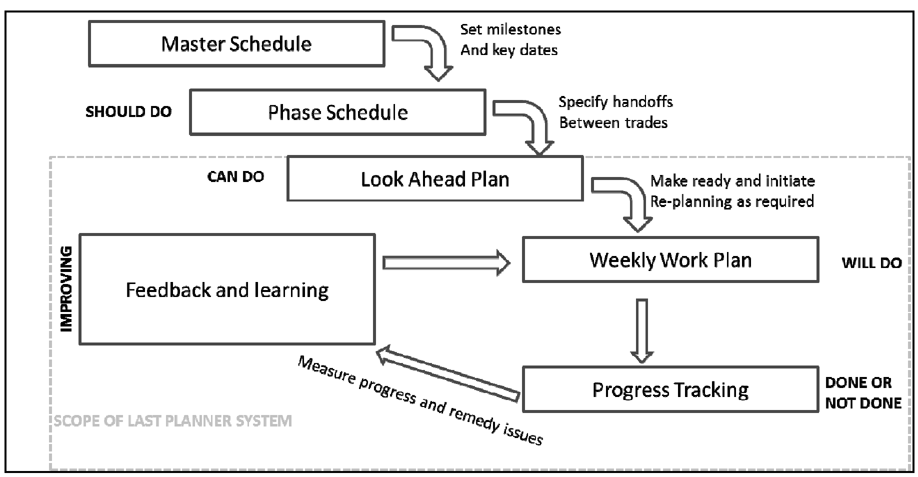

Figure 1: Last Planner System

The Lean training program at each site would start with a lean and LPS awareness workshop for the site team with top management in attendance. Over the next week or two, the lean consultant had to observe the AS-IS planning process and the site conditions, so as to come up with a roadmap for rolling out the project specific LPS. Thereafter, a LPS introduction workshop with simulation games and a working planning session would be conducted by the lean consultants to help the last planners and the whole site team to understand the LPS methodology.

The program got much needed impetus from the second site where, when the site team was able to bring the slab cycle down from 12/13 days to a consistent 8 days' time as shown in the figure 2. And after the third site, the three-month implementation plan was standardized and became a standard operating procedure. The idea was to mainly teach the LPS and VSM techniques to the sites, but in the process also create excitement within the teams by drawing on their problem-solving abilities and creating commitment and ownership within the teams to improve productivity and throughput. This also had the desired effect of helping sites and site planning and management take better ownership and adopt the lean processes and to learn and control the project using LPS.

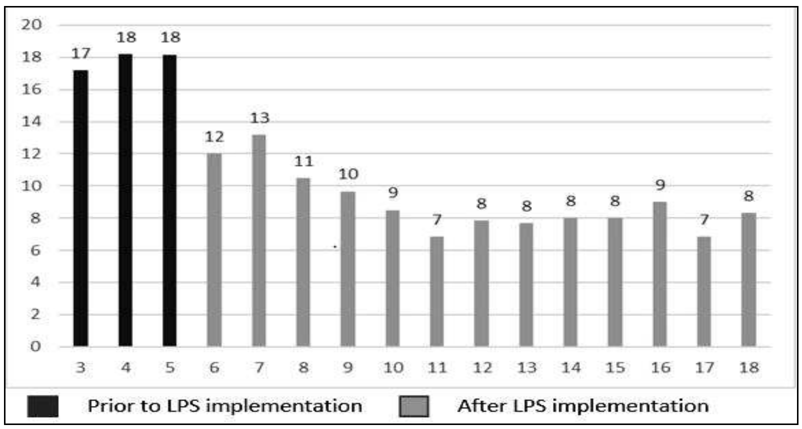

Figure 2: Pour Cycle Trend at Second Site

Project reviews by management was also changed to encourage adoption of lean principles. The monthly project reviews at the head office started to involve discussion on performance indices based on lean parameters. These included:

- Production metrics rather than productivity metrics
- Discussion around constraint analysis and removal rather than delay justification
- PPC and interventions done to avoid repeat of the top 3 delay reasons

At the end of the program, the methodology of implementing Last Planner System and conducting meetings were all standardized. The adoption of lean at the sites improved and it had the cascading effect of other projects and other sites asking to adopt similar processes and techniques.

TOP-DOWN APPROACH: DRIVING INITIATIVES

It is a known fact and people accept that adoption of lean requires changes in attitudes, thinking and behavior (Leonova, Ballard and Gehbauer, 2017). And, there is a need for creating awareness that can drive the change and develop the drivers. Lean construction must be accompanied by a conscious and consistent strategy and championed by senior level managers (Mossman 2009). The organization in question, is a residential and commercial real estate developer with projects primarily being done in Mumbai, India. They are trying to scale the organization for the next level growth. As a HR initiative for their next generation leaders to champion the growth using lean, the organization partnered with a lean consulting firm and a lean leadership training program was designed. The program's goal was to create lean awareness and impart basic knowledge of lean tools amongst the senior managers and the top management. The hypothesis was that rather than simply giving them theoretical knowledge on lean and various lean tools, they will get to appreciate it better and realize its potential if they get to apply them themselves to processes in the business or to their job routines. And once they realized the potential of lean (and the specific tools), they will be more committed change drivers that will drive change within the organization for the long term. The following is a case study of implementing this for an organization.

The organization is a forward-thinking entity that always has an eye towards leadership training programs for management personnel to keep them motivated. The organization partnered for one such training program with the consulting firm. The program was a HR initiative as part of their learning and development program that the participants had to undergo. In this case, the participants happened to be typically heads of various departments from sales, marketing, customer service, and project operations like contracts, procurement, field execution, planning, information technology etc. The goal was for each of them to learn about the various functions in the company and how the various functions are inter-connected and operates in a cross-functional learning environment using lean as the underlying theme. The program was designed as a one-year continuous learning and application program. Each quarter of the year, one or two topics of lean was introduced to the teams in a learning session. During the quarter, the participants were to apply the learning in a practical work scenario as part of application (and development of the individual/team/organization). End of the quarter, the participants had to present their experience between themselves and to the management. While team had the flexibility to apply their learnings on any of the organization's process or functions, the participants were grouped into four teams and each team was given a broad theme and encouraged to pick application of lean techniques on the theme assigned to them. Following are the teams and their initiatives:

- Quality team – First time right
- Cost optimization team
- Customer experience enhancement team
- New Product development team

Each team had an average of about seven members. And each team was consciously heterogenous with participants from various business functions and departments described above. A kick-off session was conducted where the whole of the teams was inducted on lean. The curriculum for the year was as follows:

- Learning to see – Understanding waste and value stream mapping
- Collaborative planning – Understanding teamwork and Last planner system
- Continuous improvement – Kanban, 5S, poka yoke
- Technology enablers – BIM, project controls

The structure of the course during the quarter followed the following structure. Each quarter, a one or two-day workshop was conducted to introduce the next lean topic as outlined above. Each team had to then come up with a proposal of the application of the lean topic within their daily routine based on the theme assigned to them. During the quarter, the lean consultant would work with individual teams on a weekly basis to ensure that each team was making progress on their proposal. Monthly reviews were done internally within the teams to encourage each other as needed. At the end of the quarter, each team had to present the results of their proposal to top management who acted as mentors. Successful proposals for improvement that were made to management was implemented in a pilot mode and if found successful, was operationalized into the business. This followed introduction of the new lean tool for the next quarter and a repeat of the process ensued.

For instance, the Quality team could choose to see how to ensure tile installation is done right without re-work as part of their first quarter experiment. But this team had members from execution and also from procurement, billing, sales etc. The non-execution team would bring out-of-the-box ideas on how to improve an execution function. In the process, the expectation was that, the team members would get practical experience on adapting and adopting the lean tools while also learning the functions of other departments at a working level of detail that they otherwise would not have an opportunity to know about in the “busyness” of their daily routine.

The cross-functional teams had the desired benefit of each department head learning to empathize with the functions of their peers, heads of departments of other functions in a “fun filled”, “classroom learning environment”. To finish up the earlier example, the team studied the tiling process from design to execution and came up with standards for design, procurement, and execution to ensure that quality of execution was at its highest. To take another example, execution personnel should know how and why bill processing takes “time” in the Billing & Accounts department. At the same time, billing personnel get to appreciate the difficulties of measuring productivity and work output at the sites under harsh site conditions and with sub-contractors of varying education and awareness levels and give information in exactly the formats desired by the information technology systems designed by the accounts department. Each learnt to give and take a little to collectively ease the pain and friction in bill processing. It should be noted that these heads of departments are expected to take the organization to the next level and this classroom environment gave them a safe space to become friends and teammates. The hope is that once both get back to their daily routines, they will be able to call on their friendship at difficult times. The team came up with innovation campaign and got participation from the entire company to contribute ideas for innovation.

With each passing quarter, it was evident that the teams showed improvement in leadership skills, coordination skills, analytical skills, proposal writing skills, thought process, implementation planning, etc. to name a few. Most importantly the teams developed an eye for identifying waste, appreciated the culture of collaboration and teamwork, and created an environment for mutual trust and respect and developed empathy for each other’s work and process.

At the end of one year, several improvement initiatives were piloted and successful ones were operationalized. The top management of the organization was very pleased with the learning environment that was created in the organization. In fact, the organization went on to win several awards for this initiative under the learning & development category of HR awards. It has been a couple of years since the program has been completed, but till date the improvement initiatives are created and driven periodically by these next generation leaders.

THE PROPOSED APPROACH

The discussion on each of the case studies show that individually, both had the desired effect of bringing change in the organization. In the first case, the site teams were "owning" the execution and driving improvement. But for it to become a "habit", what the authors had to do was make management change the review mechanism. If that were not done, and if management metrics continued to be the old metrics (productivity, cost, revenue, profitability etc.), the risk of the site teams falling back into old habits existed. In that sense, top management and site teams had to be aligned. But if the top management was not convinced of the potential of the lean techniques, their willingness to change is not very forthcoming.

This is where the second approach works. Here, the top management is given time and space to learn and appreciate the potential of individual lean tools and the lean philosophy and culture in general. That gives them confidence to drive change in the sites in a continuous improvement manner. In this case, if the site teams did not have the capacity to adapt themselves to the new tools and metrics (production, constraint analysis, intervention and problem-solving attitude etc.), then the top management is unable to drive the change initiative. Here the bottom up capacity building is required to get the site teams to organically adopt the lean process, plan using LPS and problem solve using VSM.

In short, each of the approaches was sort of incomplete without the other although independently, they were valuable. That leads to our proposed two-pronged approach. The approach is for both of the above to be done in tandem – have site teams learn the lean tools, LPS, VSM and build capability and capacity from the bottom up and in parallel, have top management drive initiatives for change and improvement after having realized the potential of lean and lean tools. This combined strategy, as shown in Figure 3, will have the desired effect of changing the way projects are being managed from the conventional approach to a more lean enabled production based approach. Now, the people at all levels would able to appreciate and talk in the same language and terminology of lean.

The project review mechanism/conversations would then change and metrics measured would not be conventional metrics of cost, but also lean metrics like production. The monthly or even the weekly review meetings should involve discussions on look ahead constraint analysis that is more a forward-looking problem (and delay) avoidance approach rather than monitoring delays (and pegging delays to external and internal stakeholders). Healthier discussions are possible around intervention techniques based on

PPC metrics. In a sense, the whole discussion has shifted from a negative spiral of delay analysis based on lag indicators to problem avoidance based on lead indicators.

That leaves the information technology solutions used to manage the project information. In this new environment, technology should be the enabler for the transformation of an organization into a lean organization. It has to work in this new environment of proactive information exchange, open collaboration across business functions, and measure KPIs and metrics driven by lean metrics. In short, it has to complement the lean process. This would justify the adoption of tools including 3D modelling, integration of disparate information sources like finance and auditing (ERP) systems, scheduling systems, document management systems, and building information modelling (BIM) authoring tools. The technology and process together will complement to make an approach for integrated project controls driven with on a base built on lean culture making the whole organizational strategy a holistic one.

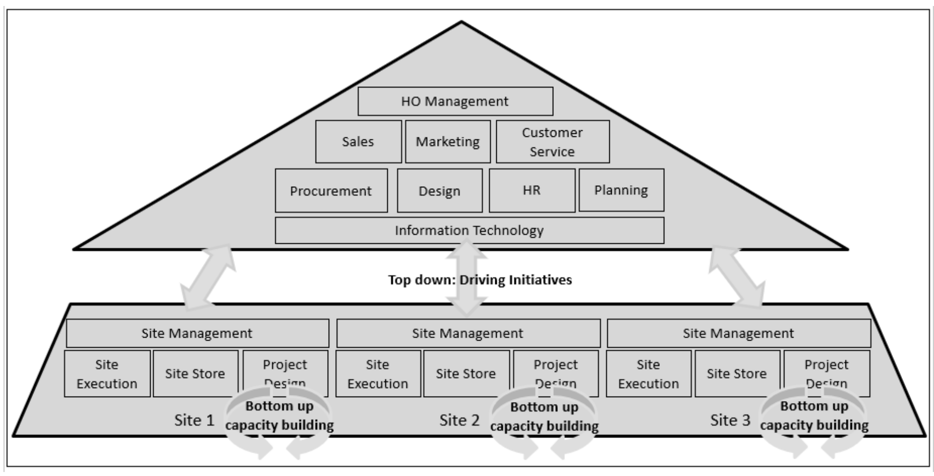

Figure 3: Lean Transformation Strategy

DISCUSSION

The authors feel that further work is required to measure the effectiveness of the transformation through organization qualitative and quantitative KPIs. Indicative ideas are metrics like employee satisfaction, business profitability, resilience to changing market dynamics etc. And a lean transformation maturity model that can be measurable should be arrived at.

There have been references and discussions about the requirement of a framework for an organizational lean transformation in literature. For instance, (Leonova, Ballard and Gehbauer, 2017) has discussed about industry transformation and has outlined strategies and an approach to lean transformation of the construction industry. (Nesensohn 2017), proposed a Lean Construction Maturity Model to benchmark the lean maturity of any organization. But they do not provide a practical approach on how to achieve the transformation. The authors here, based on their experience and benefits that customers have realized, propose a simple and practical approach for an organization to adopt in its journey to lean transformation. The approach needs validation and further development and refinement, something that the authors hope to engage in with their next assignments and report on in the future.

CONCLUSION

An approach has been shown that organizations can adopt as a strategy to bring lean transformation to their organizations. The approach consists of building capability in the teams from the bottoms up that is complemented by having management drive continuous improvements from the top down. Each approach complements the other and together they help migrate the organization from its current state to a leaner organization that drives continuous improvement. Over time, this would build a culture of lean in the organization. The approach is practical and simple. It is prescriptive, yet adaptive to various organizations. The approach is generic enough for adoption both with Owners and Contractors. The authors are planning to apply the framework in future client engagements in the near future and will report on their learnings and findings in the near future.

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A LEAN APPROACH TO IMPROVE PRODUCTIVITY IN A COKE OVEN REFURBISHMENT PROJECT: A CASE STUDY

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ABSTRACT

This paper presents a 3-phased Lean Construction Project (LCP) implemented in a specialized and integrated service company. The purpose of the LCP was to increase productivity and to re-structure Production Planning and Control routines. It was undertaken by a group of internal and external consultants for a period of four months of workshops and more four months of sustainability on-site. The construction project focused by the LCP was the refurbishment of a Coke Oven in a Brazilian Steel Mill.

The three workshops regarding the Lean Construction background were: (a) Analysing the construction activities and support process (Planning, Contract Management, Supply, Warehouse, Safety); (b) Redesigning Production Planning and Control tools, routines and responsibilities; and defining a new Work plan schedule regarding takt-time; and (c) a Productivity Workshop implemented through wastes identification, activities reorganization and work provision. For all these workshops, a work group was formed covering consultants, managers, engineers, team-leaders and front-line workers. Finally, the workshop results were assessed through comparison of the productivity indicators with the base-line defined in the Analysis Stage.

After the LCP, the project achieved its main objective with the walls assembly productivity improvement by 20%. This result was reached with fewer people performing more efficiently (less time). Moreover, the operational efficiency improvement guaranteed a 46% increase in the gross margin of the contract.

KEYWORDS

Production Planning and Control, Productivity, Lean Construction

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INTRODUCTION

At a time of great political and economic instability in Brazil, service and transformation industries, to ensure returns on their investments, more and more require their suppliers to be positioned competitively. Companies which provide construction, maintenance and mechanical assembly services, in order to guarantee revenue and a minimum profitability for the business without adversely affecting the product quality that is delivered to the customer, inevitably seek a trade-off that includes ways to cut costs.

More than ever, strategies to redesign the production chain, to analyse internal and operational processes, and to seek alternatives and opportunities to produce in an increasingly efficient way are objectives of organizations that seek to sustain themselves and grow in the market (Sage et al. 2012).In this background the current case study was developed in a company which provides repair, construction and industrial maintenance services, which in this article is called Company A, with market focused on the transformation industry (steel and petrochemicals). Since 2013, Company A has been investing in implementing tools and concepts towards a Lean culture in its projects and throughout the organization as its improvement approach

Given this macroeconomic and organizational context, this article presents a case study developed in one of Company A's projects. The construction contract, focus of this paper, concerns a Lean Construction Project (LCP) to increase productivity in a refurbishment of coke oven in a Brazilian Steel Mill. To do so, the paper was divided into a general objective and specific objectives:

The general objective of the study was to increase the operational efficiency of the coke oven refurbishment case study by increasing its productivity. To achieve the general objective, three specific objectives were proposed: (a) To catch the delay in the first phase (step 1) of the construction project; (b) To structure the contract planning process by drawing up long-and medium-term plans using the takt time; (c) To implement a system for managing the routines and production control considering takt time and the Last Planner methodology; (d) To balance and stabilize refractory assemblage by making use of improvement initiatives.

For reasons of contractual secrecy, the actual numbers of employees, costs and real profit margin will not be presented. All results will be presented in a percentage rate.

The paper presents the methodological stages of Lean implementation, the tools used, the results obtained and the transition to sustain the routines and the obtained results. Thus, the structure of this article is as follows: After this introduction, Chapter 2 describes Company A and the project. Chapter 3 sets out the theoretical basis for the project while Chapter 4 introduces the methodology and tools used. Chapter 5 presents the results and Chapter 6 draws some conclusions, and points out some limitations and suggestions for further study which are expressed as challenges to tackle sustainability.

PROJECT AND COMPANY A DESCRIPTION

Company A was founded in 1986 and have been integrated with its current German parent company in December 2014, provides customizable integrated services for several industrial segments, including Refractory, Thermal Insulation, Anticorrosion Protection, Passive Protection, Access, Electromechanical, Construction, Facilities Services, Operation and Maintenance of Energy Assets, as well as Offshore services such as maintenance, interior outfitting, crane operation and cargo handling.

In a scenario of high operational complexity and technical requirements of low predictability, the Lean Initiative was proposed for optimizing resources in works for refurbishing a coke oven in an integrated steel mill in Brazil. The hot repair of a coke plant is a strategic project for steel mills. First of all, this is because provides the carbon component that steel is produced with, and because the coke oven is critical to the Mills energy balance. The scope of the contract foresees the hot repair of 253 combustion chambers of the steel plant. The contract was implemented over 6 phases, called “steps”. The scope of the repair comprises, in a simplified form: (a) removing the metal structure, (b) demolishing existing walls to their floor, (c) evaluating the quality of the refractory floor, and (d) constructing new walls to the top, a stage that is called refractory assembly. The service is conducted under conditions of high temperature and the presence of harmful gases. Due to these critical conditions, the front-line workers act under a regime of relay labour shifts, which must meet Brazilian labour regulations. This relay, in its best hypothesis, occurs at a rate of 30 minutes on and 30 minutes off. Therefore, the present contract has always dimensioned and considered that at least double the number of workers are needed to staff this activity.

BACKGROUND

The approach proposed by Company A as the focus of its process improvement program is called the Lean Journey. Its methodological foundation stems from the fundamental concepts of Lean Production (Shingo, 1988, 1989), Womack and Jones (1990), Spear and Bowen (1999) and Liker (2004). Synchronizing the production activities, reducing stocks, reducing set-up cycle time and having quality assurance are addressed by Shingo (Shingo, 1988, 1989). Later, Womack and Jones (1990), Spear and Bowen (1999), Liker (2004) re-assessed Lean Production principles and prioritized the focus on value for customer, as well as improving the ideas of flow, quality and wastes reduction. Later, Company A, also incorporates concepts that are derived from Lean Production and contextualized within Construction. Since 1992, it has been called Lean Construction (Koskela, 1992).

From the joint analysis of this theoretical evolution, Company A based its Lean approach on 4 fundamental principles: (a) Flow; (b) Takt time (rhythm); (c) Pull; (d) zero failure. Thus, the principle of (a) flow relates the work crew dimensioning, connecting them in accordance with a logical sequence of activities. The activities are, then, classified in accordance its responsibilities and information’s inputs and outputs. The principle of (b) takt defines that Takt time is the unit of time within which a product must be produced in order to match the rate at which that product is needed (Hopp and

Spearman, 2008). Takt time is seen as a target definition for work structuring to design the production system for continuous promptly to flow (Frandson et al., 2015; Frandson et al., 2013). In accordance with the takt, it is expected to define the size of the teams, resources and inputs (Frandson, et al. 2013).The principle of (c) Pull is a fundamental pillar of Lean Production (Shingo, 1998), in which stocks are eliminated and production is defined to serve the customer at the speed (takt) he wishes. And, finally the principle of (d) Zero Failure is established; which also refers to another pillar of Lean Production (Womack and Jones, 1990) which comes from the underlying principle of Total Quality Control, which seeks to standardize and stabilize processes. Among those four principles, the Last Planner System (Ballard, 2000) will be implemented for Planning Process and the concepts of wastes defined by Ohno (1988), will be considered in the Productivity Workshop.

METHODOLOGY

The project developed in company A, in partnership with a consulting firm, was a group of workshops which were held over a period of twelve weeks. These were divided between (a) Analysis, (b) Production Planning and (c) Productivity. After these four months, Company A kept the Lean Project running under internal management for more four months focused on keep the improvements on track. Figure 1 illustrate the LCP Work plan.

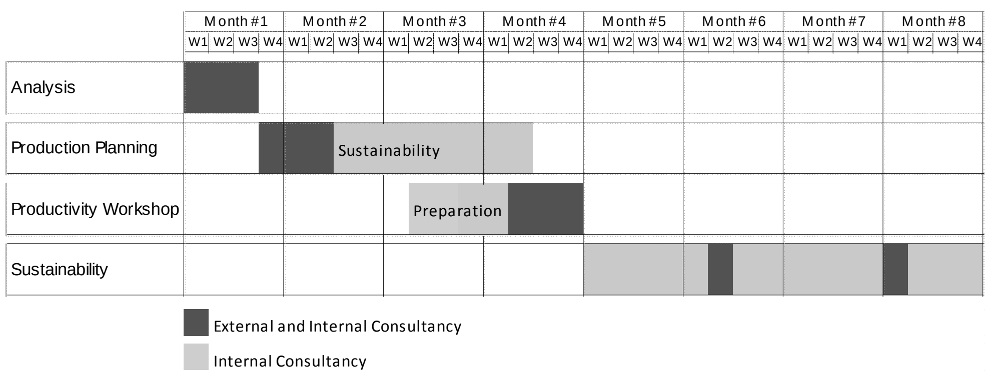

Figure 1: LCP Work plan

ANALYSIS

The start of any project is defined as being when project staff become familiar with the company’s productive and support processes (planning, supplies, engineering, and so forth); get to know the project leadership team; and analyse the company´s current performance. Thus, the first three weeks of work in the Construction Project, were defined as having this objective.

The Analysis of the project makes use of the following tools:

- Overall Process Analysis (OPA): a step in which the value chain is observed and the whole project team defines sources of problems, rework, or neglected step.

- Gemba and waste analysis: the 7 losses defined by Ohno (1988) (Overproduction, Defects Products, Movement, Over processing, Inventory, Waiting and Motion) are used as references. In order to identify these wastes and their impacts, the following tools are used: (a) Waste Walk, which consists of observing and finding evidence of the aforementioned losses; (b) Multi Moment Analysis, a count of people who add value or for some of the types of the seven losses, an analysis of several consecutive intervals of time; (c) Chrono-analysis, which consists of an unbroken period of filming over a long period (minimum of 4 hours) to observe the level of value added in complete cycles of activities.
- Semi-structured interviews with leaders: conduce interviews with the team leaders and understand from their perspective the project, its problems and opportunities.
- Performance and financial indicators analysis: They support the zero line of the Lean project and support the understanding of how performance and how the project results are presented to the Company Board.

The complete analysis allowed the consultants to understand the project. The baseline was defined by the contract managers in the very beginning of the refurbishment mobilization considering planning, budget and profit margin. Since the beginning of the first refurbishment step (Step 1), Company A recognized problems that should be controlled for the success of the contract.

The closure of the analysis stage consists of presenting the material developed to the project Board of Directors define a Work plan Workshops and an action plan can be implemented rapidly and which may have a high impact also emerge. These include: controlling overtime, resizing of night-shift teams, reviewing required capacity for hoisting equipment and because of its managerial characteristics will not be detailed in this paper.

PRODUCTION PLANNING

Koskela (2000) discussed the importance of TFV (Transformation, Flow and Value) concepts in construction, in which he argues that the aspect of flow is often forgotten in traditional production management models. The author realizes that this aspect can also be applied to the flow of information, which directly affects the flow of resources and has a fundamental role in integrating lean into production management (Dave et al., 2010, Sacks et al., 2010).

With the objective of restoring the flow of information, to continue to take this information to the field crew, to control production and ensure the takt time (Company A Second Principle), the planning workshop was divided into three sub-stages: (a) Mapping of the planning process, defining the responsibility matrix and work schedule of the office team; (b) Review of the production strategy and takt needed of each step of the project; (c) implementing Last Planner for daily field management (at every shift) with the team involved on production.

Mapping of the Planning Process

For this stage, a Workshop was designed with the planning team. It began with mapping the Planning process including all activities that were carried and those that had some standardization problems and activities that are not implemented in the routine of the sector.

Next, the responsibility matrix was dimensioned considering the activities that each member addresses. Thus, a working agenda for the team was defined, including decision-making meetings that should be taking in accordance with other members, like the monthly schedule, for example. For the activities which presented problems, corrective actions were defined and for those not implemented, tools and internal control standards were developed, as will be detailed in item 4.2.3 regarding to short-term planning and control. Figure 2a illustrates the Workshop of mapping the planning process.

Production Strategy – takt time

At the start of the project, the internal team defined a work plan and sized a standard team to carry out each modality considering the productivity defined in the budget (historic data from previous projects of coke oven refurbishment conducted by Company A). The results from the first step due to internal inefficiencies and difficulties of the client's own releases were of low productivity (7% over the budget). For the continuity of the project Company A defined the necessity of improving productivity and reduce costs.

A change to improve productivity necessarily undergoes review of the entire production process. Thus, in the Planning Workshop, the flow (sequence) of activity and takt time at which they are carried out was put under review in rounds of work with the Planning and Production teams (Mechanical and Civil team). Frandson et al. (2015) concludes that takt time deals with visual workplace to make clear to all (on and off site), who is doing the work, where, and in which pace in order to distribute control.

The methodology used sought in this Workshop to define the sequence of activities, their maximum duration in accordance with the target defined by the client and define the size of the front-line labours to reach the necessary takt time. The Production Strategy also sought to identify restrictions that could compromise the takt time (on materials, labour, equipment or the in the design). Figure 2b illustrates the outcome of the study.

Figure 2a: Planning Workshop

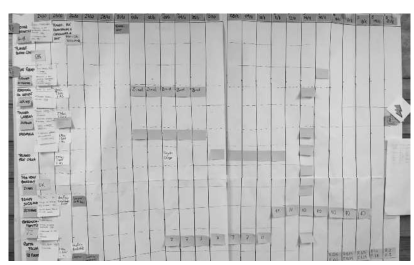

Figure 2b: Planning Step 2

Figure 2c: Meetings to control targets when shifts change

Production Management

One of the main inefficiencies of planning was the delay to have the right information in the necessary time. The activities developed were monitored and deviations were controlled but these were done by greatly detaching of time from production. In order to contain this inefficiency and to help the work to maintain the pace set for reaching the deadline, a simple system was proposed based on the Last Planner System (Howell and Ballard, 2007). The goal was to define production activities, the person responsible and the deadline for completing each of this small amount of work. At the changeovers of shift (7:00 a.m. and 5:00 p.m.), a meeting was conducted by the planning team along with foremen and engineers, the quality and safety responsible. At this quick meeting, the conduct of each activity was reviewed, the cause of the deviations was controlled and the activities for the start of the next shift were reviewed. Figure 2c illustrates an example of the meetings for controlling production targets. Thus, successively, at each shift, the entire leadership team had full information about the progress of the activities its problems and the action plan needed to keep the takt.

PRODUCTIVITY

This chapter consists of the stage when the fundamental tools of Lean Production are most applied. The Productivity Workshop is divided into 7 standardized phases consisting of (a) Team training; (b) Initial survey of the data; (c) Analysis of the Current Process (Mapping the Value Stream); (d) Defining and Prioritizing Solutions; (e) Implementing Improvements; (f) Verifying Improvements; and (g) Standardizing the Process. All these phases are conducted with the coordination and operational team (managers and technicians) of the activity focused on and the change is implemented in a short period. In this case, the Workshop was made conducted in three weeks and the work changes were applied during the next constructions steps. The productivity improvement will be measured considering the rate of total front-line workers hours spend to assemble 1 ton of refractory brick-wall. This is described as man hour per ton (mh/ton)

Thus, we defined the work team for the Workshop, involving 2 managers and three bricklayers, a coordinator engineer, and a production and planning manager. They were trained on matters that address the concepts of rhythm, flow, pulled production and zero failure, and to identify and recognize the seven wastes in production. In parallel, the consultants collected current production data, such as the plan of attack, the number of people involved, the productivity achieved, and interruptions in the production process.

In the third step of the work, the following activities were mapped: the construction process; its support activities and conditions of supplies and providing the production fronts with materials, equipment and labour. Therefore, by using the methodology of OPA, that consist of a tool which was adapted from Value Stream Mapping (VSM) (Rother and Shook, 2000) for the Lean projects in Company A. What distinguishes OPA from the classic VSM is that, at this initial moment, the teams and productivity indexes for each step are not quantified. In the design and construction of OPA, the focus is to understand the sequence of activities and, from the outset, to prompt the project team to identify failures and wastes.

After the process has been mapped, the Workshop team engages on field-work in order to identify and quantify failures and wastes. The team is split up so as to cover some formats of analysis that include: Identifying the seven wastes; a spaghetti diagram; a multi-moment analysis for periods of at least one hour of observation. The consultants are responsible for recording the chrono-analysis so as, later, to quantify the wastes. Usually the simplest forms of analysis (identifying wastes and the spaghetti diagram) are intended for members with a lower level of formal education.

After making the observations in the Project Analysis step and the field observations, the wastes and the number of people involved in each step of the activity are quantified and the Operator Balance Chart (OBC) of the current state is defined. Subsequently, using the contractual deadlines, the period of net production is calculated, and consequently, what rate of production must be followed in order to reach the contractual milestones. Thus, at the end of the third stage of the Workshop, we have the map of the current state of the refractory assembly process, the OBC in this current state and the takt time needed to reach the delivery dates of the project.

Therefore, the fourth step of the workshop consists of defining an Action Plan to implement improvements in the productivity of the service front of the refractory assembly focused on achieve takt time. Thus, actions of change in the sizing of the teams, the attack plan, tools and devices used in running and systems that supply service fronts were implemented. Actions are prioritized after an analysis is made of the potential improvement v the financial effort made by the management and coordinators of the work. In the fifth step of the Workshop, these actions are implemented and monitored. The standardization of the Process, as the seventh step of the Predicted Workshop occurred at the end of the work, in which Company A started to incorporate the improvements achieved.

RESULTS

The results of the Lean Project implemented by Company A in partnership with the Consulting Company were achieved after the four stages outlined in chapter 4. Table 1presents the main results obtained. From the analysis stage, the main results are the Project deep understanding. Quantifying inefficiencies showed that 59% of activities do not add value in the refractory wall assembly, for example: (a) were identified the waste of 23% in the shift due the temperature during the wall assemblage (average of seven minutes in each shift change of 30 minutes); (b) errors on bricks transportation and delivery to the oven assemblage caused a large amount of waiting time of labours inside the oven; (c) lack of proper transport devices made labours walk until seven times to transport bricks on hand. Another important indicator was identified verifying the planning routines that showed that only 27% of the standards set are really used for the Planning and Control, for example, long time to have field information (problems and daily production), week plans were done only by planning members; lack of feedbacks on planning review.

The Planning Workshop has the characteristic of being a structuring Workshop, as it encourages a reorganization of activities, tools and control standards, besides defining and implementing indicators and acting on the team's motivation. Throughout the project (about 6 months after the Workshop period), the team reached 93% of the standards for Project Planning and Control (previously was 27%). The average PPC reaches 80% of planned activities. For this Workshop, the qualitative gains are of great importance. Daily takt time control meetings and production targets were kept with a focus on controlling production deviations and taking actions to solve problems.

Table 1: Results Summary

Workshop	Qualitative Results	Quantitative Results
Analysis	Full analysis of the contract status; Opportunity survey to reduce costs in the order of 60% of the contract margin; Identification of planning gaps and planning routines not implemented Office-field communication failure → absence of indicators	59% of front-line production activities do not add value Only 27% of the predefined activities of the Planning standards were met
Production Planning	Definition of responsibilities matrix and schedule of production planning and control Implementation of Last Planner and control of deviations at each change of shift with the holding of quick response meetings Definition and implementation of operational and managerial indicators	93% of the predefined activities of the planning standards were met; Average PPC of 80% over the project follow-up year Reduction of staff by detailing the production strategy for each new production step → 6% reduction in each new step
Productivity Workshop	Definition of production takt and scaling of resources to achieve it (OBC) Review of the plans of attack and change of the conception of work performance on site Development of tools and devices that help the activities of production and inspection of activities Paced supply and Quality inspections of the fronts according to takt	Reduction of direct labor to each phase (step) Step 3 - reduction of 42% mh/ ton Step 2 - reduction of 37% mh/ ton Step 6 - reduction of 7% mh/ ton 20% increase in overall contract productivity Global increase in gross margin of 46%

The delay described in the chapter 4.2.2 in the Step 1 was recovered; the activities and teams were sized to take account of takt time and the routines for managing goals acted to guarantee this pace. Overall, the general objective was met. The sustained new tools and productivity control guarantee reduction of 42% in mh/ton compared with the predicted rate (mh/ton) in the project budget for Step 3; reduction of 37% in mh/ton and 7% in mh/ton in Step 2 and Step 6 respectively. Comparing those results with the problematic Step 1, the Company A performed with an addition of 7% in mh/ton compared to the same predicted budget. The overall productivity was increased by 20%, when compared to the estimated budget; and, the operational efficiency guaranteed an increase of 46% in the gross margin of the contract. To reach these results, otherwise the takt time control and deviations action plans, some operational improvements approaches were made: redesign of the assemblage strategy detailing the number of layers each labour should do in each step; implementing simple tools to assure quality during the assemblage; logistics preparation in the right sequence of brick assemblage; labour change, due the temperature, with stronger control.

CONCLUSIONS: CHALLENGES AND SUSTAINABILITY

The project presented led to good results for the Company A and to reviewing the internal procedures for planning work. A recurring challenge to Lean projects is resistance to change. We can consider that the case study described was successful in this aspect, because it succeeded in helping the team to internalize changes and to guarantee their motivation in constantly seeking continuous improvement. It is recommended that the planning and takt time control routines that have been incorporated into the present case be passed on to other the Company A projects, while always considering the alternatives of flexibility in the different contract models. In addition, it should motivate identifying companies that manage to balance the impact of an external presence such as consultancies in order to catalyse and ensure change under internal leaders of Lean Construction Projects.

ACKNOWLEDGEMENTS

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PROJECT DELIVERY THROUGH LEAN PRINCIPLES ACROSS ALL DISCIPLNES OF CONSTRUCTION IN A DEVELOPING COUNTRY ENVIRONMENT

Kaezad Karanjawala[1], Diamond Baretto[2]

ABSTRACT

Construction Industry has to counter many challenges and research studies have indicated that large projects across various asset classes typically take longer to finish than scheduled and tend to overshoot the budgeted cost. Improving labour productivity in all trades of construction has been found to be very challenging as compared to the manufacturing industry due to migrant labour, low skills and lower penetration of technology and mechanisation at the work sites. The high percentage of wastes generated in construction projects also puts tremendous pressure on natural and human resources.

In order to mitigate the above-mentioned challenges and risks and to improve our way of working, an organization embarked on the Lean journey starting with its Residential Towers using Partnering and other Lean principles for multiple stakeholder management across all our projects.

Also, to make the planning process predictable and create commitment based culture the organization amalgamated Lean into Critical Path Method by creating a Milestone Schedule given by the Top management. The Phase Schedule is derived from the Milestone Schedule and further broken down for weekly tracking into Look Ahead Plans (LAP). The LAP is prepared by field teams and is reviewed using Last Planner Meetings (LPS) and other lean tools and methodologies.

This paper portrays an organisation's Lean journey from residential to industrial projects using case studies with key learnings to explain how the success of Lean implementation is possible only when there is a cultural change brought among all the project stakeholders to strengthen team spirit and drive improvement initiatives with strong support from the Top Management. A focussed approach and imbibing the cultural changes in the organisation help to overcome all the barriers faced in the Lean Journey.

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KEYWORDS

Lean construction, collaboration, value stream, Last Planner, customer delight

INTRODUCTION

Timely delivery of the project plays a very crucial part in the survival and business performance of any organization. The organizations' rationale for implementation of Lean Construction and its various tools and techniques was with the intent of improving the cost, quality, and time and safety metrics for a project while ensuring that customer commitments are met.

According to a study by Bhim Singh - Lean implementation and its benefits to production industry- year 2010) in the production sector it is possible to quantify benefits of Lean implementation by using tool of Value Stream mapping and the operator efficiency increased by approximately 40% along with reduction in other parameters like in lead time (83.14 percent), processing time (12.62 percent), work□in□process inventory (89.47 percent), and manpower requirement (30 percent).

B Singh, SK Sharma (Measuring Business Excellence, 2009) also explains how Value Stream Mapping (VSM) is helpful in lean implementation and to develop the road map to tackle improvement areas to bridge the gap between the existing state and the proposed state of a manufacturing firm.

The organization in its nascent phase of Lean implementation had to face many barriers and a comparison between our findings after implementation across 4 projects with the study for typical barrier identification by Jagdish R. Jadhav ,Shankar S. Mantha Santosh B. Rane (Exploring barriers in lean implementation- Dec 2014) and also reinforces and reiterates that the success of lean implementation will not be entirely based on application of appropriate tools and techniques alone but also on the top managements' involvement and leadership, workers' attitude, resources and the organizational culture. Saja Albliwi (in the year 2014) has also explored the critical failure factors for Lean Six Sigma in different sectors, and indicated certain common factors for failure, such as a lack of top management commitment and involvement, lack of communication, lack of training and education, limited resources and others.

The "lean" approach eliminating non-value activities from work processes by applying a robust set of performance change tools and emphasizing excellence in operations to deliver superior customer service—has become legendary in improving manufacturing companies' operations and profitability states Max Allway, Stephen Corbett (Shifting to lean service: Stealing a page from manufacturers' playbooks- Feb 2002)

Hence, it is evident from past research done on Lean construction that it aids successful completion of projects and Lean tools help identify and reduce wastes. This paper uses case studies with key learnings to elaborate an organisations Lean journey and the main contribution is to help new lean practitioners in developing countries such as India to execute projects successfully using Lean.

THE LEAN STORY IN A LEADING CONSTRUCTION ORGANIZATION

CASE STUDY 1 - CONSTRUCTION OF RESIDENTIAL PROJECT, MUMBAI (LEAN OBJECTIVE - BENEFITS OF PARTNERING IN LEAN PHILOSOPHY)

The organization began by embarking on the Lean Journey way back in 2011 with Institute for Lean Construction Excellence (ILCE) for guidance to drive partnering using the Lean Philosophy of Collaboration with our vendors in the Project. It conducted a Workshop / Partners Meet with all its vendors and the Top Management which involved Team building games, Sharing of Project related experiences by vendors & Painting competition with Lean Construction Theme.

The focus at this preliminary stage was on gaining trust by increasing transparency with stakeholders necessary for creating a firmer foundation for implementing Lean Construction. The project was at the finishing stage in which handover to customers was scheduled in the next three months. Involving contractors and sub-contractors and changing the methodology from independent team schedules to a schedule based on the work flow methodology for the project. By doing this, handover the flats on time by improving the flow of work on site using tools such as Weekly work plans, visual control of processes and team meetings. However, since Lean was applied at the finishing stage of the project, substantial benefits could not be achieved.

CASE STUDY 2 - CONSTRUCTION OF INDUSTRIAL PLANT, AMBERNATH (LEAN OBJECTIVE – PARTNERING FOR INDUSTRIAL PROJECT)

Based on the early learnings in concluding phase of the organizations residential project, it was decided to improve certain aspects of applying Lean Partnership Philosophy at its next project for the organisations Business Unit (2012). A workshop was conducted to evolve an appropriate Project Charter by involving all concerned stakeholders to get their commitment to deliver project on time and within the budget. The project was named "Project Delight". It captured the following key objectives of all stakeholders Safety first, Positive Attitude, Team Spirit – Have Fun, Effective communication, Proactive approach, Care for Environment and Society and Profit for all.

KEY LEARNINGS FROM CASE STUDY 1 AND 2

In these two projects, the organization was partly successful in implementing its Lean plan. While it did achieve marginal savings in time and cost, it could not completely align all our partners towards the common cause. Despite the good efforts put in by many of the stakeholders, some issues were not effectively resolved on time due to the trust deficit that is commonly observed in many construction projects. However, these early learnings were useful in implementing Lean more effectively in the organisations subsequent projects.

CASE STUDY 3 - CONSTRUCTION OF HIGH RISE TOWERS, MUMBAI

(LEAN OBJECTIVE – IMPROVING PROJECT PERFORMANCE BY CONSTRAINT MANAGEMENT)

Having gained a better understanding of certain Lean principles, the organization was now ready to deploy a few Lean tools on our next project - Construction of Tower B1 and B2 (FY 13-14) from the early construction stage of the project.

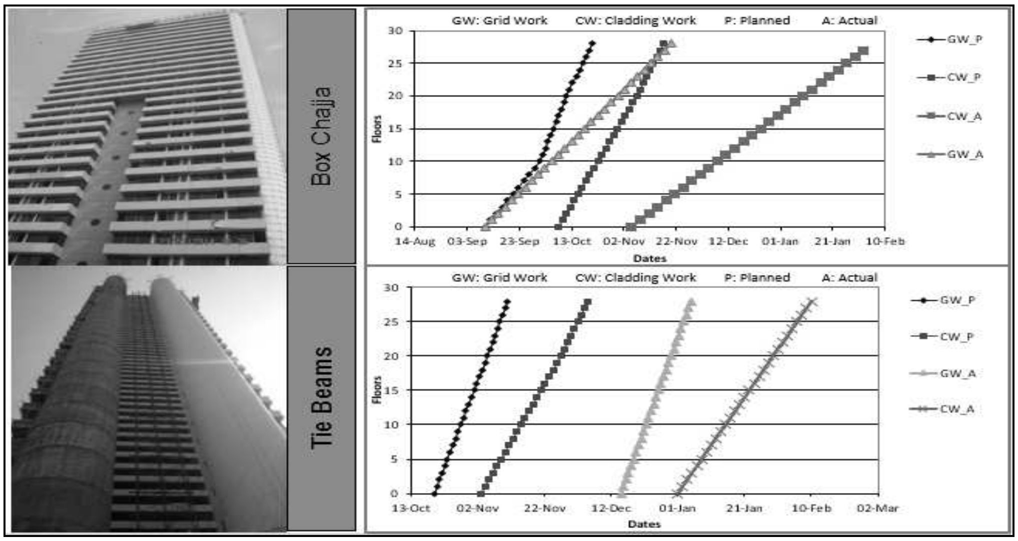

Figure 1: VSM for CSAS Cladding for Visual Tracking

Lean tools such as Last Planner System, Work Sampling, Value stream mapping, etc. were applied across various trades for effective conflict resolution and reduction of the non-value-added activities.

The following are some examples on how Lean tools were implemented on this project:

VALUE STREAM MAPPING (VSM)

Pre-Fabricated Coated Solid Aluminium Sheets (CSAS) was being used for the first time by the organisation as a Façade system for our residential building project. We were aware that this a long lead activity and was critical to timely completion of the project. Therefore, we decided to implement VSM as a Lean tool to plan, monitor and control this work package more effectively.

The organisation engaged all our concerned stakeholders including the Façade Engineering Consultant, Façade Construction Contractor, the concerned Project Engineering Team members and the Safety Engineers to help map the entire process in the Current State right from material sourcing to installation at site. This helped to design and optimize the Future State more effectively. The Non-value steps and constraints were identified and eliminated, thus reducing the turnaround time for this critical work package.

LOCATION BASED PLANNING SYSTEM (LBPS)

Along with the earlier mentioned VSM, LBPS was also adopted for effectively completing the CSAS façade work package as per the planned schedule. Deviation in planned v/s. actual for Grid framework and subsequent cladding work which were closely monitored by LBPS. The graphical representation of activity progress of Façade work helped Project Management team to review the progress at a macro level. The mapping of actual productivity against the plan over a longer period helped in planning the subsequent Towers more effectively.

WASTE MINIMIZATION

The organization being a Green Certified Building, waste management initiatives were effectively planned for and deployed during the Design and Construction phase. This included optimization of materials through effective design, segregation of waste at source, recycling and re-use of waste generated from the project.

LAST PLANNER SYSTEM (LPS)

The organization adopted LPS with various agencies at site and motivated workmen to deliver results. The entire Project Delivery to the customer was looked upon in a holistic manner by LPS using Last Planner with Weekly Plans, Look Ahead and Constraints Analysis for collaborative planning. This helped the organisation ensure timely handover to the customers as per the committed terms of the agreement.

The entire project team along with the Top Management participated in the Lean training and Implementation Program conducted by a leading educational institute and was awarded the 1st prize at the National for one of the project (residential) for Lean Implementation in the same year.

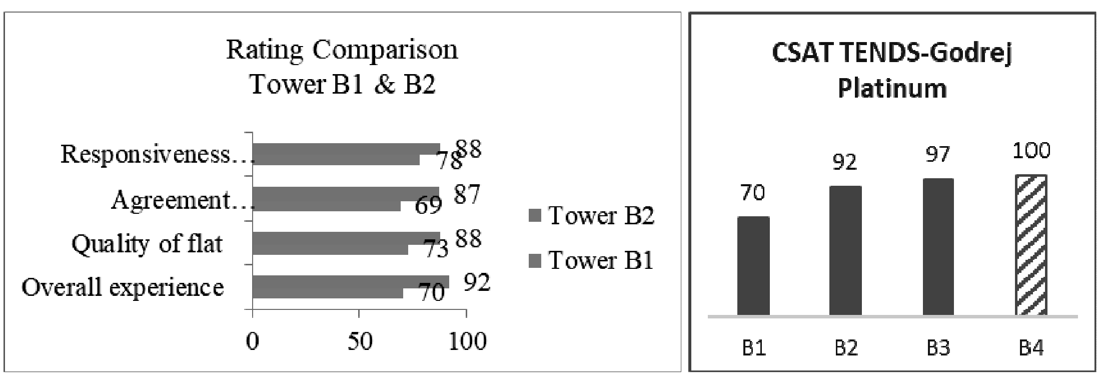

Figure 2: A Third-Party Feedback Report: Vulnerable share and Commitment share for A-type (GGE) and Tower B1 and B2

RESULTS & CUSTOMER VALIDATION

Implementation of Lean principles should ultimately lead to benefiting the customers. As part of its ongoing journey towards Business Excellence, the organization the engaged the services of leading Market Research agency for conducting a detailed third-party Customer Feedback Survey. The findings clearly showed significant improvements in several key parameters. While all the improvements in customer satisfaction ratings would not have been necessarily attributed to implementation of Lean principles alone, these results helped assure us that we were on the right path on our Lean Implementation Journey.

With continued focus on meeting customer commitments, the organisation could reduce the Vulnerable Share from 9% of the previous project to 4% over the last 7 years.

Also, the Commitment Share has improved from 83% to 87% over the same time as indicated in the adjoining graph.

KEY LEARNINGS

LEAN IMPLEMENTATION AT THE ORGANIZATIONS HIGH RISE TOWERS HELPED ACHIEVE:

Timely Project work Completion of Tower B1 & B2

- Improved Customer Feedback (As indicated in the chart above)
- No cost overruns. In fact, through better planning and coordination the cost of construction of Tower B2 was 4% lower than that earlier completed Tower B1.
- For LEED (Leadership in Energy and Environmental Design) certified building construction projects, the adoption of Lean principles is also helpful for waste minimization through effective waste segregation, recycling and reuse.
- Improved transparency with concerned stakeholders through team meetings for the Last Planner System.
- Improved morale of workmen, supervisors and project engineers by giving them a forum for sharing their requirements in advance and obtaining necessary support from the other team members for faster resolution of issues. Most of our project team members confirmed that adopting Lean principles helped reduce conflicts, which are often observed in fast track projects.

CASE STUDY 4 - CONSTRUCTION OF INDUSTRIAL PARK PROJECT, KHALAPUR

LEAN OBJECTIVE – BROADENING OUR SCOPE FOR LEAN IMPLEMENTATION – APPLICATION OF LEAN ON A SIGNIFICANTLY LARGER PROJECT WITH A MORE COMPREHENSIVE APPROACH, FROM DESIGN MANAGEMENT TO DELIVERY

The organization's Mega Project under the Maharashtra Industrial Policy 2013 is spread across more than 300 acres of land with an estimated built-up construction area of 3.3 million square feet.

Encouraged by the learnings, the organization decided to drive Lean to the next level from Design Management to Delivery for ensuring effective handling of multiple stakeholders' expectations. This was taken up with the strong support of Senior Management and able mentoring by a leading educational institute. At the beginning, it conducted a Lean Project Management Orientation workshop with various teams such as Design, Material & Contracts Procurement, HR, Planning & Delivery Assurance, MEP, Engineering teams for effective deployment of Lean. The biggest challenges in this project were multiple customers and the complexities in their requirements, Communication Management between multiple stakeholders, Frequent changes in design were requested by the customers.

To overcome these challenges, the organisation deployed Last Planner System which was highly useful for effective communication within the teams and it ensured decision making at right time by involving Senior Management. A project based Lean Organization structure was prepared comprising of Lean Mentor, Lean Champions, Lean Coordinator and Project Engineers.

The **Concept of Big Room Meetings** was introduced to Review Percentage Plan Complete (PPC), identify root causes and develop Corrective and Prevention Action (CAPA); Review Look Ahead Plans for constraint identification and their resolution, Unresolved issues which needed Senior Management intervention were taken up in another forum “Steering Committee” which comprised of Project head, Section Heads and functional Head who were actively involved in the project.

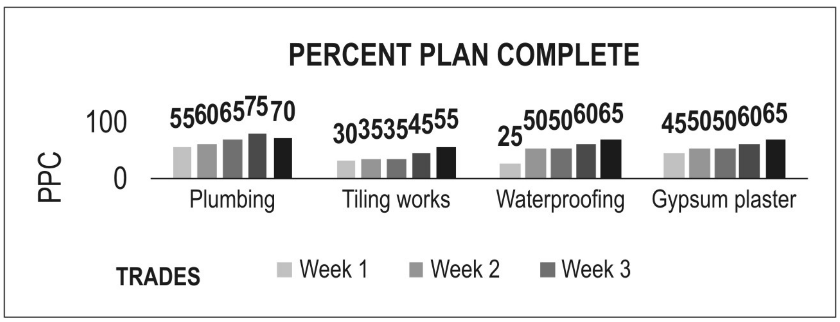

Figure 3: PPC Trends

The **Steering Committee** was formed to resolve issues which were put up by the teams working on the project which required senior level support and could not be resolved in Big Room meetings, resolve issues related to Contractual deviations in time and cost, To review impact on stakeholder commitments & Timely communication from Management to the Project teams. Results show poor development and linking between the master schedule, phase schedule, look ahead plan, and commitment/weekly work plan. Performance at the commitment level and PPC become loosely linked to overall project progress. This reduces the power of the Last Planner system to forecast and increases the team’s reactive approach to performing work activities especially under high uncertainty conditions. Research findings underline the deficiency in current planning systems mainly due to the lack of instructions and lack of application of standardized planning processes that clearly explain planning processes such as schedule development, feedback, responsibilities, and updates.

THE LPS CAN BE SUMMARIZED BELOW

Hence the organization decided to amalgamate PERT and CPM with LPS and derive a balanced planning system which gave the Top Management control over key milestones related to key customer deliverables while empowering various stakeholders in planning routine activities required for successful project delivery.

5S- 5 S Audit Report is indicative that it is easier to implement Sort and Set in Order, however Shine, Standardise and Sustain take a lot of time since each project is unique and time bound.

It also involves recurring training to contractor and having a dedicated 5S champion to drive the initiative.

Material storage with labelling

Figure 4 – Last Planner Schedule of a Week

Period / Description	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Agenda	➢ Individual team meeting ➢ Submission of PPC Sheet by afternoon	➢ Submission of LAP by afternoon	➢ Big Room Meeting	-	➢ Steering Committee Meeting	-
Purpose of meeting	➢ Review of root cause ➢ Corrective and preventive analysis	NA	➢ Review of PPC (Root Cause Analysis) ➢ Review of LAP (Resolve Constraints)	-	➢ Issues Related to Technical, Cost, ➢ Quality, Safety & Decision needed	-
Party Involved	➢ Engineering, Procurement Construction, MEP P&DA	➢ Engineering, Procurement Construction, MEP P&DA	➢ Engineering, Procurement Construction, MEP & P&DA	-	➢ Steering Committee & party who seek decision	-
Remarks	➢ Meeting for PPC to be done by Individual team	➢ To be done for Rolling 4 Weeks ➢ Lap to capture cross functional constraints	-	-	➢ P&DA to Facilitate PPC to be maintained by P&DA	-
Output from meeting	➢ Root causes analysis	➢ Constraints interfacing	➢ Unresolved issues as agenda for steering committee	-	➢ Unresolved issues to be discussed with top management	-

NOTE : Submission of PPC & LAP by lean Champion at Site & HO

Figure 5: Photographs of a 5s stacking at Site

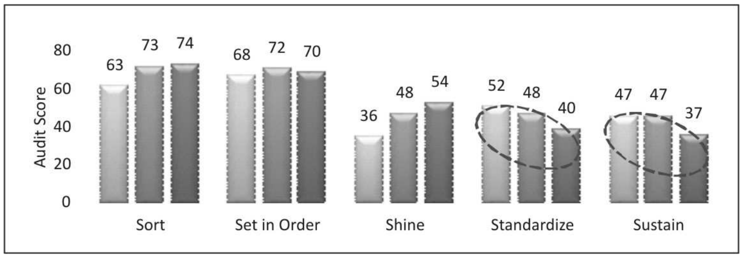

Figure 6: The 5S trends across 3 months post implementation

KEY LEARNINGS

The organization witnessed improvements in Communication and Collaboration Management by implementing LPS on the project. Almost all the stakeholders have expressed that LPS has helped them to resolve their constraints early and get the work done as per the schedule milestones. 5S at site has given tremendous advantage in maintain good housekeeping standards. (refer Fig 5)

The main learning at the project is that if designers imbibe the Lean philosophy, larger benefits can be reaped such as lesser design iterations which will not only help the Project execution team to complete their deliverables but also helps Procurement and Contracts team to complete the Tendering and Contract award process faster.

SOME OTHER INITIATIVES: - VENDORS MEET

The organization's Contracts & Procurement Team conducted a Vendors' Meet to realign them to our Vision, Mission and Values (VMV) and provide an enabling environment for becoming credible partners. Vendor Feedback was also sought to identify focus areas for improvement and initiatives to address these were taken up. (refer fig 7)

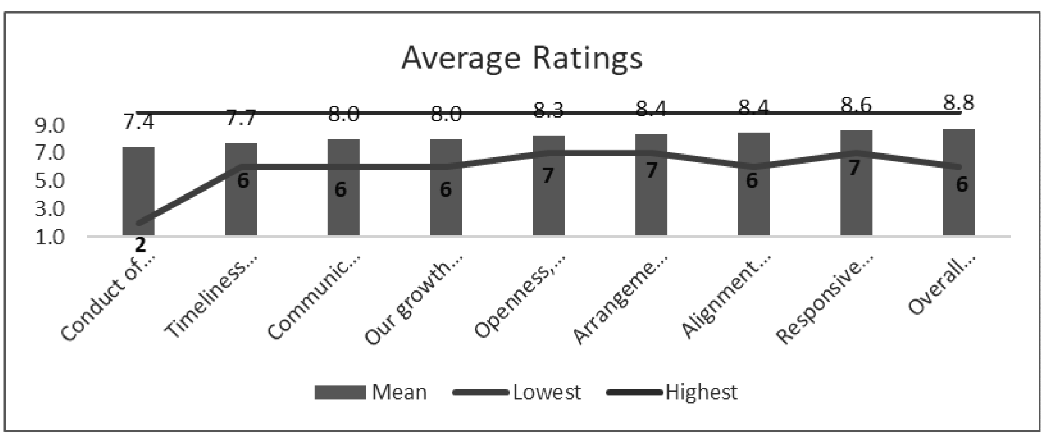

Figure 7: Vendor Feedback Ratings indicating good performance

CONCLUSION

The implementation of Lean Construction has helped in successful execution and commissioning of our projects by:

PARTNERING

- Creation of better relationships with our stakeholders (Case study 1 & 2)
- Identification of constraints and non-value adding activities (Case study 3)
- Trust & Transparency (Case study 3 & 4)
- Open communication (Case study 1, 2, 3 & 4)

RESOURCE OPTIMIZATION

- Waste minimization & 5S implementation (Case study 3 & 4)
- Smooth process flow for efficient project delivery (Case study 4)
- Better monitoring and controlling using "pull" mechanism (Case study 3 & 4)
- Early flag off to arrest the potential delays (Case study 3 & 4)
- Enhanced safety using technology (Case study 4)

BARRIERS IN THE ORGANIZATIONS LEAN JOURNEY

Lean is perceived as an additional exercise to existing work assignments, tendency of project team members to focus on Lean tools rather than effective deploying Lean philosophy. Lean Tools are only enablers in effective implementation of the Lean philosophy, Project teams expect the benefits of Lean to be seen immediately.
Moreover, the success of Lean Construction is not very evident and easy to quantify into measurable units. Also, since most organisations have improvement initiatives running parallel to Lean implementation, the benefits of Lean may not be attributed with certainty to Lean alone.

ROAD MAP FOR FUTURE STRENGTHENING OF LEAN CULTURE:

Lean is not something complex it can be summarized as a philosophy to drive continuous improvement with customer focus by doing three things right - eliminating waste, simplifying everything and creating a flow. In the future, the organisation plans to further strengthen the Lean Culture in our business operations through the following initiatives:

1) Implementing Lean in Conceptual Design stage of the project
2) Quarterly Lean Newsletters.
3) Improving the Productivity of Operations at Construction sites by Lean Principles
4) Reduction of Customer Complaints by 33%
5) Improving Efficiency at all Sites.
6) Creating a Lean Culture in the organization through Human Resources Trainings.

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SHORT TAKT TIME IN CONSTRUCTION – A PRACTICAL STUDY

Marco Binninger[1], Janosch Dlouhy[2], Mathias Müller[3], Marco Schattmann[4] and Shervin Haghsheno[5]

ABSTRACT

Takt Planning and Takt Control (TPTC), as a method of Lean Construction, has been developed over years and has increasing applications in construction practice over the last years. The collective understanding is that this method can only be implemented when there is a high level of repetition in the structure of a building project and in fact it is frequently used in such kind of projects.

A case study shows how this method was implemented on a construction site with no obvious repetition in the structure. Takt Time was reduced to a level of one hour and the single room construction site was split into small areas. A high collaborative approach of the TPTC was used. The completion time was reduced from over ten days to three days.

This paper documents the steps of the implementation, the integration of the team and subcontractors and also compares the typical approach before the optimization with the results after the Takt Time integration.

KEYWORDS

Takt Time Reduction, Takt Planning, Takt Control

INTRODUCTION

Construction projects are often characterized by long durations, being unique one-offs and having many participants. In many projects the long duration is not a significant factor as the client only expects completion by the date agreed in the contract and has made other operational arrangements for the period up to this date. However, in projects where temporary solutions are being used until the new building is completed offer significantly worse conditions, or if completion is urgent for other reasons, then project duration becomes a focus. In extreme cases, the construction process may even cause the client's operations to come to a standstill. This is especially the case for retail clients where every day of shutdown causes significant losses in turnover.

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This situation applies in the case study of this paper, which deals with a concrete situation where the effects of the methods of Takt Planning and Takt Control on the duration of a project are investigated. In this example the lever for reducing project duration is Takt Time. Through incremental steps and short-cycled repetitions project duration can be reduced while process quality is significantly increased.

DEFINITION AND FOUNDATIONS

RESEARCH QUESTION

The method is often used if there is an obvious repetition in the project. One purpose of the research was to figure out if the use of TPTC is possible for projects with non-obvious repetition in the projects. Based on this idea the paper will answer the following research question:

a) Is it possible to apply this method in projects with non-obvious repetition?

The freedom in finding and defining the repetition leads to wide latitude in setting the Takt Area and Takt Time. The paper shows a comparison of different variations, the benefits and the effects induced to the project lead-time. The second research question is:

b) What is the impact of varying Takt Times on project lead-time?

RESEARCH METHOD AND STRUCTURE OF THE PAPER

Takt Planning as a method of Lean Construction is already applied in some projects worldwide e.g. Finland, Norway or Brazil. Especially in the German market there is a strong community using this method in practice. The methods used when introducing Takt are described in many publications within the community of the IGLC (Binninger et al. 2017; Dlouhy et al. 2016; Frandson et al. 2013; Haghsheno et al. 2016; Linnik & Berghede 2013; Vatne & Drevland 2016; Yassine et al. 2014). Planning and Control according to a standardized unit of time - the Takt Time - is a unique aspect of this method.

There are many advantages to this method in comparison to traditional time planning. For example, Takt Planning allows work to be completed at a consistent rate and allows reliable pre-planning of activities. Additionally, the Takt Plan can be built upon a mathematical-algorithmic approach and can be easily adapted with few changes to the basic parameters. For example, the construction time has a direct relation with the number of Takt Areas, Takt Time and the process sequence (waggons) shown in the following formula. Takt Time is based on the Standard Space Unit (SSU), the manpower and the performance factor. If there is only a single room construction site with no architectural and structural limits, like in the following example, the basic parameters can be varied and optimization of the project duration is possible.

In the case of retail fit-outs time plays a critical role. Using a mathematical-algorithmic approach to build up a Takt Plan, the construction timeline can be optimized to allow earlier handover to the client. Based on this idea, the use of Takt Planning will be applied to retail fit-outs in order to be investigated and optimized.

The method described in this paper is oriented toward the 12 steps described by Binninger et al. (2017).

This paper considers a real case study. In the following section the starting point and as-is situation will be described. In the body of the paper, execution of the project using Takt Planning will be described together with various options for construction time optimization. In the final part of this paper, one option is selected and applied to the case study. The implementation of the method and its effects will be described in full.

SHORT TAKT TIME

The method of TPTC supports the construction process, reduces waste and thereby increases productivity (Vatne & Drevland 2016, 173). Construction duration can also be shortened actively. Friedrich et al. (2013, 50). name an example of a project with a reduced construction duration of 20%. A case study by Frandson et al. (2013, 534) achieved completion in five months rather than the usual eleven by using Takt Planning. This is a time saving of 55%.

The construction time of takted projects can be calculated using the following formula (Nezval 1960, 42):

$$Construction\ time\ = (No.\ Takt\ Areas + No.\ Waggons - 1)\ x\ Takt\ Time$$

Therefore, construction time depends on the number of Takt Areas, Waggons and Takt Time. The number of waggons is strongly depending on the process and product. This parameter is only lightly influenced in the case study of this paper and does not play a significant role. Where the amount of labor (number of employees) is constant, the Takt Time and size of Takt Areas are directly related. The size of a Takt Area also determines the number of Takt Areas. Therefore, in the approach stated below the Takt Time is reduced by reducing the Takt Area size. Through reducing the size of Takt Areas, their number is increased. In the formula above, the Takt Time has a significantly higher effect on construction time than the number of Takt Areas or waggons.

In practice, varying Takt Times are used. Kaiser (2013, 113) names a two-day takt as the minimum Takt Time able to be used in the construction industries when taking all constraints into account. In practice a Takt Time of one week is frequently used. This is also reflected in the experiences of the authors of this paper, who have documented approximately 80 construction projects where Takt Planning was used. Of these approximately 75% used a Takt Time of one week. In contrast an example of Heinonen and Seppänen (2016) describes a Takt Time of 15 minutes. This example shows that under very specific circumstances a short Takt Time can be achieved. This idea cannot be directly applied to building projects without changing the classical approach and traditional frame conditions.

Subdivision of spaces is one way of showing the effects and interrelationships between different Takt Area sizes and Takt Time durations. The retail areas are located in a large space that due to a lack of load-bearing walls can be reconfigured as desired. Through subdivision the choice of SSU is simplified. Firstly, the biggest possible Takt Area and its required Takt Time is determined. Following this the Takt Areas and Takt Time are successively reduced until a Takt Time of 15 minutes is reached. In the view of the authors, a shorter Takt Time is difficult to execute and therefore not recommended for this case. The maximum possible size of a Takt Area is the entire retail area as this is also the entire working area.

Due to the short project duration and limited project scope in the case of renovating retail spaces, a weekly Takt is not practicable. A more reasonable assumption for an effective Takt Time is one day or less. Based on the research of the authors a construction with such a short Takt Time is not recorded in any IGLC paper and common literature. This paper will, however, show that it is possible to plan construction projects with a Takt Time of significantly less than one week.

THE REAL CASE STUDY PROJECT

PROJECT DESCRIPTION

The real case study is from a middle size general construction company in the south of Germany. The concepts and the results of the study are part of a master thesis. The as-is situation of the current state of the project was derived from interviews, site-observations and reviewing the project documentation. In the as-is situation, every trade has been allocated a window of time of one to three days to complete their works (or work steps) on a retail fit-out project. The works for painting, drywall and flooring are allocated a combined five-day block and not described or divided in any greater detail. Figure 1 shows the planned construction sequence of the as-is situation. This is a standard construction plan set by the client.

day	**-**	**0**	**1**	**2**	**3**	**4**
activity 1	last opening day	Dismantling of the shelfs	Dismantling Electric	Painting the ceiling	Painter, Dry Wall, Floor	
activity 2			Rest works Dismantling of the shelfs			
delivery/ extra work		Container Metall		Container Mixed Things	Delivery Floor	

day	**5**	**6**	**7**	**8**	**9**	**10**
activity 1	Painter, Dry Wall, Floor			Electrical works		
activity 2	Sanitary	Sanitary		Advertisement		Cleaning
delivery/ extra work				Delivery Pay Desk and Light	Delivery Interior	

Figure 1: Construction plan of the as-is situation

Where additional works are required for a special project such as assembling drywall, additional working days will be added. In addition, electrical works must also be executed. Three days are planned for these works. In the sales area LED strips are to be fixed to the ceiling and connected to the distribution boxes. However, in the electrician's opinion, three to four workers would not need more than one day for these works.

Advertising works occur at the same time as electrical works, and has been allocated two days. The works include, for example, applying adhesive foils and signage to the shop front. Two workers were on-site for these works. Final cleaning of the retail area on the last day of electrical works completes the fit-out project. Altogether, this sequence results in a total of ten working days.

In the case of supplementary works, the fit-out duration is increased in accordance with the additional works required. The additional five working days for removing and replacing stock were not accounted in the ten days. The reason for this is that these works are completed by the client and not awarded to a contractor. However, this process still has the potential for shorting the project duration and causing the handover date to be earlier.

Apart from the sequencing of works, observation of the project also led to the following wastes being determined:

- Sometimes individual subcontractors set up their own intermediate storage areas. These were later hindrances to other subcontractors.
- Shelves and palettes with the shop's products were left in the space and had to be relocated many times. This causes additional transport and waiting time
- Materials were delivered by the retailer. These were not delivered at optimal times in relation to the construction sequences and caused waiting times
- There was almost no coordination between the subcontractors and this meant that they frequently hindered one another.

APPROACHED USED IN THE PROJECT

The first step was analysis of the as-is situation as described above. The main part of the as-is analysis was, on-site observations over a week-long period as well as a visit to the client and client representative.

The result was the analysis of a process by describing sequence of working steps and dependencies between them.

Additionally, the space was divided into lots during the phase of Takt Planning. Multiple options were carried out and conclusions regarding the optimal Takt Time were drawn. Theoretical calculation and estimation were carried out through multiple calibrations and adjustments by the project team. Practical work packages were devised and the Trains were established. The result was a Takt Plan that served as the basis of coordinating with subcontractors. In multiple cases the Takt Plan was adjusted and discussed with the client. Where the project duration is so short, there must be a strong focus sequence of works to ensure deliveries were organized JIT (Just in time).

The goal of this approach was to create a basic construction sequence that could be applied to other projects and individually adjusted as needed.

DEVELOPMENT OF THE TAKT PLAN

Using the as-is situation as observed results in a Takt Time of one day. This suits the actual duration of some work packages (for example dismounting electrical fixtures and fixing lights). Figure 2 shows execution of the works when using a Takt Time of one day. A working day of eight hours is assumed.

Takt Area	hole selling area
# Waggons	7
Takt Time	1 day
Fertigstellungszeit:	7 Tage

Tag 1	**Tag 2**	**Tag 3**	**Tag 4**	**Tag 5**	**Tag 6**	**Tag 7**

Waggon	**Work Packages**
1	Dismantling Electric
1	Dsmantling other things
2	Painting Preparation
2	PaintingDoors, Income Area
3	Painting walls, ceiling
4	Floor 1
~~5~~	~~Drying time~~
6	Floor 2
7	Electric
8	Advertisement
8	Cleaning

Figure 2: Takt Plan with a Takt Time of one day and the entire sales area as a single Takt Area (option 1)

For option 1, the waggon allocated for drying time is eliminated as the drying for the waggon 'Flooring 1' can occur overnight. This results in a completion time of seven working days for seven waggons.

For the following considerations, it was assumed that the 'train length' would remain as eight waggons. In the table below the Takt Time was halved in each step with the Takt Time being adapted accordingly. In the sixth step a Takt Time of 15 minutes is reached with size of each Takt Area (TA) being 1/32 of the retail area. In this instance the flooring subcontractor has 15 minutes to lay each 10 m^2 of flooring for a space of 320 m^2. If the tasks are tightly interlinked, this results in a theoretical finish time of less than 10 h.

Table 1: Dividing into lots in the case of a constant amount of waggons

#	Takt Time [h]	Size TA (based on 1))	# TA	# Waggons	# Waggons incl. empty Waggons	Through-put Time [h]	Finish Time [h]	Time Improve-ment [%]
1)	8	1	1	8	8	64	64	-
2)	4	½	2	8	9	32	36	44
3)	2	¼	4	8	11	16	22	39
4)	1	1/8	8	8	15	8	15	32
5)	0,5	1/16	16	8	23	4	11,5	23
6)	0,25	1/32	32	8	39	2	9,75	15

This theoretical example shows the effect of reducing the size of lots. However, in the case of practical applications specific room conditions must be adhered to meaning that the train length of eight waggons is not implementable in practice. The drying time of eight hours is a constant, and if the Takt Time is reduced, the number of waggons will increase. Due to the drying time of eight hours remaining constant, the amount of time saved in each step is less significant than the number of waggons staying constant. The results are shown in table 2.

Table 2: Overview of the Takt Area reduction steps

#	Takt Time [h]	Size TA (compared to 1))	# TA	# Waggons	# Waggons incl. empty Waggons	Through-put Time [h]	Finish Time [h]	Time Improve-ment [%]
1)	8	1	1	7	7	-	56	-
2)	4	½	2	7-8	9	-	36	36
3)	2	¼	4	11	14	22	28	22
4)	1	1/8	8	15	22	15	22	21
5)	0,5	1/16	16	23	38	11,5	19	14
6)	0,25	1/32	32	39	70	9,75	17,5	8

Reducing lot size results in five steps in total (see table 2). Compared to Step 1 the completion time is reduced by 69% to 17.5 hours. Figure 3 makes clear the significant impact of the drying time (red waggons) for the plasterer. This timeframe occupies a large part of the train and the surface area of the Takt Plan. This is the applicable size for calculating the duration of fit-out works for a Takt Time of 15 minutes.

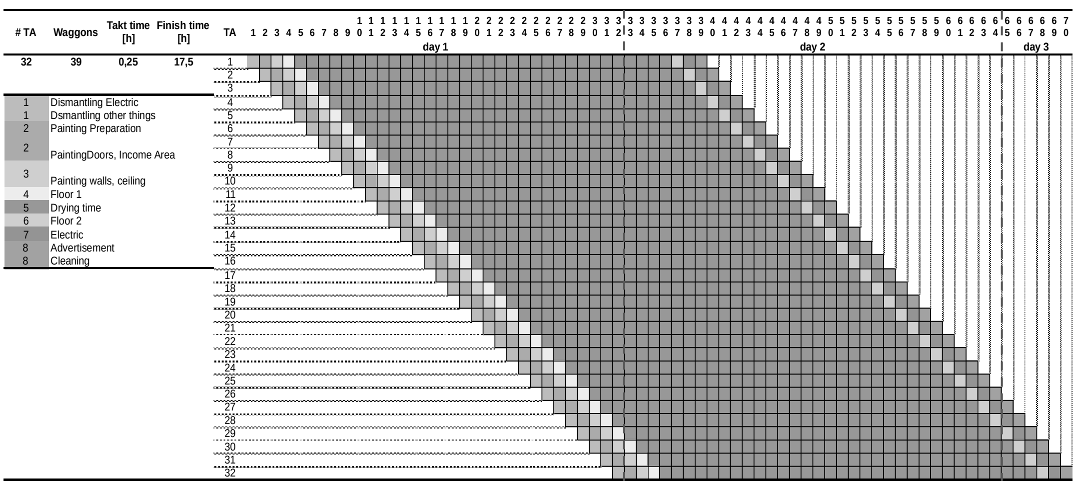

Figure 3: Takt Plan with a Tatk Time of 15 minutes and a Takt Area of 1/32 of the total area (option 6)

The size of a Takt Area is determined according to the Takt Time. Deciding a Takt Time is according to the example of lot size reduction. This showed that the length of the Takt Time has a significant effect on Takt Planning. Determining the Takt Time is based on the eight-hour working day. This leaves a buffer for increasing the working day length to nine or ten hours. A shorter Takt Time leads to a reduction in the duration of construction process. The effect relatively decreases from option 1 to option 6 because the drying time plays an important role. In this example it applies especially for a Takt Time between 15 and 30 minutes. The Takt Plan for a Takt Time of one hour is shown in

Figure 4 as an example. With 19 waggons and 12 Takt Areas the completion time is 30 hours. This is approximately four working days.

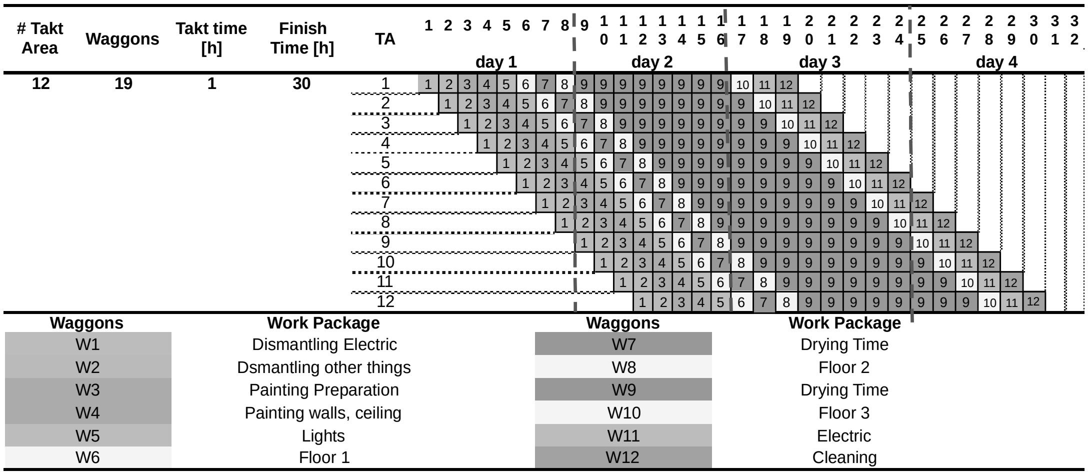

Figure 4: Takt Plan with a Takt Time of one hour and 12 Takt Areas

EXECUTION

A Takt Time of one hour was selected for the example project. Using such a short Takt Time means there are more short-cycled quality control inspections, the completion time is shorter and the learning curve is steeper for all participants. The contractors can move between the waggons allocated to them, and thereby use time saved on the waggons completed ahead of schedule to support any waggons behind schedule. The contractor was not willing to risk an even shorter Takt Time in the first project in which it was trialled. This was in conjunction with the idea to hold short meetings at the end of every Takt Time to discuss improvements to the process. In theory the project variables can be scaled up and down without any limits. In practice the Takt Areas must be sized and allocated so as to fit with the geometry of the building. The project in this case was divided into the following Takt Areas:

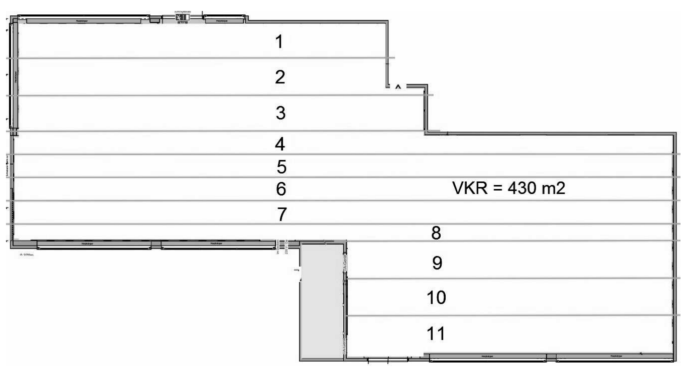

Figure 5: Division of the project into Takt Areas

The subcontractors were introduced to the project, and the test began in December 2016. The construction manager and foremen set aside three days to intensively supervise and document the project. The following pictures give an impression of how the project unfolded.

Figure 6: Takt Plan with Post-Its (left side) and impression of the construction site (right side)

The left-hand side of the figure represents the information board used during meetings. The right-hand picture shows a tightly integrated project sequence and its allocation into linear Takt Areas.

RESULTS

The results achieved have matched the predicted three-day duration of construction. Hereby the pilot project was able to achieve a 70% reduction in construction duration. This is however, not the only effect. At first the subcontractors were very critical of the new method of execution. During contract negotiations some subcontractors expressed concerns that their own effectiveness would be compromised by such a tightly integrated construction sequence. The construction manager also voiced concerns. The manager accepted the risk and promised the subcontractors full payment over three days even if they did not have any work for parts of these days. This message and the participation and active involvement of the manager gave the project an added level of importance as well as a clear signal to the subcontractors. By the end of the first day all participants understood that this construction site worked in a different way to usual construction sites and a small competition emerged. The subcontractors were surprised how seamlessly the project was run and were pleased that their Takt Area was free from other subcontractors.

The learning curve was also very steep. Due to an unsealed flat roof construction the sequence of the Takt Areas had to be significantly rearranged shortly after construction began. This change was incorporated very quickly and without problems. The Takt Plan helped with the adjustment and enabled greater transparency. During the course of the first day the construction manager had to make frequent interventions. This required a high level of management effort, as the construction sequence was new to the subcontractors. They worked in an uncoordinated way and thereby overestimated their working capacity. At the beginning of the project the level of understanding for waste was very low, and there was little improvement over the three days. One reason for the overestimation was that the workers achieved 100% of the required work despite constant interruptions from phone calls and additional coordination effort.

In summary, it could be determined that in the pilot project the using Takt Planning enabled a significant reduction in construction duration. Through close supervision and comprehensive documentation additional potential was uncovered.

CONCLUSION AND OUTLOOK

The paper shows an outstanding practical example of TPTC under project conditions, which were apparently not perfectly suitable for takted projects. The project in the case study had obviously non-repetition, because there was only one single room. The case study shows that it was possible to find repetitions, if the process, time and space are divided detailed enough (research question a).

A Takt Time reduction has a highly positive impact of the project duration (research question b). But the scalability is limited due to the increasing impact of drying times.

The company Heinrich Schmid must be highly commended whose management was a driving force in this project. The positive effects of the pilot project is due to a higher amount of preparation work which must be optimized in future projects

The uncovered potential must also be developed further as this would allow the construction phases to be even more tightly integrated. The first half of the sales areas could be handed over in half of the previous total construction time. The retailers can thereby set up their shops significantly earlier than the previous case. Alternatively, this can be integrated into the Takt Plan used by the client to significantly reduce the amount of time needed for finishing the circulation areas.

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REAPING THE REWARDS OF PRODUCTION TRACKING

John Cleary[1], Anthony Munoz[2]

ABSTRACT

Traditionally, project controls translate to “monitoring results.” In a *true* lean project, it is redefined as *“making things happen,” with a measured and improved planning process to assure reliable workflow and predictable project outcomes* (Lean Construction Institute). By monitoring productivity, a Project Team can more effectively identify and respond to “hot topics” that may hinder flow and predictability. The consistent communication of this information provides the transparency needed for decentralized decision-making, empowering the Project Team to take action and maximize value.

Through an Integrated Form of Agreement on a Southern California healthcare project, self-performing Constructors tracked and reported productivity. This information was used to provide *real-time* updates to schedule, production planning, and budget forecasting. These metrics were compared to the original rates, serving as key performance indicators. Underperforming critical activities would be earmarked to conduct a Deming Cycle for improvement. Activities with high measures would be assessed to identify factors contributing to their success or if the baseline was ill defined. Ultimately, this information was used for Continuous Improvement with a goal of reducing overall schedule in productivity improvements, reducing overall budget by way of production savings, and contributing to and maintaining a positive work environment.

KEYWORDS

1) production planning, controls 2) Integrated Form of Agreement 3) job-sequencing 4) target cost 5) team morale

INTRODUCTION

This industry paper observes an Integrated Form of Agreement (IFOA) project on which weekly productivity tracking and reporting were utilized to influence delivery, design, construction, and Team morale. The objective is to share what benefits this Project Team gained from Constructors tracking and reporting actual production rates of work-in-place to all Integrated Project Delivery (IPD) Partners throughout the life of a construction project.

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BACKGROUND

This study is within the field of construction project management where the critical success factors of scheduling, budget and team morale are analysed, specifically the influence productivity tracking and reporting and its corroboration to overall project success.

Studies have shown that time wasted during construction is attributable to poor management practices. Fischer et al. (2017) provides that successful production planning can only be accomplished when the Production Management Team understands the scope and pace of work necessary to achieve the defined milestone goals. A production schedule must represent real capabilities under real-world conditions, utilizing a rapid feedback loop to incorporate what is being learned from ongoing work. The Team must also be able to review progress and quickly determine if production, safety, and quality objectives are being met. This is the role of productivity metrics.

This submission aims to identify the benefits of productivity tracking, reporting, and metrics as it pertains to schedule, budget, and Team morale.

METHODOLOGY

The content of this industry paper is the product of its authors' experiences through action learning. Action learning is a means of development that requires responsible subject involvement in some real and complex problem, to achieve intended improvement (Revans, 1982: 626-627). This concept is based on the premise that learning emanates from reflection followed by action to solve real problems (McGill and Beaty, 1995) where reflection and discussion occur in small groups.

ACTION LEARNING –AUTHORS' EXPERIENCE

The Temecula Valley Hospital Imaging Project is a 28,000sf first floor expansion providing facilities for a hybrid operating room, a biplane angiography room, 2 cath labs, 7 PACU bays, 7 pre/post bays, 1 CT scanner, waiting area, community room, OPS/bulk storage, 3 operating rooms, and shelled space for one additional imaging room. The project was built as an Office of State Health Planning and Developing (OSHPD) 1 under the 2013 California Building Code.

The Owner, Universal Health Services (UHS), identified and selected IPD Partners utilizing a Choosing By Advantages (CBA) methodology. UHS has been a pioneer of employing this delivery method in Southern California and throughout the United States, citing its inherent promotion of collaboration and incentive based Target Value Design (TVD). Partners for this project included the Architect, Structural Engineer, Electrical Engineer, Civil Engineer, Mechanical/Plumbing Engineer, General Contractor, Concrete/Framing/Drywall Contractor, Electrical Contractor, Mechanical/Plumbing Contractor, and the Owner.

Each of these Partners placed their respective profit pools at-risk and were additionally incentivized with an enhanced profit pool if the Project was completed and satisfied several performance criteria. Of these criteria, completing the project 4 weeks ahead of the original contract schedule represented 50% of the available enhanced profit pool. As such, the Project Team prioritized value engineering and improvement suggestions to meet this objective resulting in a greater attention, analyzation, and utilization of production planning.

In this Case Study, the problem/objective goal was to optimize schedule to satisfy the performance criteria which represented 50% of the available enhanced profit pool, requiring completion of the project 4 weeks ahead of the original contract schedule. The Project Team prioritized value engineering and improvement suggestions to meet this objective resulting in a greater attention, analyzation, and utilization of production planning.

The remainder of this section will address how production was benchmarked, tracked, analysed and reported, specifically by the Framing/Drywall Contractor. It should be noted that the Electrical and Mechanical Contractors used similar methods and analytics but are not being represented herein.

DIGITAL PRODUCTION TRACKING

Digital Production Control is a software based program that was used to create baseline metrics using the original estimated take-off of systems, units, and quantities. When a particular system is selected, percent complete and the associated work breakdown structure along with committed costs are also provided. Each week, responsible Team members, such as superintendents, foreman, project managers, or project engineers, would log work in place by actual measured units or percent complete. Figure 1 provides an example of Digital Production Tracking. As shown in Figure 1, work in progress is denoted by the red highlighting.

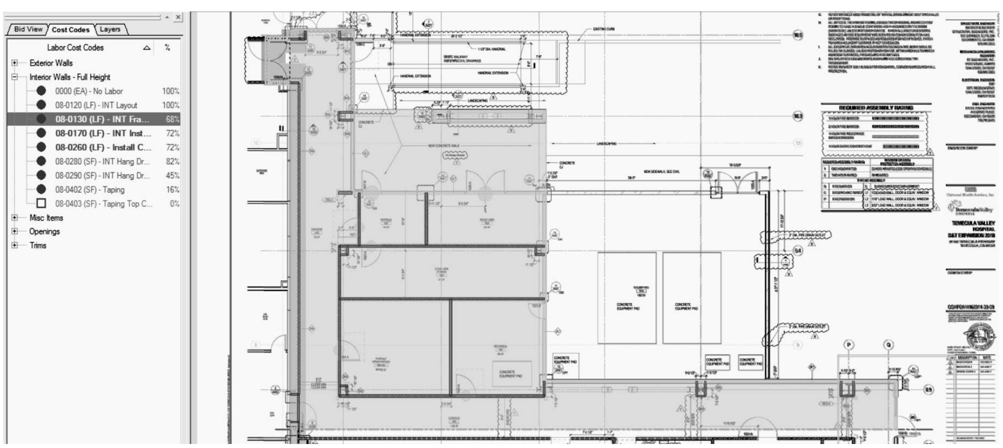

Figure 1: Digital Production Control Screenshot on12/15/2017

REPORTING PRODUCTION

Using a project management or data collection software, in this case CMiC, quantities of work in place were logged on the Friday of the week they were actualized. Labor Transaction Reports, which tabulate and summarize labor hours expended on each cost code, were also processedeach Friday and by the Tuesday of the following week, a production report could be gathered and presented to the Project Team.

Figure 2 provides an excerpt from a Production Tracking Sheet used by the Framing/Drywall Contractor. Production rates are represented by the quotient of quantity complete over man hours expended on the respective cost code. This rate was then compared to the originally budgeted rate. A macro was created to determine the quantities remaining and projected hours to complete based on the actualized production rates as of the data date. The difference in budgeted vs actualized rates were represented as Projected Variance. Collectively, this information provided a high-level barometer of activity efficiency. These reports were presented to the entire Team during weekly Big Roomand addressed as needed.

	Budgeted				Current Job to								Projected
	Quantity		Hours		Thru Week Ending			% Complete		Projected	Remaining		Variance
Phase Description	Budget	U	Budget	Rate	Quantity	Hour	Rate	Quantity	Hours	Hours	Quantity	Hours	= (-Over
INT Layout	4,791	lf	256	18.7	4,424	152	29.1	92%	59%	165	367	13	91
Int Frame Walls	3,609	lf	2,815	1.3	3,123	1,535	2	87%	55%	1,782	486	247	1,033
INT Beam Stickers	1,019	ea	112	9.1	990	84	11.8	97%	75%	86	29	2	26
INT Top Track/Plate/Bolts	4,200	lf	680	6.2	3,621	364	9.9	86%	54%	422	579	58	258

Figure 2: Partial Drywall Production Report run 12/05/2017

RESULTS AND BENEFITS

IMPROVEMENTS IN DESIGN

The project experienced multiple instances in which production tracking and the consequential reporting resulted in design changes throughout each of the stages of the project. While "rework," in this instance redesign, is one of the eight deadly wastes, the Team more critically valued Deming's philosophy of plan-do-check-act for continuous improvement, employing in its most immediate applications. Ultimately, this compromise was made in the investment for a greater overall value to the project.

A specific example of this involved the framing design/detail for top track installation. The original design called for a heavy gauge track which was to be screw anchored into the corrugated metal decking above with fire protection stuffing in the void between the decking and the top track, as required. The budgeted production rate was 6.2 linear feet of track to be installed per man hour. The installation of this detail proved to be a challenge for the installing carpenters. Using production tracking, an actual rate of 4.9 linear feet of track per man hour was recorded. Not only did the over-the-head material handling and effort to install the screw anchors prove to be inefficient, but it also proved to be unsafe. This decline in production was immediately reported to the Big Room.

The Team identified this matter as a "hot topic" and swarmed the issued. Following this effort, a more efficient, more safe, and still code compliant detail utilizing shot pins in lieu of screw anchors was recommended and approved. That very day, the carpenters were installing per this revised detail. The final actualized production rate was calculated to be 9.9 linear feet per man hour. This exercise alone saved the Project Team upwards of two hundred and twenty hours, amounting to $18,307. This collaborative effort by the entire Project Team not only contributed to lowering the final PTC with cost savings, but also helped to improve the overall project schedule, allowing critical mechanical/electrical/plumbing overhead activities to start 6 days ahead of the original scheduled dates.

BUDGET ACCURACY

As illustrated in the provided example, productions savings can be substantial. When utilizing an IFOA/IPD delivery method, savings such as this contribute to funding the profit pool or even an enhanced profit pool, that is shared amongst the signing Partners. To the contrary, fluctuations in productivity could be the source of the greatest risks to a PTC. A 2013 research article from the Alexandra Engineering Journal, *Applying lean thinking in construction and performance improvement*, that the productivity of the construction industry worldwide has been declining over the past 40 years. (e.g., Aziz et al. 2013) The Lean Construction Institute (LCI), corroborates this study, citing that over 70% of construction projects are over budget and delivered late.

In order to effectively manage the PTC, budget, and schedule, a Project Team must constantly monitor primary contributors. By monitoring and reporting productivity tracking and resulting production rates, a team can create a key performance indicator (KPI) representing the collective of primary contributors as one. In the instance of the subject project, the Team utilized this KPI reading to adjust course such as to avoid greater impacts to both budget and schedule. Additionally, the regular reporting of overall PTC served as a second KPI for original estimates and budget. This information serves as a gauge for the need of immediate value consideration, if critically necessary, to maximize value at the project level as opposed to attempting to optimize every activity. If not critically important, this information would be used to inform estimating and budgeting endeavours for future improvements – i.e. continuous improvement.

MORALE

Collecting data on morale and team bonding can be challenging compared to quantifying the impacts on the previous two topics of budget and design. That being said, it is a testament to the team that productions rates increased as reports of production were released to the construction workers at a weekly production review meeting. These meetings were held onsite, during the middle of the week. There was lots of feedback early on in the process that the construction workers took these production rates very seriously and enjoyed being able to see the rates in which they were hitting. Workers were constantly asking questions about the rates, quantities and hours.

Construction workers weren't the only team members showing an interest in actualized production rates. On multiple occasions, design team members while doing job walks or on the phone asked about production rates. It was noticed that during design changes, the engineers and architects would call the trade partners and ask for their opinion on the most efficient way to design and install the change. This camaraderie helped build confidence in our builders and design in each other and created a sense of considerate for the craft.

By having these open levels of communication, not only was more attention spent on diving into the details of the project but also know the budget and scope including in all the line items. It is the team's belief that this lead to higher morale and pride amongst the workers and lead to eliminating rework on the project.

CONCLUSION

There are three main benefits of accurately tracking, analysing and reporting production rates throughout the life of a construction project. Design is optimized for improved efficiency and increased safety of the installing craft. Budget is accurately and timely being tracked, forecasted, reported and used as a KPI for overall project health. Morale is improved though camaraderie and a shared sense of pride amongst all levels of the Project Team – from inception through execution. Based on its actualization of these benefits, this Project Team recommends that all projects, IFOA/IPD or other, employ regular production tracking, monitoring and reporting for improved project health.

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VISUAL PLANNING FOR SUPPLY CHAIN MANAGEMENT OF PREFABRICATED COMPONENTS IN CONSTRUCTION

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ABSTRACT

One of the challenges in the supply chain management of prefabricated components is the communication gap between the jobsite and the fabrication shop to coordinate on the deliveries. The context is the supply chain of light gauge metal stud panels that are digitally fabricated using BIM and CNC Robots in the US construction industry. The solution implemented was a cloud-based ordering application. the superintendent in the field interface with the BIM of Metal Stud Panels on an iPad, sequences the panels in the order he/she wishes to install. The order placed by the superintendent is received by the fabrication shop, which then initiates the fabrication of the panel from the same BIM, in the same sequence using the CNC robots. Once fabricated, the panels are divided into batches and transported to the site for installation. This helps in prioritizing fabrication, assembly and shipping of panels as per the needs of various jobsites. The just-in-time fabrication and delivery enables lean workflow of construction material, and minimizes waste in over-production, transportation and inventory. The paper will focus on the process in detail and benefits from this approach.

KEYWORDS

flow, visual management, job sequencing, logistics, supply chain management.

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INTRODUCTION

Overall logistics management for engineer-to-order components is well managed by creating batches and defining sequence, the progress of fabrication and installation is tracked using tracking tools(Bataglin et al. 2017).The product centric approach defines the product life cycle. Activities from design phase, fabrication phase, assembly, shipping are tracked through the product(Dave et al. 2015). This paper focuses on sharing an insight into the issues in the current supply chain dynamics of prefabricated construction components (in this case, Light Gauge Metal Stud Panels) and an approach to solve those by the application of above mentioned principles.

In this case study, Building information model (BIM) enabled mobile application (iPad app)has been used as a primary mechanism for solving the issues. (Peñaloza et al. 2016) mention the guidelines such as aligning production and installation plans, achieving real-demand from site by using 4D BIM tools, helps in reducing the wait time for installation.

The issues addressed in this paper, in the context of supply chain dynamics, are demand variability, material re-handling, coordination challenges with other trades, inefficient planning and design change creep into the submittal/shop drawings and procurement phase thereby either reducing the lead time for fabrication or wastage.

Changes to the construction schedule area challenge for fabricators. It is important that the subcontractors and fabricators efficiently create and update the installation and fabrication plan throughout the process(Viana et al. 2015).This paper shares a methodology on how timely planning helps to achieve a better production control as production logistics is based on real time demand and feedback from site.The context of this paper is a factory of prefabricated metal stud panels that ships these components to construction projects. Installation of these prefabricated panels takes four times less time than manual installation. This paper presents the challenges that the factory is facing due to varying demand and communication inefficiencies from construction jobsites.

DETAILS OFFACTORY

The factory is operated by a specialty contractor and manufacturing firm that fabricate sand installs metal stud panels. The panels fabricated in the factory are assembled and transported to various project sites. The factory has a team that develops BIM for the projects. This BIM is also used in coordination with other building trades. Once the coordination is complete, the factory receives orders from the superintendent on the construction jobsite, which starts the fabrication process. The setup includes moulding sheet metal to form metal studs with proper sizes, cutting them in required length, punching holes, these operations are carried out by CNC machines. Robotic arms are used to weld the studs together to form a panel. Sheetrock is mounted on the panels once the fabrication is complete. All the panels are stacked at a storage yard, which is then transported to the sites as per the demand. All processes mentioned here is BIM enabled.

EXISTING PRODUCTION PROCESS

The superintendent on site is aware of site conditions and have in-depth idea of construction schedule for the project. In the existing process the factory receives installation sequence for the superintendent in the form of marked up PDFs. The usual practice is modellers in the factory email panel drawings to the superintendents on site and they finalize the installation sequence. Since there are different types of panels like the priority panels, load bearing, non-load bearing, leave-out panels, metal studs ceiling assemblies, joists, exterior panels etc., the sequence of installation changes as per the type of panels as well as the location of panels. Thus, these marked up drawings not only have sequence numbers assigned to the panel, but also distinct colours applied to the different panel types. Sequence numbers are marked on the pdf and emailed to the factory. These marked up drawings are the basis for fabricating the panels and other downstream supply chain activities.

METHODOLOGY

BASIS OF SOFTWARE DEVELOPMENT

Fabricators have been facing challenges like bulk ordering, multiple orders, less correspondence, miscommunication, schedule delays. The orders are placed in bulk which leads to higher inventory cost. The gap between site and subcontractor is a common problem in construction. Furthermore, miscommunication between site and fabricator results in overproduction, wastage of material, delay in delivering panels on site, logistics problem like re-handling and thereby, causing overall delay. The focus in developing this software application is to overcome/reduce these challenges and to have a smooth flow of information as well as lean flow of panels throughout the process from ordering to fabrication to installation. There are two factors considered while implementing requirements to the software. First is that the sequencing data input should be done directly from the authorized person on site and secondly, input it in a format such that it can be digitally used for fabrication and assembling purpose. Thus the proposed system supports process transparency through visual management by making it easy for all involved to see and order parts (panels), cycle time reduction due to the streamlined process, potential elimination or reduction of other types of waste such as rework, waiting, re-handling and excessive transportation(Koskela 1992). The focus is to streamline the overall process. The benefits over existing process using the app “Flow” is presented in the following sections.

MORE TIME AVAILABLE FOR PLANNING

Panel installation activities are typically on the critical path. Furthermore, design and coordination changes often take more time than planned, thereby shrinking the lead time of panel production at the factory. Within this reduced time period, the superintendent and the fabricator must finalize the sequence of installation before fabricating the panels. In the existing process, the fabricator provides panels drawings to the superintendent only once BIM coordination is signed-off. In the new process, the superintendent can start the panel sequence planning right after the design phase and has the entire coordination and submittal phase to finalize the planning for installation. The reason here being that existing sequencing process being 2D pdf based, is not agile enough to absorb change intensive coordination phase and thus this effort is preferred to be a onetime approach, ideally best done after the coordination phase. The new approach is BIM enabled with sequencing done real-time on the latest model (automatically fetched from A360 docs).

Model changes are easily incorporated to the BIM enabled sequence planning process based on model version comparison. Figure 1 below represents additional time available for the superintendents to plan the work.

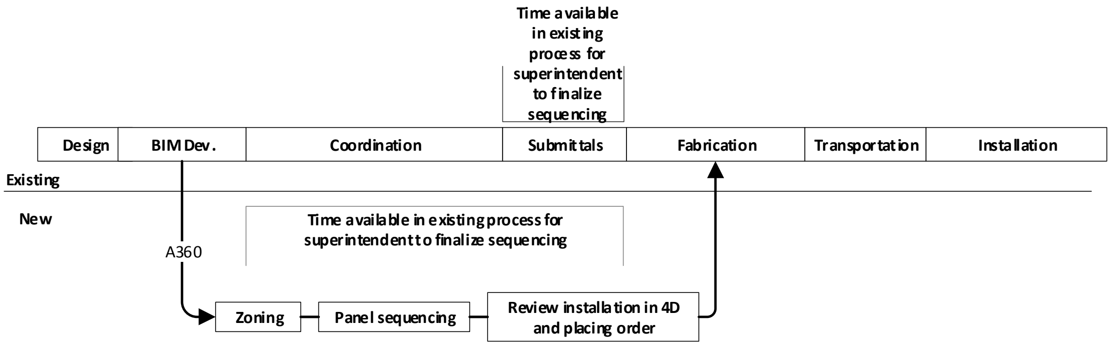

Figure 1: Comparison between Existing and New

ABILITYFOR EVALUATING MULTIPLE SEQUENCING SCENARIOS

The process of manually adding sequence numbers is tedious and time consuming. There is very little scope for iterations to these mark-ups in the short duration of time. The Figure 2 below shows manual sequencing of panels achieved using pdf-based application. The new application holds ability to maintain sequence data and BIM in a database. The usage of the BIM model within the app outperforms the current manual pdf-based approach due to the agility of the BIM model to run multiple sequencing scenarios, use of quantity information in the model to derive duration of installation and evaluation of each of the scenarios based on total installation duration. This ensures that the sequence planning is optimum and has been vetted out carefully. The workflow ensures use of the latest and greatest BIM as the iPad app fetches it from Autodesk 360 platform on a real time basis.

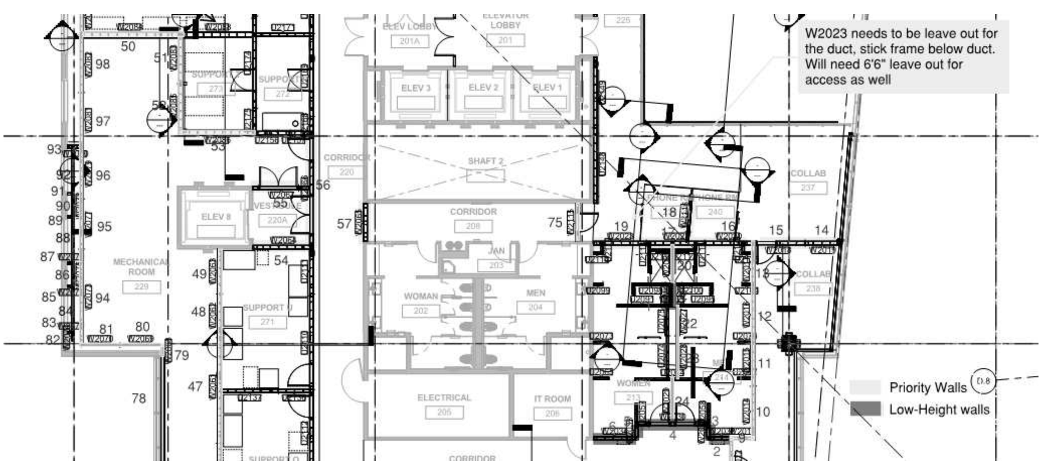

Figure 2: Manual sequencing done by Project Engineers using Bluebeam Revu

ABILITY TO PLAN SEQUENCING BY ZONES AND ACROSS FLOORS

The existing 2D pdf-based process does not provide the capability to prioritize sequencing of panels between floors. The superintendent sequences panels on separate 2D panel install layout drawings in a disjoint manner. The new process using app ‘Flow’ has a location-based management system (LBMS) through which zones/areas/workface are defined to group and segregate panels. The size of these zones is defined based on the amount of work that can be done within a planning cycle under the last planner approach (typically a week).Figure 3 shows sequencing of zones between levels, thereby providing another dimension in sequence planning which was not available while it was being done using 2D pdf drawings. Panels in the building are divided in two major scopes based on the functionality as shown in Figure 3, interior panels and exterior panels. Interior partition panels and ceiling/floor panels are included in interior category, whereas exterior face panels are included in exterior category.

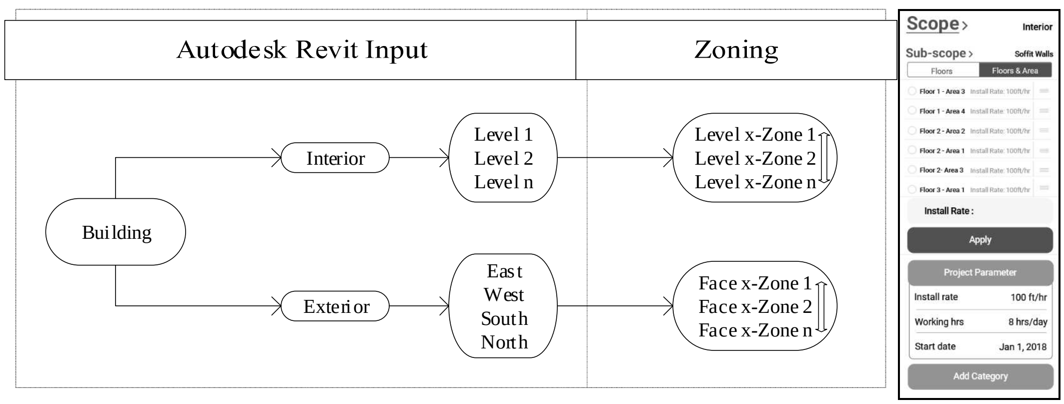

Figure 3: Floor Zone combination concept (Left) and
Floor Zone combination in app (right)

QUANTITATIVE INFORMATION

2D drawings do not provide readily available quantitative information. It does not automatically tell the planner how long the sequenced panels will take to install. The ‘Flow’ automatically gives this information. The process is, once the areas are drawn on floor plan, user needs to select Floor and Zone (FZ) combination and apply install rate. Generally, installation rate is determined in linear feet (lf)/day/crew and the length of panel varies from 8’ to 12’. Based on the available data on number of crew shifts and leveraging the quantity information in BIM (lf of panels), this install rate helps identify the quantum of work that can be put in place in one calendar day. As mentioned earlier, different types of panels (load bearing, non-load bearing etc.) are categorized under sub-scope. Install rate varies from one type of panel to other and it varies even by location. It also helps in validating the work area definition, if the number of panels within a work area can be installed within the planned duration or not. Color-coding of sequence numbers instantly notify number of days required for installation.User can sequence the panels for an area at any point of time.Figure 4 shows manual sequencing and sequencing using ‘Flow’

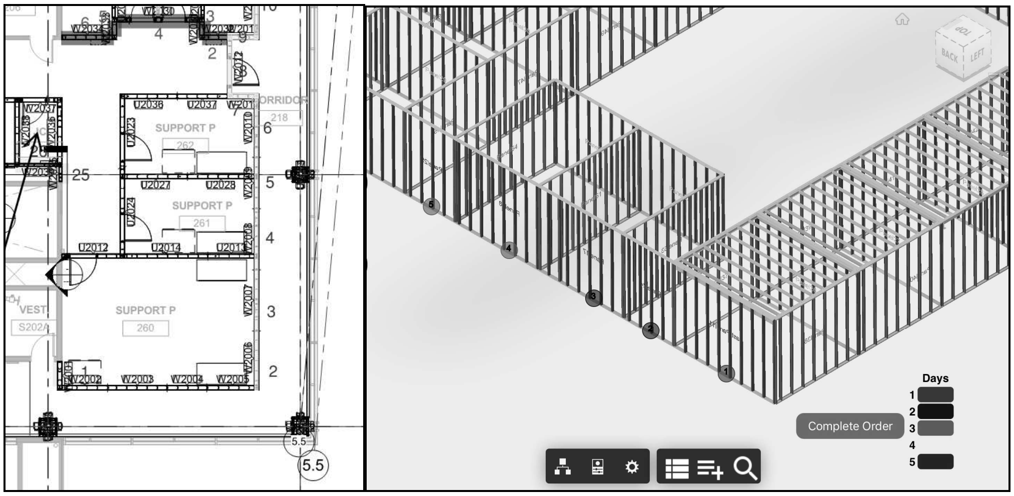

Figure 1: Manual sequencing (left) & Panel sequencing using App (right)

4D REVIEW OF PANEL INSTALLATION

Another challenge observed in the current process is effective coordination with other trades. Since the panels are prefabricated, they need to get installed prior to MEP installation. The factory has experienced challenges in the past, when MEP subcontractor installed utilities before the panels. This happened because factory did not receive any indication about the priority panels and leave-out panels from the project team. Lack of communication between the site and the factory has often led to delay in installation of panels, since either the MEP trade had to remove their parts while drywall team waited to install or MEP trades were not able to remove the runs and multiple panels needed to be modified or were not installed and those walls had to be manually installed.

Current application provides ability to specify and visualize priority panels and leave out panels. 4D visualization helps in understanding the overall installation of panels in context to other building trades. Though the current development does not show installation of other trades, in the ensuing version the user can manually export user data of zones, sequence numbers and start date of panel installation to master construction schedule and see the overall 4D.Plannerscan better visualize, accurately analyze, communicate and reduce possibility of coordination errors with other trades.

The superintendent reviews the order via 4D and places the orders. He/she reviews the system generated delivery date for the panels and can edit it if required. Once the order is confirmed, factory initiates fabrication process and once fabricated panels are shipped to arrive on site by the delivery dates as specified in the order. Figure 5 shows the order summary report.

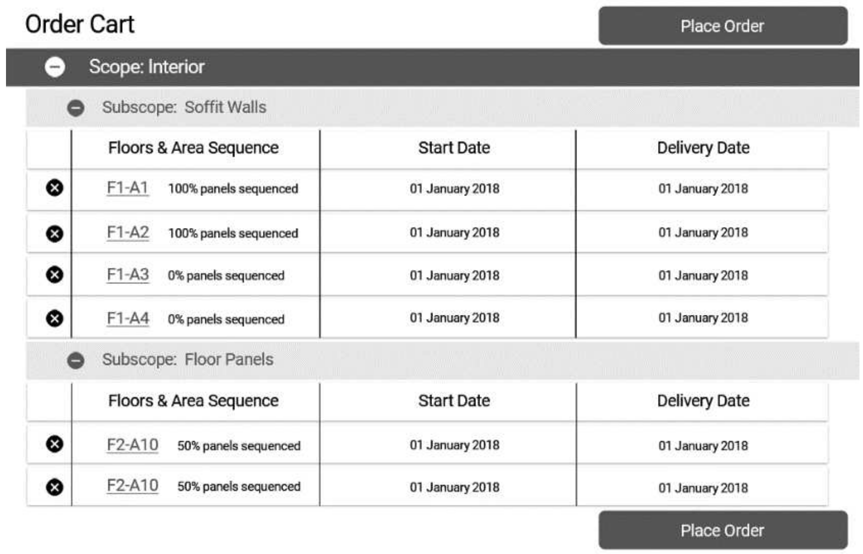

Figure 5: ‘Place order’ on app

MINIMIZE MATERIAL RE-HANDLING

Post-fabrication, panels are bundled, stored in factory, shipped, stored on site and installed. If panels are not fabricated as per the installation sequence it leads to the risk of material re-handling in each of the stages mentioned above.Improper placement of panels on loading yard and trucks affects their unloading on site. Because of this, site crew had to first rearrange the panels and then move them to the installation location. Also, there have been instances when schedule got delayed because the panel bundles received on site were not those expected by the project team. Proposed app provides sequencing data, which is used to create bundles, using which panels are stacked as per Last In First Out (LIFO) logic.The process of creating panel bundles is shown as in Figure 6.

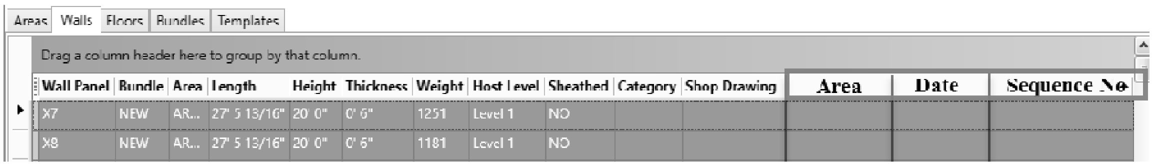

Figure 6: Process of panel bundling

DEMAND VARIABILITYDUE TOMULTIPLE PROJECTS

The current process provides sequencing data from multiple projects in a format (pdf) that does not support effective supply chain across those projects with the factory. The new process using the app ‘Flow’ proposes to enable efficient coordination of panel fabrication and shipping between projects. The app ‘Flow’ will provide order summary report and 4D output in a format that will enable assimilation from multiple projects to fabrication workflow. Figure 5 (Order Summary) and Figure 7 (4D time liner review) shows the input to the fabrication workflow.

Figure 2 : 4D timeliner

CONCLUSION AND FUTURE SCOPE

The future version of app ‘Flow’ will include functionalities for tracking status of material delivery (using IoT) and progress tracking of installation on site. It is also planned to include the other trade models to improve the overall installation sequence. The Application can further be extended in future versions to record and track other stakeholders’ reviews/comments, design and constructability review features on a single platform. This paper explains qualitative comparison between existing and new process for managing the demand and supply of metal framed panels which is summarized in the following Table 1. Quantitative comparison between existing and proposed processes is yet to be measured as the app is in beta testing phase.

Construction process	Existing Process	New Process using App 'Flow'
Planning the installation of building elements and sequencing	Sequence of installation is defined by the superintendent only when all the submittals are ready.	The process using the app gives the project team the ability to plan the installation sequence from design phase. The app user can define the categories of panels, E.g. priority panels and leave-out panels (Reduced cycle time due to streamlined process)
Location based planning	The superintendent provides markup of installation plan on the panel install layout drawings. The process of marking zones and sequencing on 2d sheet is tedious and a cumbersome process. Sequencing across floor is not possible.	Areas can be easily marked on 2d sheets. Panels can be added/removed from a zone hence sequencing across floor is made possible. (Reduces the share of non-value adding activities)
Communication between the Superintendent and the factory	Information flow in this process may lead to misunderstanding and waste due to rework	Sequence report generated through the "flow" application gives a clearer picture of fabrication requirement. (Elimination of waste such as rework, waiting, re-handling and excessive transportation)
Quantitative planning	Existing process doesn't give the idea of overall production levels from different projects	Integration of BIM and IT will help to understand the forecast. (Increased process transparency through visual management)
Review of installation	Review of orders cannot be done.	4D of panel installation will be used as a review by the superintendent (Increased visualization of the process)

Table 1: Comparison between as-is and as-proposed process

There are some limitations and challenges to the app implementation. For the app to work properly the models and the sheets must be uploaded with predefined nomenclature. Framing elements should have scope and sub scope properties defined for the app to read and accurately pull them in respective categories. In the project setting a user at present cannot define holidays and the app uses a linear process for calculating the start dates of installation. Another limitation is that the app user cannot import construction master schedule and link the activities to the framing elements in the current app version. File types for models is limited to particular file formats such as .nwc, .rvt and .dwfx. The app is at present developed for iOS and not for other platforms like Android, Windows, etc.

The current version of this application mainly focuses on improving the existing production process. The application proposes to help the fabricator to streamline the process with clearer picture of production requirements. It will also consider the demand variability due to multiple projects in pipeline. The app proposes an effective integration and communication between projects and the factory. Fabricators using the app will better understand the installation of panels with respect to other trades, which will reduce the risk of rework on the field.

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RESPECT FOR PEOPLE'S WELL-BEING: MEDITATION FOR CONSTRUCTION WORKERS

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ABSTRACT

Stressful environments are often found in construction industry which makes important to study the relation between stress and work. Alcohol or illicit drugs were reported to be common short-term alternatives to reduce anxiety in male-dominated industries and have long-term implications for health and well-being. "What countermeasures can be used by construction workers?" A set of emotion-focused coping strategies is identified, such as physical exercise, recreational activities and meditation.

According to the Brazilian Ministry of Health, meditation is an instrument of physical, emotional, mental, social and cognitive strengthening that promotes concentration, stimulates well-being, relaxation, reduces stress, hyperactivity and depressive symptoms. "But would construction workers be willing to meditate?" The purpose of this paper is to assess the initial perceptions of construction workers under meditation training.

This research has a qualitative approach and its strategy is a unique case study. Four meditation sessions were applied at the construction site during lunch break. Multiple sources of evidence were used: interviews and videos. The data analysis was qualitative. The results indicate: (1) construction workers consider that meditation values them and (2) they also recommend its implementation. This research gives some information that there is viability for meditation in construction.

KEYWORDS

Lean Construction, Safety, meditation, workers' health, well-being.

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INTRODUCTION

Thirty per cent of lost productivity worldwide is caused by psychiatric conditions such as depression, anxiety and schizophrenia — all of which are exacerbated by chronic stress(Nestler 2012).Work stress is recognised world-wide as a major challenge to workers' health and the healthiness of their organizations(Leka et al. 2004).Work-related stress in developing countries is often made worse by a broad spectrum off actors outside the work environment from gender inequalities, poor paths of participation and poor environmental management of industrial pollution to illiteracy, parasitic and infectious diseases, poor hygiene and sanitation, poor nutrition, poor living conditions, inadequate transportation systems and general poverty(Houtman et al. 2007).Stressors can be one-time and acute, such as unexpected job transfer or job loss, or more chronic, such as bad bosses, broken peer relationships, and dysfunctional team members(Tabibnia and Radecki 2018).Scientific evidence demonstrates that construction personnel, including both professionals and manual workers, experience various types of stressors(Leung et al. 2015).

Under stress, the body ramps up its production of certain hormones, such as cortisol, and other biochemical factors to mediate an appropriate response to short-term stress, but when overproduced for months or years, they can alter gene expression, probably with deleterious effects(Blackburn and Epel 2012).

There are two particular coping styles in response to managing a stressful situation: problem-focused coping and emotion-focused coping(Langdon and Sawang 2017).The practice of meditation appears to be beneficial in environments where people have high levels of stress, such as the workplace (Cramer et al. 2016; Elder 2014). During meditation, our experiences are not intentionally confronted, but only observed, and its practice turns into learning how not to be negatively influenced by understanding facts as mere mind flows (Teasdale 1999).The cognitive psychotherapy assumptions state the interpretation of facts is more relevant than the facts themselves(Menezes et al. 2011).

The aim of the study was to understand the perceptions of construction workers who had participation of a meditation-training program as emotion-focused coping. The objectives were to discover if they would be willing to practice meditation, and its preparation stretching, respiratory exercise and relaxation.

BACKGROUND

MEDITATION

Meditation is a wide term and gathers several techniques that help focus attention in a non-analytical way, avoiding discursive, persistent and obsessive thoughts (SHAPIRO, 1980, quoted by, KRYGIER et al., 2013). Among different meditation practices, there is the so-called full attention, which consists of paying attention to the present moment with no judgements of the experiences (KABAT-ZINN, 1990, quoted by HOLZEL et al., 2011).

Meditation practice and improvement in psychological symptoms and perceived stress, suggest that the improvements result from regular practice and are related to the significant reductions in psychological distress and perceived stress (Carmody and Baer 2008).

The role of emotion regulation in meditation is demonstrated by the alteration of emotional responses in terms of the overcoming of sorrow and distress as part of meditation practice (Holzel et al. 2011).

The psychological and organizational literature suggests that full attention meditation can have a meaningful influence in the well-being of the employees (Good et al. 2016). Figure 1 summarizes the flow of full attention influence mechanism in the work environment results.

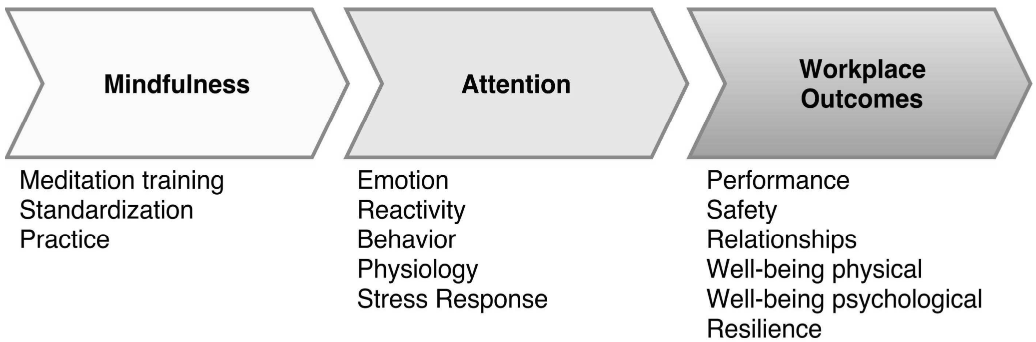

Figure 1: Chart that relates full attention to the workplace results. Elaborated by the author and adapted from Good et al. (2016).

Meditation is also new for those who search for an effective and economic strategy to face stress (Choe et al. 2014). Leisure activities can help people to forget or stay away from life stressful events and keep mind busy for a short period of time, whereas meditation offers long-term effects towards emotion control, physiological benefits, development of emotional intelligence and compassionate emotions (Choe et al. 2014).

CONSTRUCTION WORKERS' WELL-BEING

Researches show that some life habits, such as smoking, alcoholism and other drugs, increased their occurrence after some employees started to work with construction (Haupt et al. 2016).Along with physical inactivity and inadequate food habits, smoking is the main risk factor for chronic non-communicable diseases, which kill the most in Brazil and around the world (Duncan et al. 2012).

Studies indicate that the mechanisms to face stressful events, adopted by construction workers, lead to worse feelings of psychological suffering (Langdon and Sawang 2017).

Wellbeing is a new concept that was introduced to expand the social pillar of sustainability (Vasconcelos et al. 2015).

Table 1 summarizes five types of stressors that construction personnel experience.

Table 1: Types of stressors(Leung et al. 2015).

	Type stressor	Numbers on Faces
1	Personal	Type A behaviour and work-home conflict
2	Interpersonal	poor interpersonal relationship
3	Task	work overload, role ambiguity, role conflict, effort-reward imbalance and lack of feedback from superior
4	Organizational	lack of manpower support
5	Physical	poor office environment and unsafe site environment

RESPECT FOR PEOPLE

The organizations that show respect for their workforce and discuss their questions tend to have less problems, either when they recruit or when they keep their top-quality employees. Besides, workers who feel valued and respected are more likely to increase the opportunity of identifying themselves with and add value to the team and the organization (Thomas and Thomas 2008).

Figure 1 shows how people understand the respect concept as a key to successful partnerships and teamwork integration, which are also viable through team members' personal relationships.

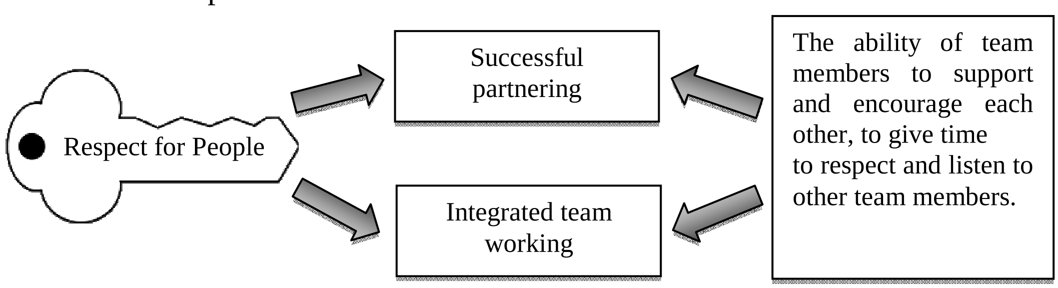

Figure 1: Diagram of concept association and dependence elaborated by the author and adapted from Thomas and Thomas 2008.

Lean value streams must be developed with respect for people(Rother and Shook 2003).The results of respect for people will be beneficial to all, because in showing respect for the workforce, it earns both the respect of the workforce and the public in general(Movement for Innovation 2000).

METHOD

APPROACH

This research has a structuralist epistemological paradigm (Gomides 2002). Considering the nature of the data, this study is qualitative (Vasconcelos and Arcoverde 2007).

Qualitative method was used, because the meaning of meditation for the lives of people in real conditions, and the focus is on the participants' perception. For contribute with insights about emerging concepts that can help explain human social behaviour, multiple evidence sources were used, according to Yin (2011).

RESEARCH STRATEGY

The action research method is adopted as a strategy, because the empirical basis is conceived in close relation to action or solution of a group problem, in which researchers and participants are involved collaboratively (Gil 2008). The action research method approaches scientific research from an interventionist's viewpoint, and researchers both observe and participate in the phenomena under study(Baskerville 1997).

Qualitative data-collection techniques were combined, including interviews, direct observation and filming, in order to understand a contemporary phenomenon (Yin 2001).As the meditation training intervention went by, information collection happened with camera recording participants for later analysis of filming.

The study design is made of three stages. The first one was about the literature review, searching for the main concepts that guided this paper: “respect for people”, “well-being” and “meditation”. The second stage was about applying Action Research method, when the construction workers went under meditation training. A corporate meditation program was developed and took four weeks long. Guided Meditation technique was applied and included: Preparation with Stretching, Respiratory Exercise and Relaxation. Through the progressive relaxation, students arrive at a relaxed mental state in which their distractions are reduced and their imagination can flow more freely(Marques et al. 2014).Guided meditation first uses the vocalization of the body's topography for relaxation of the body, then we induce the observation of external stimuli, sounds and sensations to go as far as mind observation and mental relaxation, then induce a specific internal focus for concentration that can be in the sensation of breathing.

On the third stage, there were discussion and analysis of the experiences to build the research final report.

The analysis unit is the workers’ well-being of a Lean Construction-Based company. The informants are the teamwork members, as well as coordinators and managers, a total of eight respondents. The analysis of the problem was based on a qualitative approach through the Research-Action-Participant. Thus, we did not use sample logic commonly used in quantitative research. This work followed the logic of replication (Yin 2001, 2013): construction workers were invited and participated in the research-action-participant voluntarily in order to demonstrate results, without pretensions of generalization. The research point of view is that of construction workers.

THE COMPANY

The case study was carried out at C. Rolim Engenharia, a company located in Fortaleza, Ceará, Brazil, founded in 1977 and with a 14-year lean working day. The choice of the company was guided by the information, to maximize the usefulness of the qualitative information that would be provided to the research objectives (Takahashi 2013). The choice of company is justified by its management model, highlighting practices that have Lean, Life, Green and BIM elements. Lean as a central idea and the main concerns; the human capital represented by Life; the environment identified as Green; and the search for innovation and information technology and communication applied to the construction process represented by BIM.A construction company that develops social practices (such as giving away school kits to the workers' families and birth kits to the workers' newborn children)

RESULTS

Figure 3 brings the socio characterization of the research participants. Out of the 8 participants, 75% were married, 37.5% were bricklayer's mate, 25% finished High School. The participants' level of education and age were also observed.

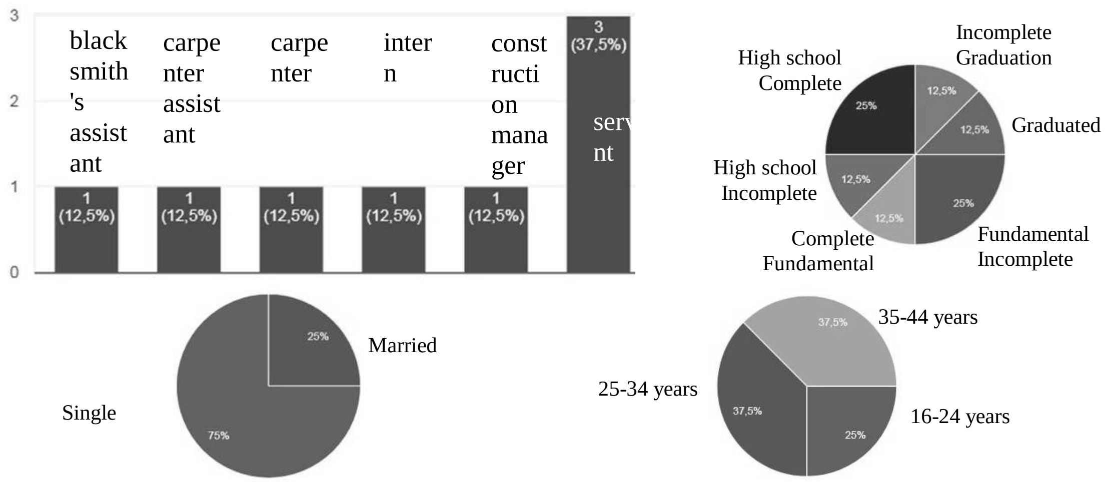

Figure 2: Distribution of socio variables, work position, marital status, education, age.

Figure 4 shows construction workers practicing conscious breathing and relaxation techniques. Based on analysis of filming realized it was possible to observe that construction workers did not have great difficulties to put in to carry out the practice. It was observed that all participants followed teacher's instructions with seriousness and attention and performed the exercises of conscious breathing and relaxation, which had purpose of preparing for meditation moment.

Figure 3: Shots of conscious breathing and relaxation techniques in the job site

It was observed that construction company provided a space for well-being at construction site, equipped with chairs and sun beds contributed positively to realization of meditation training. Figure 5 demonstrates construction workers during meditation practice that occurred in the lunch break with the use of music as a focusing tool. The day of the week in which the meditation training was applied was planned to not coincide with the scheduling days of machined concrete. In this way, noises produced by the pumping of concrete were avoided, which would make the practice of meditation unfeasible.

Figure 1: Shots of meditationin the job site

The analysis of the data collected through interviews indicated that majority of the interviewees that practiced meditation in the job site totally agreed there are demands to implement this activity in the job site. Interviewees agreed there are barriers to put the activity into practice. About the usefulness of meditation in construction, majority of the interviewees fully agreed in favor of meditation. Majority of the participants would recommend meditation to their colleagues, including the ones who work for other companies. Interviewees analyzed positively meditation practice in construction. Majority of interviewees agreed meditation in construction values the workers, contributing more for good attitudes that intend to offer higher satisfaction levels to the workers of the approached company.

The barriers against meditation could be overcome with good planning along time, in a way it does not mess the employees' work routine and their work pace. For example, workers would receive well the idea of practicing meditation early in the morning. Most of them arrive early, which is a positive aspect. Practicing meditation at lunch time or at the end of the workday would interfere in their resting time and delay their home arrival. This data was positive, considering that the ones who participated on the first day invited other workers to come for the next sessions. One of the interviewees said that, after the first day of practice, he tried to teach his family what he had learned from the training in the job site.

CONCLUSIONS

First, this research shows there is viability for meditation in construction. The results indicate: (1) participants construction workers consider that meditation values them and (2) they also recommend its implementation.

The study also shows it is viable to introduce a meditation routine, as a emotion-focused coping, within the weekly activities at a construction site.

The main contribution of this paper is to offer, in the construction industry context, an opportunity to express respect for the workforce and obtain benefits out of this important principle. It is believed that, through these actions, the company is "building" people before "building" houses. By the way, these actions are evidences for one of the Toyota Production System Principles: Respect for People.

Finally, this research was limited due the short period of time available for practicing the meditation routine at the construction site. Thus, the analysis was qualitative, exploring the expected impacts and results for the workers wellbeing. The research findings provide important insights on how the construction industry could improve the quality of life of it is most important resource: people.

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BEHAVIOR-BASED QUALITY, CASE STUDY OF CLOSING THE KNOWING-DOING GAP

Rodney Spencley[1], George Pfeffer[2], Elizabeth Gordon[3], Fritz Hain[4], Dean Reed[5] and Marton Marosszeky[6]

ABSTRACT

This is a case study of a large US general contractor's efforts to rethink and implement a new behavior-based approach to quality to achieve zero errors, zero defects, zero rework, and zero surprises. This GC has a long history of building a culture of Behavior-Based Safety and has approached quality the same way. Recognition of upstream behaviors that resulted in quality issues and unpredictable results during construction led to a focus on changing the mindset and behaviors of all project stakeholders to enable the team to achieve the intended results. While owners and designers have an indirect connection to safety results, their behavior and actions directly affect quality outcomes. Although developed independently of Quality Function Deployment (QFD), this GC's approach is similar. Its approach focuses on understanding the customer's expectations and what is required technically in detail from suppliers to achieve them. It focuses on understanding and describing in technical terms what are the '*distinguishing'* features of the work from each stakeholder's perspective, and on aligning its teams on measurable acceptance criteria to achieve customer expectations. This process for making knowledge explicit in order to agree on what quality means to the customer allows the team to fabricate and install its products correctly in such a way as to close the '*knowing-doing'* gap that plagues most companies and projects.

KEYWORDS

Quality, workflow, indicators, Behavior-Based Safety (BBS), Behavior-Based Quality (BBQ), Quality Function Deployment (QFD), Rework

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INTRODUCTION

A few years ago, during a continuous improvement conversation, one of the General Contractor's (GC's) Business Unit Leaders recognized a disconnect: there were many Zero-Defect letter shanging on the walls in the office, but they were still going back to fix work. Some of those projects experienced simple warranty calls; others involved substantial rework. It appeared that something wasn't working. Rodney Spencley, the director for safety and quality, began investigating and found that actual quality results across the company didn't adequately align with the company's definition of success:

- Sometimes they delivered work right the first time to very satisfied customers.
- Sometimes they achieved Zero Defects at substantial completion but spent extra time and money in doing so.
- Sometimes there were warranty call backs.
- Sometimes they delivered work in accordance with the plans and specifications only to have the owner or architect view the work and say, "that wasn't what I was expecting, tear it out."

In response, the GC's leadership committed to doing something different. They developed an approach to quality much like their approach to safety: a behavior-based approach that wasn't hierarchical or bureaucratic, but instead inspired and motivated people to think and act differently. This paper describes the approach and its application to several case studies.

THE PROBLEM

Rework, or "the waste of correction" was first identified as a key waste by Ohno (1988).Rework has always plagued the construction industry. Research suggests that rework amounts to anywhere from 2% to 12% of project value (Burati et al. 1992; Dougherty et al. 2012, Ledbetter 1994, Love 2002, Marosszeky 2002, Thomas 2003). Marosszeky and Thomas reported on a 2002-3 study in which the direct and indirect costs of rework incurred by the general contractor and subcontractors was measured through the analysis of 3,500 defects on $60 million of construction activity spread over four projects. The Australian Centre for Construction Innovation(ACCI) research team (Thomas, 2003) reported that total rework cost ranged between 3.4% and 6.2% of project value, of this the direct rework costs represented only some 60% while the balance was the indirect cost of organising the rework.

In 2012, the Navigant Construction Forum™ (Dougherty 2012) reported a much higher range of costs for rework:

- Survey responses estimated the direct cost for rework in the range from 4.03% to 6.05% of project value and it was estimated that these should be marked up 80% to account for associated indirect costs,
- Survey responses estimated that on average the schedule grows by 9.82% due to rework

- One-third of survey respondents in a 2011 Construction Industry Institute (CII) study believed that that their recorded rework was only 50-75% of actual rework experienced

The ACCI research examined the causes of this problem in some detail, primarily speaking to general and subcontractor management and workers. The research team identified the following challenges to the achievement of quality.

- Lack of consistent standards, tools and procedures between projects
- Limited continuity/transfer of knowledge and procedures between project teams
- Fragmentation of the supply chain makes it harder to manage work but easy to shift blame
- Management attitudes and competition between teams makes it hard to introduce change
- It is difficult to train subcontract workers and to manage the quality of their work
- The costs of post-project completion rework are generally hidden by transferring the cost to the next job
- It was found that none of the subcontractors interviewed considered the following trade to be a customer

The ACCI research team concluded that in summary, the problem was not that project teams were unable to get quality right, they felt that the skills and knowledge were available, rather the problem was that project teams were hampered by the above, which impacted their ability to get it right every time.

MISALIGNED BEHAVIORS

Safety and quality reflect a similar disconnect between ambitions and results. In safety, even though nobody wants to see anyone injured, injuries still occur. In quality, even though everyone is committed to producing acceptable quality work, unacceptable work is routinely produced. In both cases, ambitions are aligned, but behaviors, knowledge, and practices are not.

This GC has a long history of applying Behavior-Based Safety in its business. (Trethewyet al. 2000). When Rodney Spencley, the company's safety lead recognized that they could install work in accordance with the plans and specifications and still have stakeholders unhappy with the end result, he realized that, much like safety, they needed to look more deeply at upstream behaviors and communications to affect change. Different parties have a critical influence on achieving safety and quality outcomes. For safety, the general contractor's leadership and behaviors directly influence the culture and safety results. Owners and architects indirectly affect safety through the requirements they set and how actively they support the general contractor's safety culture and program. In contrast, the behaviors of the owner, architect and engineers critically and directly influence the project's quality outcomes.

To Rodney, the industry's existing quality approach was too ambiguous and too focused on lagging indicators. Lagging indicators track misalignment of expectations after work has been delivered. Typical examples from compliance-based efforts (think "thou shalt") include failed inspections, issues documented after a first-installed review, and issues discovered during a quality walk. This approach can be best described as '*do work, check work, put issues on a list, and redo the work*'.

Many industry quality programs focus on requiring a higher level of documentation to achieve zero rework, zero errors and zero defects. Many quality management systems document lessons learned and feed that knowledge upstream to project teams at regular intervals throughout a project, such as at design reviews, submittal reviews, mock-ups, and first-installations. At these milestones, teams check work received from the design professional, trade partners, and the craft against a database of knowledge. But it's often overlooked that relying on a database of lessons learned and a lot of checklists will not guarantee a quality product. This approach alone has been unsuccessful in delivering the quality that the customer expects.

THE SOLUTION

LANGUAGE AND PERSPECTIVES

Marton Marosszeky interviewed Rodney for his book, *Total Construction Management-Lean Quality in Construction Project Delivery*, and described his approach. "Rodney sees that a major challenge in achieving quality objectives is the absence of a common language among the parties. The owner's language is about costs and key operational and aesthetic outcomes; the architect's language is primarily focused on the aesthetic, and end-user functionality; the fire engineer's language is about flame spread; the structural engineer's language is about structural integrity, etc. There are so many different languages being spoken that inevitably everyone is having a different conversation, even though they may be in one room." Although stakeholders sometimes have common words to bridge the gap between these many different languages, stakeholders often come from different backgrounds, have different perspectives, and likely have different motivations. So these common words mean different things to each stakeholder. Without spending time to clearly define measurable acceptance criteria for each expectation, the stakeholders each have unaligned assumptions and expectations. "The result is that some of the owner's key functional concerns are lost in the babble." (Oakland and Marosszeky 2017)

UNDERSTANDING EXPECTATIONS

The starting point and primary focus of this GC's approach has been to work as closely as possible with project owners and designers to understand their requirements and expectations of the work. Initially, stakeholder expectations may be abstract, but a series of alignment conversations that focus on what quality means to the delivery team members in light of the customer's expectations move stakeholders away from the abstract and result in aligned measurable acceptance criteria for each expectation. This is a process for moving from the ambiguous unknown to the defined. Alignment activities can be monitored and tracked as leading indicators that evidence the focused effort on meeting quality expectations. (Oakland and Marosszeky 2017). Leading indicators measure the likelihood of success. For example, if the team has agreed on acceptance criteria before beginning work on a deliverable, then there is a higher likelihood that expectations will be met and there will be no surprises when the work is complete.

Although this approach was not inspired or informed by knowledge of the "Quality Function Deployment" (QFD) developed in 1972 at Mitsubishi's Kobe shipyard, it shares the intention to deeply understand customer requirements, these are then translated into language and objectives that are clear to all those responsible for producing the work, supported by measurable criteria that support everyone within the supply chain engaged in realizing them (Hauser and Clausing 1988).

And similar to Behavior-Based Safety, the focus of quality management is shifted to the behaviour and knowledge/understanding of people: what those representing the owner, design team, general contractor and trade contractors want, know, and believe should be done. All are stakeholders in quality.

Foundationally, it's about initiating conversations to identify what each stakeholder believes is important or "distinguishing" about a system or building element consistent with the customers' expectations. We call these "Distinguishing Features of Work" (DFOW). It's okay for every stakeholder to have different viewpoints on what's distinguishing. But once a DFOW is identified, the stakeholders must discuss and agree on what quality means for that piece of work. We call this process developing "Measurable Acceptance Criteria."

A TWO-PRONGED APPROACH: PRESCRIPTIVE AND DESCRIPTIVE

Quality requirements generally fall in two categories: prescriptive and descriptive. The construction industry has historically focused almost solely on prescriptive, or compliance-related, expectations. This typically includes testing and inspecting to verify that construction meets applicable building code and the requirements in the drawings and specifications. The owner, designers, general contractor, and trade partners tend to overlook descriptive expectations, however, which involve developing and agreeing on objective criteria to measure the aesthetic/craftsmanship elements of quality.

For example, prescriptive expectations for a curtain wall system will typically include verifying materials, periodically inspecting welds, performing water testing, and verifying consistent sealant joint widths around penetrations. Descriptive expectations could include those same sealant joints having no blemishes visible from an agreed upon distance.

While recognizing that this two-pronged approach to quality must be scalable to various sizes and types of projects, and stakeholder involvement, this GC strives to make it an intentional process that starts during the pursuit phase and is carried through preconstruction and construction.

POINTS OF RELEASE

A concept that underpins this two-pronged approach is called "Point of Release," which Digby Christian (2012) of Sutter Health identified as the point when work is released for prefabrication or purchase. Digby explained in remarks celebrating achievement of a major completion milestone for the Sutter Health Eden Medical Center

Hospital that all design, code compliance and coordination questions must be answered to minimize lost time and increased costs due to rework.

The GC's quality leaders recognized that the Point of Release for quality was in fact many hand-offs from design through construction, commissioning and building turnover. For quality conversations to be useful, they need to happen before and account for each Point of Release. If the team has aligned on measurable acceptance criteria for the deliverable and the deliverable meets the agreed to acceptance criteria, the risk in releasing the work has been minimized. If the alignment activities did not occur, however, the hand-off becomes a point of contention, instead of a Point of Release.

THE QUALITY WORKFLOW

This GC's approach can be broken down into the four steps shown in Figure 1.

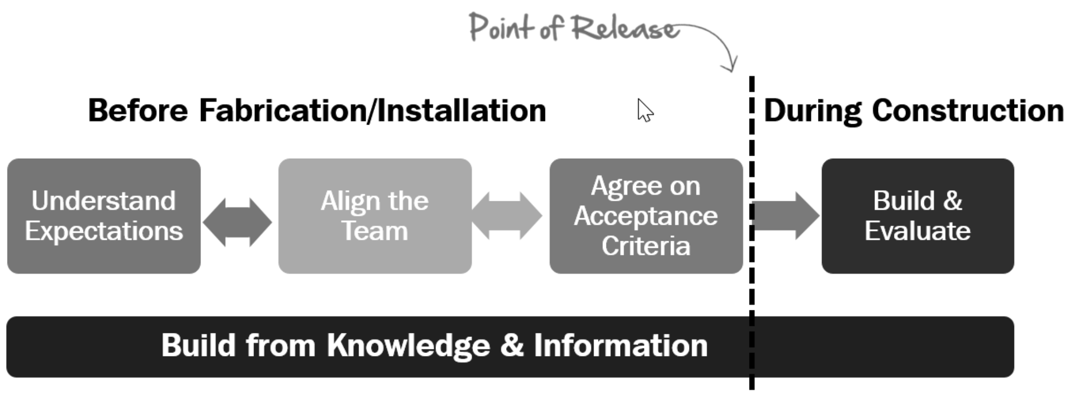

Figure 1: The four steps to quality.

- Understand expectations. Educate project stakeholders on the vision of no surprises, and develop a preliminary list of Distinguishing Features of Work (DFOW). DFOW should include common issues that usually need to be resolved in the design documents before construction; those features of the work that have caused problems in the past; common sources of rework; new or unique features of the work; and those areas that require increased attention in order to achieve the intended result. Then, after compiling an initial list of DFOW, agree on a path forward for developing measurable acceptance criteria for both the prescriptive and descriptive elements of quality.
- Align the team. Every workgroup should fall under a shared leadership group. Depending on the project, these workgroups could be set up by phase, area, or scope of work. Every team member must know who the accountable lead is for the owner, designer, builder, and any major trade partners for their particular work product, so they can understand and help achieve aligned acceptance criteria for that work. This "4 in a Box" concept (or essentially the number of major stakeholders in the DFOW supply chain) should be in place from the lowest to highest levels of the project organization. It's power flows from forcing joint accountability, which is required to achieve a high performing team.

- Agree on measurable acceptance criteria before starting work or releasing key deliverables. The project stakeholders should understand how both descriptive and prescriptive expectations for key features of work need to be communicated in the construction documents and how they will be evaluated and signed-off during construction.
- Verify that the delivered product complies with the agreed upon acceptance criteria. As acceptance criteria become more complex, a mock-up should be built. When evaluating the mock-up to the initial acceptance criteria, evaluation of the work should fall into three categories 1) it meets the acceptance criteria; 2) the owner or design team would like to change the measurable acceptance criteria and all stakeholders agree that the change should be made; or 3) it does not meet the agreed to acceptance criteria and should be redone in which case, the team should gather together to understand the root cause,develop a strategy to mitigate the situation, and learn from the shortcoming, so as not to repeat the same mistakes.

CLOSING THE KNOWING-DOING GAP

Most companies suffer from an inability to convert what they know into action, which Stanford professors Jeffrey Pfeffer and Robert I. Sutton (1999)labelled the “Knowing-Doing Gap.” Hauser and Clausing (1988) in writing of the challenge in converting ideas into reality say “None of this is simple. An elegant idea ultimately decays into process, and processes will be confounding as long as human beings are involved. But that is no excuse to hold back. … What is also not simple is developing an organization capable of absorbing elegant ideas. The principal benefit of the house of quality is quality in-house. It gets people thinking in the right directions and thinking together. For most U.S. companies, this alone amounts to a quiet revolution”.

The Quality Workflow method seeks to close the Knowing-Doing Gap, or to convert what is known into action. It’s a method in which the customer, design team, and construction stakeholders share their expectations and knowledge and agree on acceptance criteria for important product features, so they can be fabricated and installed correctly. Knowledge becomes explicit and this creates the basis for doing the right things at the right time.

This GC recognizes that not all project owners and designers will fully engage in this four-step approach to quality. Nonetheless, they are committed to advancing the vision of predictable results by striving to align the behaviors, knowledge, understanding and practices of all stakeholders. Experience has shown that the greater the engagement by all project stakeholders, the greater the chances that the end result will be a high-quality project.

RESULTS SO FAR

Wherever project teams have embraced the Quality Workflow early in the project—even for just a few scopes of work—they have delivered high quality work with no surprises. The outcomes from three projects have inspired other teams to shift to the new approach.

UNIVERSITY CENTER FOR CONVERGENT BIOSCIENCE, EXTERIOR GROIN VAULT STORY

The University community had high performance expectations for this 190,000 square foot project that included labs, Class 100 and 1,000 nanotechnology clean rooms, imaging suites, and conference and classrooms. The building would "bring together research in engineering and biomedical sciences to fast-track the detection and cure of diseases." ("USC Michelson Center for Convergent Bioscience" 2017).The University also had high aesthetic expectations for the exterior façade. They needed the building to match the surrounding historical buildings and blend seamlessly with campus aesthetics. The team applied The Quality Workflow to the exterior brick groin vaulted ceilings, a DFOW of the campus and to the project architect, which resulted in zero rework and a celebrated element of the project.

Through a series of conversations, they were able to identify DFOW from each stakeholder's perspective and align on measurable acceptance criteria. For example, the random brick color was very important to the University. They discovered that each stakeholder had different expectations as to what the common term "random" brick colormeant. Their trade partner and the GC thought random meant pulling bricks from the pre-blended boxes and installing them. To the campus architect, it meant there would not be any dark spots or dark stripes. Finally, to the project architect it meant that the pattern would match the look and feel of the mock-up. Ideally, these conversations and development of acceptance criteria should have happened before constructing the mock-up. Although there were different expectations, the group agreed before starting production work that the measurable acceptance criteria for random color, meant that no more than six dark colored bricks would be touching. This required the bricklayers to pay special attention when they pulled the veneer bricks from the pre-blended boxes.

Figure 2: Center for Convergent Bioscience, exterior groin vault.

Even though this expectation was uncovered after the scope of work was procured, the GC's trade partner said that executing this expectation would not cost anymore because they could communicate these requirements to their foreman ahead of time. The foreman had the acceptance criteria and verbally communicated expectations to the craft during morning huddles. The GC found that the most effective communication of expectations is person-to-person. When the designers reviewed the installed work, there were no surprises and they were very happy with the result.

The Instagram post by the President of the University mid-way through construction appears on the left in Figure 2: "We're making excellent progress on the construction of USC Michelson Hall – the entry vaults, are now installed (Top-R and Bottom [photo]). On the Top-L, you can see what it will look like when it's completed! Fight On! #USC #FightOn." The completed work can be seen in the photo on the right in Figure 2.

UNIVERSITY MEDICAL CENTER

The University Medical Center project included construction of an emergency department and an eighteen-story patient tower, in two phases. The team completed Phase 1 under a more traditional approach to quality and achieved a Zero-Defect Letter. Quality activities focused on documenting, tracking, and closing out issues during construction. But, when the GC team heard how their company was shifting its quality focus to DFOW and measurable acceptance criteria, they recognized an easier and more efficient way to achieve Zero Defects.

The team launched the new quality approach on the Phase 2 interiors and realized even better results. The architect saw how valuable these conversations were and offered to bring the entire design team into the quality conversations. The stakeholders worked together to make sure everyone's expectations were reflected in the construction documents.

The results were fascinating. For the elevator lobbies, which were identified as a DFOW, only eight Requests for Information (RFIs)were needed before work started. And zero RFIs were issued after work started. Trade partners also realized increased field productivity. The team originally planned for 53 work days on the elevator lobby; the actual duration was 32 days.

Figure 3: Medical Center Elevator Lobby Distinguishing Features of Work.

The process of identifying and aligning around DFOW organically focused all stakeholders on what was important and improved communication. DFOW and measurable acceptance visuals were posted on site. Before starting a DFOW area, kick-off meetings were held at the DFOW location to review the quality expectations. Foremen were asked to sign a copy of the DFOW and acceptance criteria.

On-site DFOW visuals also increased communication between trade partners. Trade partners were often seen gathering around DFOW visuals and coordinating amongst each other. It increased production, reduced rework, and increased trust between team members.

When the team completed drywall on the first floor of the patient tower, it resulted in no issues or punch list. The architect was so impressed with the quality process and results, he saw no need to walk the drywall scope again until the floor layout changed. The image on the left in Figure 3 shows how the GC team captured and communicated DFOW and acceptance criteria to the craft for the elevator lobby space. The rendering on the right in Figure 3 depicts the elevator lobby space. Both images were posted on site for the craft.

PHARMACEUTICAL LAB

Our final example shows how the Quality Workflow can be applied to any process or deliverable to produce predictable results and no surprises. That’s because it becomes a way of thinking, a mindset. This project is a pharmaceutical lab project with a fast-paced scheduled. To meet our customer’s timeline, the team had to present a fully coordinated building model around the same time as the design was scheduled to be complete. This necessitated an early involvement design-assist approach for the electrical, plumbing, and mechanical scopes of work.

Applying the Quality Work flow was crucial to the success of the project. The team developed DFOW for the design, specifically the information our trade partners would need from the design team, so they would only need to draw it once in the BIM. They also identified when information would be needed so as to complete modelling and start fabrication and installation; the Point of Release. The crucial element was the GC sitting with their trade partners’ project management and field to develop a specific and measurable list of criteria for each design DFOW, along with dates the criteria was needed.

The results were intriguing. Although the modelling team did not receive all information they needed before every Point of Release, the project team was able to identify and implement mitigation plans beforehand to maintain the construction schedule. The design team was aware of why each identified piece of information was critical to the BIM process and understood the consequences of not providing the criteria before the Point of Release. Creating this understanding and communication developed trust and allowed the trade partners to adapt more quickly, and it added value to the coordination process. For example, the GC and trade partner knew early that a certain air valve would not be defined when requested. Instead of drawing air valves and redrawing them when they were specified, the team used a reasonable place holder approach that allowed work to proceed. Without this quality-based mindset, the coordination process would have halted or resulted in a significant amount of re-coordination.

CONCLUSION

The paradigm shift for the construction industry will come from recognizing that quality is not just about a series of checks and checklists at key milestones. Quality Workflow goes beyond checklists in a powerful way. It forces people to talk, discuss, and eventually agree on what they will give and get, aligning expectations. Through those conversations, they move from implicit to explicit. Because they understand what they need to deliver, people can make better estimates of the time it will take for them to deliver. Planning, the first step in the Plan-Do-Check-Act (PDCA) cycle, improves. Wherever Quality Workflow has been implemented, results have been more predictable for the trades performing the work and for the customer.

Once people learn this approach, they quickly see that they can use it for all their tasks because it forces them to think about and agree on what is important about the work, and, most importantly, what they will provide to the customer. When this occurs, we say they have shifted to a “Quality Mindset,” and have learned to focus first on meeting the customer’s acceptance criteria. Implicit knowledge becomes explicit, and guides people’s actions. The knowing-doing gap is closed and most of the challenges identified in the ACCI research are effectively addressed.

For many professionals, this approach can be challenging because it requires them to be vulnerable and perhaps admit that what they were planning to deliver might not have been clear to the suppliers and may not have aligned with customer expectations. In the traditional approach, where conversations about quality take place when looking at the installed work, there is room for plausible deniability. When the work is installed to undefined expectations, the owner or architect can take the position that “the contractor is experienced and should have known this isn’t what we wanted” and the contractor can fall back on a standard defence: “How could we have known the implicit expectations? They weren’t captured in the plans and specifications.” These are “get out of jail free” cards that reflect a two-sided failure. Quality Workflow conversations are about making each stakeholder's assumptions explicit—and measurable—and creating a no excuse culture. It’s about communicating in a way that builds trust and accountability and produces meaningful work.

Changing this GC’s culture started with a simple vision and an elegant solution: a behavioral shift. The more they described why they were changing their approach—and how simply changing their focus and behaviors would have a tremendous impact on their ability to deliver work—the more their leaders also saw the benefit in challenging the status quo and moving to a predictable way to deliver a quality product. No worker wants to produce a product that is unacceptable.

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Poster Papers

Monyane, T.G., Emuze, F.A., and Crafford, G. (2018). "Identification of lean opportunities in a South African public sector projects cost management framework." In: *Proc. 26th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.),* Chennai, India, pp. 1185–1194. DOI: doi.org/10.24928/2018/0207. Available at: www.iglc.net

IDENTIFICATION OF LEAN OPPORTUNITIES IN A SOUTH AFRICAN PUBLIC-SECTOR PROJECTS COST MANAGEMENT FRAMEWORK

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ABSTRACT

The prevalence of cost overruns in public sector construction projects in South Africa has been observed. This has been attributed to ineffectual approaches to cost management within these projects. The prior study by the authors has made sense of these observations an understanding of existing cost management approaches. Accordingly, this study seeks to identify Lean opportunities from existing cost management practices. Such opportunities will enable identification of effective cost management during project delivery. Adopting a qualitative case study research design, the study relies on data obtained from a purposively selected list of interviewees from a cadre of cases, i.e., recently completed public sector construction projects in South Africa. These interviews will be juxtaposed with evidence from project-related documents. Based on the data, the study will provide a vignette of lean-led cost management frameworks applied to these projects. Encompassing various stages of the project delivery lifecycle, this vignette will enable an identification lean lead cost management on these projects. Subsequently, the vignette will be validated by interviewees. The expectation is that findings from this study will provide a brief picture of cost management frameworks and enable the introduction of probable lean-based solutions to reverse this unbecoming trend.

KEYWORDS

Construction Projects, Cost Management, Public Sector, Vignette, South Africa

INTRODUCTION

The public-sector client emphasized infrastructure investment as a driver of the economy, but the consequence of constraints realized on project delivery did not provide expected

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outcomes. Efforts of Watermeyer*et al.*, (2013) purported that infrastructure spending will not necessarily lead to economic growth. However, Watermeyer*et al.*,.(2013) Supposed that improved infrastructure that is delivered and maintained in a way that minimizes waste of materials, time and effort permissible to generate the maximum possible amount of value, is most likely to contribute to economic growth. To create value, Orihuela, Orihuela, and Pacheco (2015) state that the service rendered by professionals must be improved and the cost of the services to be reduced or enhanced to the satisfaction of project participants. According to Forbes and Ahmed (2011), productivity in construction has always been lower than that of other industries. Again, Forbes and Ahmed (2011) emphasize that much of the improvement in the construction industry is attributed to research and development work in the manufacturing sector relating to machinery. Consequently, the construction industry research and development remained low as a result. There are attempts by the South African public sector to improve the project delivery methods in the country. Such attempts can be attributable to the separation of the supply chain of general goods and infrastructure procurement implemented from July of 2016.. However, there still remains a challenge on how early contractor involvement is to be adopted to the current procurement system. Thus far there hasn't been any public-sector project that has used the strategy as due to the challenge on how to introduce the contractor early in the current procurement system.

However, pre-contract cost management in a South African context involves an advisory service provided by consultants to a client on the price to design and construct a project. This is very much an isolated task driven solely by the cost manager on the project with little regard to collaborative costing by all project participants. The practice of neglecting collaborative approach to costing has arguably been the major cause of cost overruns experienced on construction projects (Namadi, Pasquire and Manu 2017).

Prior studies by the authors of this study reported on the status quo of projects cost management; study identified the challenges hindering effective project cost management in the delivery of projects in South Africa. Four case study projects were evaluated and validated by interviews with project participants to strengthen the comprehension of the status quo of cost management approaches used in the South African construction industry. The objective of this study is to provide a vignetteof lean-led cost management framework applied to these projects. Various stages and activities by the project planning teams are revealed from inception until project construction completion. The vignette displays lean opportunities to add value by eliminating waste, reduction of lead times, cost optimization.

LITERATURE REVIEW

PROJECT COST ESTIMATING

The process of estimating costs in South Africa considers the numerous life cycle phases until the final design is completed and the Bill of Quantities (BoQ) is produced (Clough & Sears, 1999: 19) cited by(Seeletse and Ladzani 2012). For cost management to be successful, cost estimating is one of the primary tools to develop such estimates (design, bid or control) as may be required (Oyedele 2015). From the onset as soon as the project owner provides a project definition task to the professional team, instantaneously every activity undertaken from thereon affects the cost of the project. Cost is of vital importance to the planning, designing and constructing of a project (Grant and Owen 2009). According to PMI (2015), management from a project perspective involves the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. Estimates are prevalently used for the initial estimate and feasibility of the project. Also, the estimates are produced from preliminary sketches undertaken by the architect from the project definition stage given by the project owner. Assessment of conceptual estimates An et al., (2007) identified the following factors to affect estimate accuracy: changed drawings, changed specifications, and changed project scope and concluded that it is impossible to predict all expected changes correctly. In South Africa, the estimate is being conducted by the quantity surveyor developed from the preliminary drawings supplied by the architect. The cost management process follows the traditional method of design-bid-build of which in South Africa is referred to as design by the employer. According to Odideran and Windapo (2015), there is no doubt that the driving force of project success is emanating from effective project cost management.

PROJECT COST MANAGEMENT

Project cost management involves various elements that, once followed diligently, make the cost management process easy and straightforward. Project cost management entails resource planning, cost estimating, cost budgeting, and cost auditing and or cost control (Knipe, van Der Walt, van Niekerk, Burger and Nell 2011). Bestowing what Kirkham (2007) purports, cost planning as a process is complicated to outline succinctly as it entails various procedures and techniques used concurrently by the quantity surveyor or building economist. The management of costs in a project is a common thread that runs through the complete life cycle of the project (Steyn, Caruthers, du Plessis, Kruger, Kuschke, Sparrius, Eck, Visser 2013). According to Keong (2010), cost management of a project is one of the fundamental processes to bring about the success of a project to be delivered within budget and control expenses incurred in the project. As Kirkham (2007) reported traditional cost planning will usually follow a conventional outline design, and then detailed design process. The management of costs begins with the financial viability study, progresses through all the costs that are required to purchase all the resources needed by the project, through to using cost control to ensure that all work that is done is adequately completed (Steyn et al. 2013).

Figure 1 below is an observation made by the authors in a previous study, were a vignette has been produced for the status quo of cost management process for the delivery of the public project is South Africa. The South African Public Works procurement system uses the traditional design-bid-build and has not established any other method of procurement to deliver projects. The public works execute projects with the mandate from other national client departments. As such the public works projects are only allowed to use competitive bidding system from contractors according to the Public Finance Management Act. This hinders an opportunity to introduce early contractor involvement and appoints based on lowest price. And then contractors are hesitant to revise prices lower than appointed costs, due to fear of losing out on profit margins.

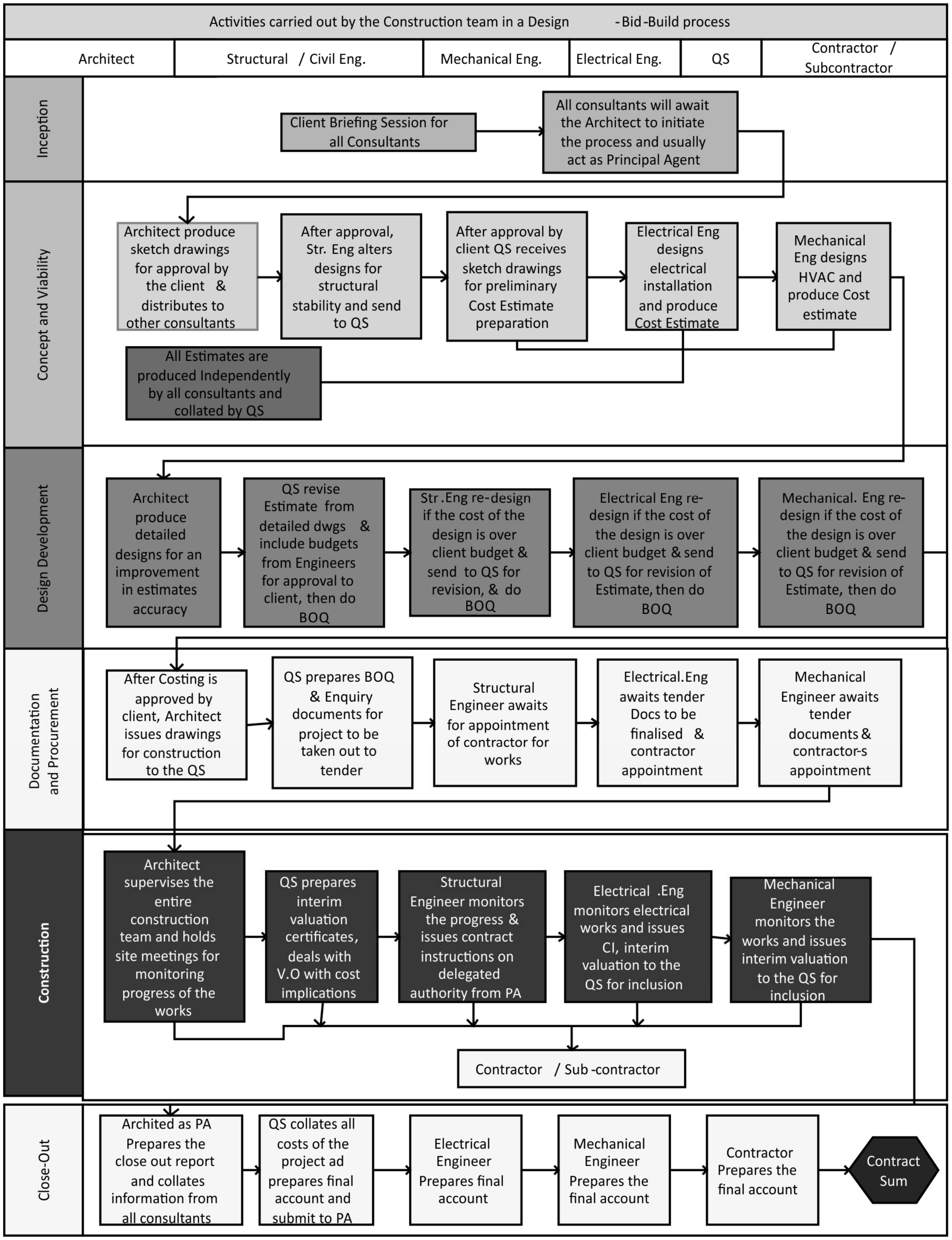

Figure 1: Activities by project participants on public sector projects (Monyane et al. 2017)

RESEARCH METHOD

To achieve the purpose of this research, the study adopted the qualitative research design, from a coterie of recently completed cases of the public sector in South Africa. Usage of a case study is prevalent in situations where researchers intend to understand a contemporary phenomenon within a contextual condition when they possess low control over proceedings. A descriptive case study was chosen, and Yin (2014) imply such type of case study is employed when context-specific insight is sought. Also, a case study is known for its legendary reputation for promoting a painstaking investigation of a phenomenon within its contextual context. To sustain a replication logic across cases, multiple cases were encouraged to be employed in this study including numerous sources of evidence to advocate construct validity (Yin 2014). Means of document analysis analysed the textual data. The document analysis data were supplemented with semi-structured interview data collected from project actors in the selected cases. Interviews were recorded and transcribed using thematic analysis. To rule out bias sample comprised of participants form the cases chosen for the study. 15 Semi-structured interviews which lasted from 30 to 40 minutes were employed to gather data for the avoidance of same questions but that of similar ones if structured interviews were used (Denscombe 2010). From the cohort of interviewees professionals such Architects, Project Managers, Quantity Surveyors, Structural, Mechanical, Electrical Engineers were drawn from the sample respectively. Pre-set themes which were aligned with the research objectives of the study were developed and utilized for this study. Pre-set themes evolved from the coded data. Interviewees were requested to discuss their processes of designing and cost management in the pre-contract stage through to appointment of the contractor. Secondly, the interviewees were asked to validate lean opportunities identified from the process of design and cost management of public projects, specifically the project cases selected for this study.

RESULTS AND DISCUSSIONS

Table 1 below is two cases of projects selected for document analysis of the cost performance of projects in South Africa. The two projects performed poorly regarding both cost and time performance regarding the project management success parameters. The projects used the traditional system of executing projects for public sector clients. Table 2 is the other two cases of projects selected for document analysis, which performed well concerning project management success parameters. Two schools' projects employed the Design-build procurement system while the two hospital projects employed the traditional-bid-build, procurement system to execute the projects. Response by interviewees of the professional team regarding the reasons for such deviations from the poorly performed projects based on cost and time, was that every project is unique, and changes will always occur, and it is part of the construction process. The role of the project manager on such projects was somewhat clashing with that of the architect who is project managing the project due to being appointed Principal-Agent (PA) according to the Joint Building Contracts Committee 6.1 edition on the two schools. The contract does not necessarily stipulate who should be the PA, but since the architect gets appointed first, the position automatically favours the latter and other appointments are made after.

Table 1: Project 1 and Project 2

PROJECT INFORMATION	**Project 1**	**PROJECT INFORMATION**	**Project 2**
Department	Department of Health	Department	Department of Education
Project Name	Extension to Boitumelo Hospital	Project Name	New Primary School
Town	Kroonstad	Town	Bothaville
Date of site handover	28 July 2011	Date of site handover	02 October 2013
Actual start date	21 November 2011	Actual start date	02 October 2013
Completion date	November 2014	Completion date	29 May 2015
Actual completion date	April 2015	Actual completion date	29 May 2015
Contract Amount	R138 263 009.29	Contract Amount	R28 152 536.86
Final Amount	R170 339 718.37	Final Amount	R32 758 734.81
Overrun amount	R32 076 709.05	Overrun amount	R4 606 197.95

Table 2: Project 3 and Project 4

PROJECT INFORMATION	**Project 3**	**PROJECT INFORMATION**	**Project 4**
Department	Department of Health	Department	Department of Education
Project Name	New Mantsopa Hospital	Project Name	New Special School
Town	Ladybrand	Town	Kroonstad
Date of site handover	12 August 2010	Date of site handover	02 March 2016
Actual start date	12 August 2010	Actual start date	02 October 2017
Completion date	12 January 2013	Completion date	02 October 2017
Actual completion date	12 January 2013	Actual completion date	02 October 2017
Contract Amount	R264 662 777.29	Contract Amount	R39 400 000.00
Final Amount	R264 662 777.29	Final Amount	R38 977 652.13
Overrun amount	R0.00	Overrun amount	- R422 347.87

The status quo of South African construction remains a challenge to get projects to enhance their performance. Figure 1 above from previous study represents the process of cost management of public projects in South Africa. This figure has been developed based on the findings of the semi-structured interviews by supply chain officials and the project participants. Projects performed poorly in terms of cost and time from the cohort of case studies above. The two projects that performed poorly, resulted from revision of drawings by the architect on instructions from the client. This brought about variations with cost implications to the projects. Other reasons are request for information by the contractor to the client which response was very slow therefore halting certain tasks by the contractor due to lack of information forthcoming. There is an initiative by the regional public works to employ early contractor involvement to be part of the design and cost management process, but the challenge is on how it should be implemented. The question was around whether the contractor be a consultant to the project or appoint the contractor early and based on which criteria as the public sector has a challenge of using competitive bidding as per the Public Finance Management Act. The contractor's aim is to maximise profits and if appointed based on price, then contractor might not agree for project cost to be revised lower which brings a challenge of revising the procurement system of traditional design-bid-build system. The challenge brought by the traditional design-bid-build is that it does not allow multi party agreement and to use incentives to promote collaboration between project participants.

The objective of the study is to identify opportunities for lean construction from the above vignette in figure 1 of the outcome of extant cost management. Within the South African context, little is known about the application of Lean thinking strategies to better the overall success of the project. Lean introduction for the past two decades has no doubt posed a challenge for the traditional project management practice (Alarcon, Mesa, and Howell 2013). The identified lean tools from lean-led case studies were suggested to the Interviewees for them to comment on whether they will assist to overcome the poor performance recorded based on time and cost on the public-sector projects in South Africa, see figure 3 for such tools. Figure 2 below is the identified lean opportunities to convince the project participants interviewed based on the case studies of South African projects in this study.

As mentioned before lean is a new philosophy in South African construction, and most practitioners believe the status quo still works if more effort is emphasized on public sector procedures. Whatever waste arising from different projects, to most of the interviewees it is a norm that projects will perform badly with some, and projects will perform better with others. Applying innovation to reduce waste arising out of the cost management process is not the only thing that will root out the problems. The arguments put forward by the project participants required an evidence-based approach to obtain their buy-in of the lean opportunities deemed appropriate for the current status quo of project cost performance.

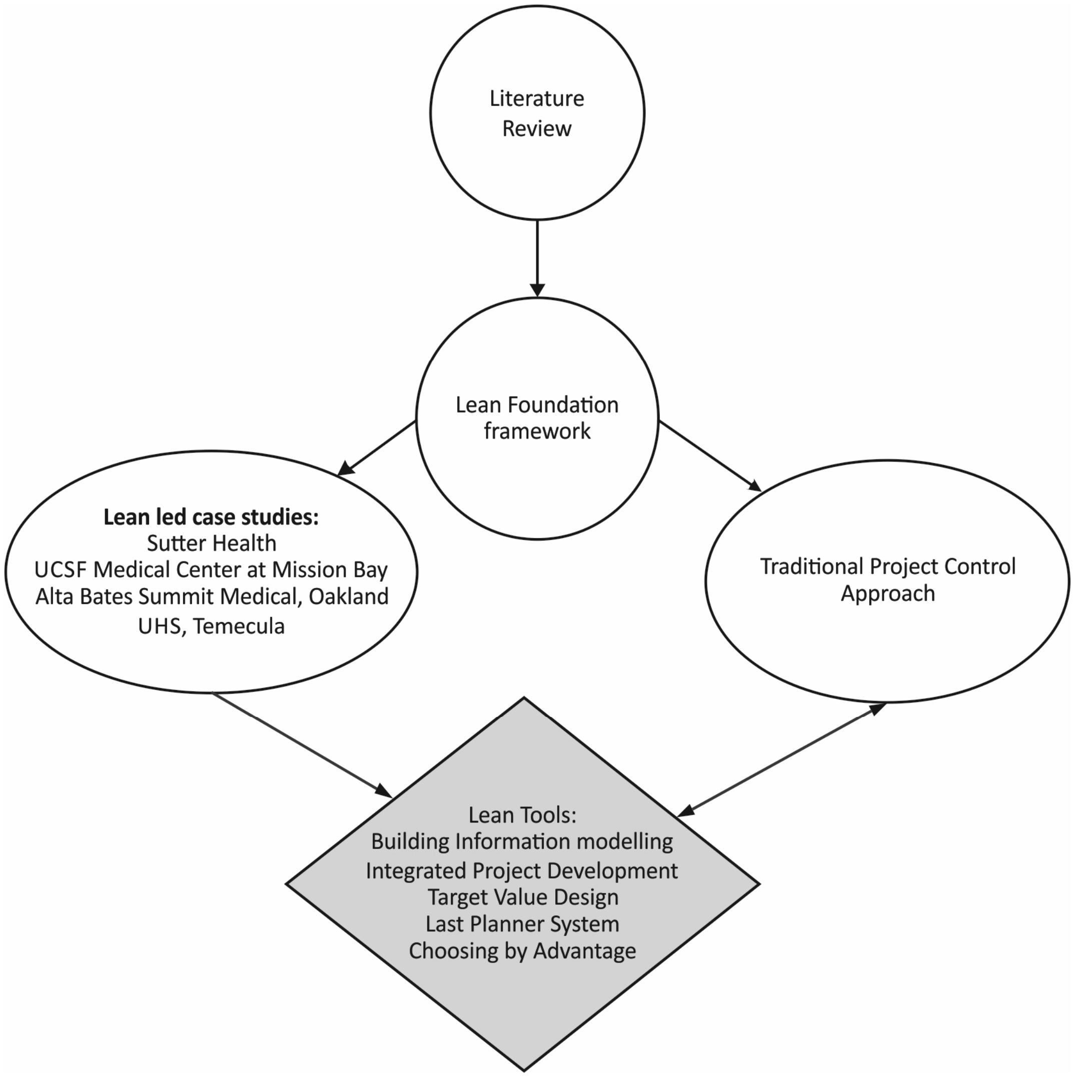

Figure 2: Lean Opportunities Identified (Author)

The authors chose the lean foundation framework, coupled with literature to support the identified opportunities of lean suggested tools. Secondly, the lean led case studies were compared with the traditional project management practice project executed in South Africa were waste dominated the entire lifecycle of the projects. Lean case studies were shown to the respondents, and a few of the well-known projects that performed poorly were drawn from the literature as well. Various lean tools were then suggested and explained to the respondents on how they will be applied and their benefits to the improvement of project performance and how they were used on lean-led case studies already demonstrated to the respondents earlier. BIM, Lean IPD, TVD, CBA, Last Planner System to be implemented on the constructions stage to improve the duration of projects. The respondents agreed that such lean tools are convincing to improve the current status quo and although some of them will require the political support as they affect policy changes notably the appointment of contractors, to bring them early to get involved. But BIM was supported entirely by respondents and agreed that it has a high possibility of improving the flow of design and construction at the same time. BIM was supported based on the fact that it provides the opportunity to fine tune the design and evaluate any clashes before construction starts. Designs can be viewed in a 3D to eliminate any errors early, rather than a 2D drawing which does not illustrate the entire design. TVD was preferred by the respondents highly, however, the disadvantage was that they preferred it on mega projects which requires time before the design can be finalised. It was however, ruled out on small projects and when time is of the essence to implement projects. Other tools were suggested, but if they were time-consuming, the respondents ruled them out on the basis that they are usually not provided such a long time to implement projects. Last planner system was supported fully by the respondents and with training respondents believe that it has a future on construction projects in South Africa. IPD will still take some time before it can be fully implemented in South Africa as respondents alluded, that IPD*ish* at the moment poses a challenge as there is no consensus on how to

CONCLUSIONS

The study intended to bring across results of the status quo of public sector projects and sought the cost management process of executing those projects through the interviews and identify lean opportunities that may be implemented to reverse the ills experienced on public projects. The lean opportunities identified, have the highest chance of improving the cost management process and the projects in its entirety as some were deemed appropriate but due to limited times sometimes offered to implement projects respondents ruled them out on projects were time was limited to implement but appropriate for mega projects. The authors believe that the most significant challenge of achieving lean in South Africa will mainly be culture change before lean construction can flourish as a philosophy to bring about change.

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SYNCLEAN: AN APPLICATION FOR IMPROVED LEAN CONSTRUCTION PRACTICE

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ABSTRACT

Visual management (VM) is instrumental in implementing lean construction philosophy and principles. The lack of communication and sharing of information among construction professionals in construction projects hinders workflow. Visual management improves the performance of workers and optimizes workflow. This paper introduces a mobile application, Synclean, inspired by the virtual Obeya room of Toyota Production Systems (TPS) to ease the transfer of information between site personnel. Synclean will boast a user-based task manager, showing the weekly tasks schedule, covering task descriptions and constraints while including a Kanban-like notification system that addresses tasks for each participant. SyncLean provides the needed platform for signalling the end and start of tasks to those responsible directly, all while holding accessible information in the cloud associated with these tasks like drawings and work methods. These and other features will ensure Synclean is relevant to the very last planner on construction sites and will support collaborative value-adding, waste-minimizing work. The application mobile interface was tested by users and the impact of this application was tested by surveying site personnel of various positions for the application's necessity. Results show the need for a visual tool like Synclean to bridge the communication and information sharing gap between site personnel.

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KEYWORDS

SyncLean, lean construction, application, Information Technology (IT), visual management (VM).

INTRODUCTION

Today's construction industry features a wide range of clients who demand an even wider spectrum of projects. To meet these demands, full utilization of all available resources is needed. Of these resources is the evolving field of Information Technology (IT) (Sommerville et al., 2007). However, IT alone falls short in deciding the most suitable configurations for the construction industry issues (Sommerville et al., 2007). To better meet the mentioned demands, the construction industry is adopting lean practice which will, if utilized according to recommended guidelines, show considerable improvement to projects (Hamzeh et al., 2012). Bell and Orzen, in the book "Lean IT", mention that a staggering magnitude is spent on poor implementation of IT in projects. The authors explain, that focus on tools without the clear grasp of Lean principles, is like "sailing a ship without a rudder" (Bell et al., 2010). That leads to the realization of the need for lean thinking in information systems (Bell et al., 2010), and the need for a collaboration between the mentioned in today's construction industry.

Through visual management, experts in IT can develop the right user-friendly interphase that will embrace both construction and lean practice in construction. By visualization, core values, goals and culture will be aligned within a project by the stimulation of human senses (Brady et al., 2012). The availability and reliability of mobile phones provide an already existing platform for implementing the mobile application, "SyncLean", proposed in this paper, that will utilize Information Technology and Lean philosophy in the favor of the construction industry. SyncLean will employ visual management tools to help improve construction site workflow, quality and safety by incorporating the latter into a mobile application.

SyncLean, through its features, will ensure flow on construction sites through a proactive view on the construction schedule. The application being a mobile phone accessible application is an overall improvement to the availability of site personnel on site. The application will indirectly reduce waste, knowing site personnel can now "Go and See", *Genchi Genbutsu*, and spend more time on site, all while using the application. Other principles of the Toyota production system

DEVELOPED/PROPOSED APPLICATIONS ENABLING LEAN THROUGH IT

Keeping up with the pace of technology, many software applications have been proposed/developed in the field, each aiming at improving the workplace from a different perspective. These applications will ensure better construction practice, from the standpoint of lean theory and practice. Of these software applications are the following, along with some of their features:

- Simplean (Faloughi, et al., 2014): Featuring process visualization, tasks and their constraints and a drawings viewer, this proposed application promotes transparency between project participants. Other features are live sharing and updating of information about tasks and their prerequisites.
- SwiftKanban ("SwiftKanban - The Best & Most Powerful Visual Kanban Software", 2018): It is a software that enables visual management, optimizes the work flow and delivers products faster. Communication and collaboration with different parties, analytics and performance tracking are some of the many features offered by SwiftKanban.
- LeanKit ("Kanban Software for Lean Project Management", 2018): This software creates a visual model of the workflow and provides shared understanding of the work status. It features virtual whiteboards to visualize the workflow through cards. Also, it contains collaboration features for asking questions and updating the work status.
- KanBIM (Sacks et. al, 2010): The KanBIM system is a software that aims to control the work flow on construction sites using building information modelling (BIM). It provides a clear visualization and a work status of the planned tasks.
- Instantask (Daou et al., 2015): Instantask is an application that helps in showing emergent tasks that are noticed during execution. It makes these unplanned tasks visible to all users.
- LOSite (Bascoul et al., 2017): LOSite is a location-based scheduling program that aims at visualizing the space between all subcontractors on projects. This program manages the space on site, hence facilitating production control.

What these applications/programs offer is only one of many features that describe a lean execution. Safety in particular, is not tackled by any of the applications or programs mentioned despite being a crucial goal in the Toyota Production System. What is needed in the field of construction, is a comprehensive mobile application combining all the capabilities above and more, into a user-friendly individual-based visual interface, available to even the Last Planner in a project. Such an interface will provide the means of communicating the different aspects of the projects to all its entities, hence further engaging these entities in value addition. SyncLean will provide effortless access to all its features from anywhere on site, without the need to visit site offices or use computers, a luxury that many of the mentioned applications does not make possible.

METHODOLOGY

The aim of this paper is to propose a new technical tool in the field of Visual Management (VM) and explain why this tool is strongly needed in construction projects. VM offers solutions to the problems that arise from the lack of communication and slow flow of information, and SyncLean is a visual interphase that will ensure the mentioned obstacles are overcome. The research process will consist of assessing the need for such an application through the review of literature, developing the application interphase and testing of the application features and effectiveness on a small student community and some accessible site personnel. The Appery.io online mobile application development platform will serve as a tool to build and develop SyncLean into a functional application that will then be tested for its contribution to construction, lean construction in particular. The performance of SyncLean will finally be rated by a satisfactory survey issued to the previously mentioned users.

SYNCLEAN: AN OVERVIEW

SyncLean, as revealed, is a visual application that can be used by all construction site personnel. It aims at providing an easy to use visual interphase that will ease the process of construction and optimize the flow of information between the participants. This application will provide (1) the description, constraints, progress of tasks, hazards associated to these tasks and the option to add emergent tasks, (2) a weekly or biweekly look-ahead schedule that can be updated from upstream and downstream, (3) access to useful documents like site plans, drawings and methods of statement, (5) a communication system consisting of messages and tap-to-talk, (6) an Andon system for any problems that pop up and (7) other useful analytical features.

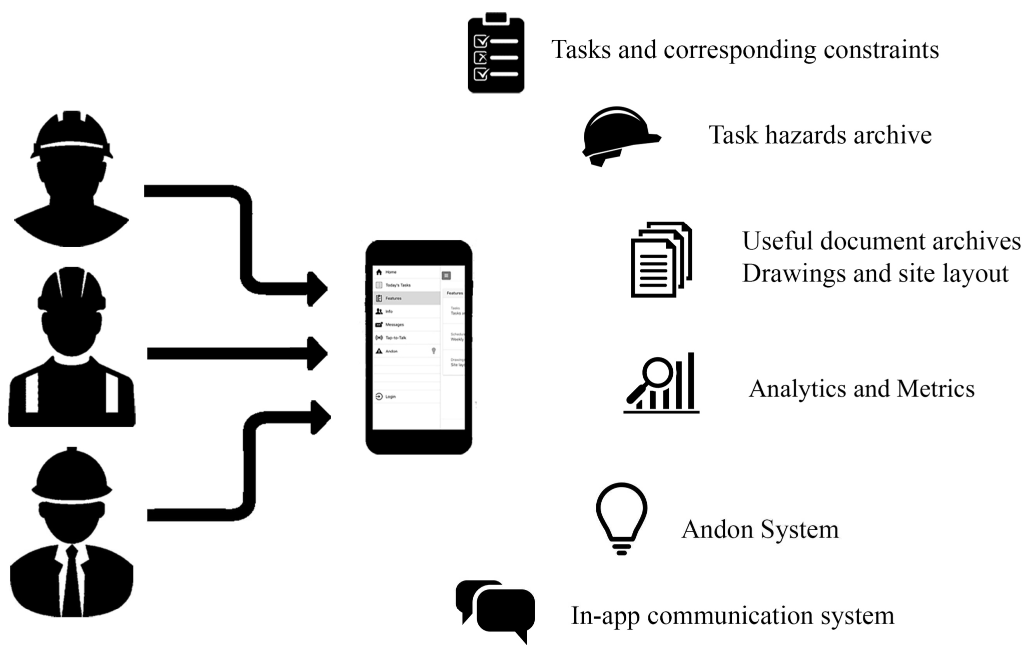

Figure 1: A conceptual model showing the different features offered by SyncLean.

TASKS AND CONSTRAINTS

SyncLean users will each have a separate account depending on their position in the construction site hierarchy. This will provide every user with only the information relevant to him/her. Tasks then, will be introduced based on the user's role. Each user will have access to his own tasks and the tasks that he is related to (predecessor and successors) i.e. tasks related to concrete will be shown to the concrete foreman and steel fixing will show as a predecessor. The application also has a daily tasks page that shows, from the schedule, the tasks to be executed on a workday. As for the tasks themselves, they will each have brief descriptions and their corresponding constraints listed. The mentioned page will also contain a task hazards tab that will link the user to the risks a task he's responsible of might pose. Also, the duration in days or the start and end dates will be included, where the amount of resources needed, type of equipment to be used and where they are located on site is provided. As mentioned before, constraints will appear in the form of tasks for the responsible users. An example would be formwork being a constraint to steel fixing, when the formwork is done by the formwork crew, they will check the task completion box in SyncLean, which will in turn be reflected as a met constraint for the steel fixing foreman. This will be relayed automatically to the steel fixing foreman as a notification. When all task constraints are met, the relevant user will be notified via SyncLean to start a task. This will be done automatically by the application itself. Also, not only will SyncLean list information about the tasks themselves, but also link the task page to the location of the task on the site layout feature that will be discussed in its corresponding section.

SCHEDULE

Schedules are used to keep track of the work on site. This feature will be accessible by the foreman and engineers. When the daily tasks done are uploaded, the schedule will be automatically updated, showing any delay if present. This guides the calculation of percent plan completed and triggers the personnel in charge to find solutions to increase the pace of work and get back on schedule. SyncLean then, provides upstream and downstream updates of schedule, enhancing the overall rescheduling experience.

DOCUMENTS

Site Layout and Drawings

This tab is mainly designed for viewing different sections and plans of the site but is not limited to this. It is divided into two parts, being the Site general layout and specific drawings. Safety being highly considered, the general site layout will contain locations of first aid kits, automated external defibrillators and fire extinguishers. Open shafts will be located on these drawing as a redundant safety measure to ensure an incident-free project. The general layout will also show updated stock locations. Workers don't have to search for materials in case there is no specific lay down area. For an efficient use of space, and to avoid falling into space constraints, the position of different teams working on site will be identified through an in-app location system. The tasks tab will have a site location feature that will show the user where the selected task is on the site layout plan. The other subsection of this feature is the drawings section that will hold plans, sections and longitudinal sections aiding engineers and foremen in their tasks as well as a 3D model that will better explain the site to users. As-built drawings can also be updated regularly to give a visual representation of the completed parts of the project. This will ensure time is not lost attaining drawings from the site offices and will ensure the correct execution of work relating to the now always available drawings.

Methods of Statement

Quality being taken very seriously, methods of statements are now an indispensable part of construction projects. These documents will guide workers to a defect-free result. Within Synclean, these documents will be easily accessible, where every user is able to access methods of statement that are relevant to him and his discipline.

COMMUNICATION

For the ideas and practices of lean construction to be successfully disseminated, effective communication is at a premium (Seymour et al., 1997). As such, all the parties within the same project must be connected to each other through several ways that facilitate their modes of communication. The latter is achieved within SyncLean through two features: messages and tap-to-talk. The messages tab is a common platform for all users who are logged in, to chat whenever needed and to receive notices from their superiors. Through this messaging tab, users can easily reach each other for necessary aid or inquiries. In addition to the messages, there is the tap-to-talk button that facilitates instantaneous communication between personnel, it mimics the walkie-talkie system we all know.

ANDON

Andon is visual management control tool that is used to manage the operation status of the work in the work place (Lean Enterprise Institute, 2008). This definition applies to production systems. Similarly, in construction, this system is used to alert engineers if there is a problem that cannot be solved by workers or foreman. This Andon system consists of three colored buttons. By default, it is set to green, indicating a normal flow of work. When a problem arises, the Last Planner tries to solve it, if it is too complicated, he/she presses the yellow button which directly sends a notification accompanied with an alarm tone to his/her superior. After assessing the situation, if the superior cannot solve this problem, the red button is pressed, and a notification is sent to people higher in the site hierarchy. This feature will provide autonomy and encourage the workers to ask their superiors for help when needed.

ANALYTICS

Another feature provided by SyncLean is generating a daily report that is available to even the last planner of the project. All that is being monitored on site will be sent to the engineer's inbox as a report. This will be developed into what we know as site daily report. Management can then monitor the performance of the site body by the reports generated by SyncLean.

SURVEY AND DISCUSSION

SATISFACTORY SURVEY RESULTS

The application was tested by a small student community at the American University of Beirut and the results turned to be mostly positive. Users praised several aspects, mainly the task hazards tab, the Andon/notification system, and the analytical features that automatically generate metrics. The users also reported the ease of use of SyncLean, and the simple design that ensures a fast learning/adaptation process. The below infographics show results from the survey.

Figure 2 shows the users satisfaction with SyncLean where most responses ranged between 4/5 and 5/5 indicating a favourable overall response.

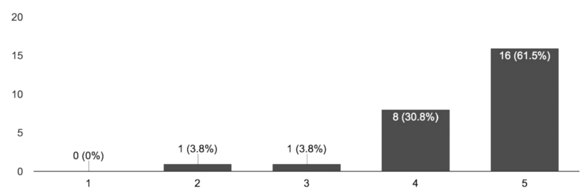

Figure 2: User satisfaction.

Figure 3 shows the most preferred features voted by the users, results indicate that the most favoured feature is the "task hazards archive" followed by the "tasks and constraints" feature.

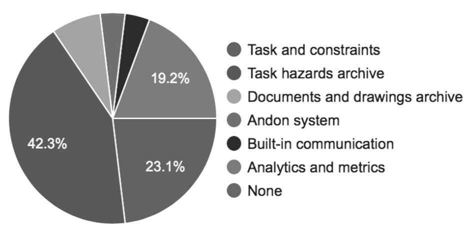

Figure 3: Most preferred SyncLean features.

Figure 4 shows the least preferred features voted by the users, results indicate the "Built-in communication" feature was not highly valued by users.

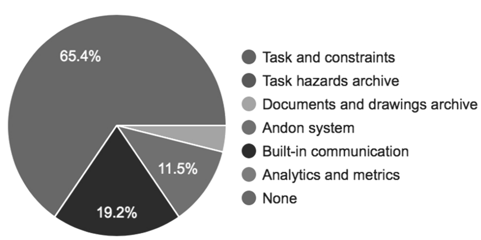

Figure 4: Least preferred SyncLean features.

DISCUSSION

Employing Visual Management, one of the foundations of the Toyota Production System "House Model", SyncLean will help reduce waste, by allowing site personnel to spend more time on site while having access to needed information. The site professionals will be able to "Go and See", *Genchi Genbutsu*, while having access to the application. Another foundation of the "House Model", that is the standardization of processes, will be tackled through the SyncLean documents archive that will include standard work methods for construction. Through its proactive view on the construction schedule, SyncLean will improve construction flow, with the goal of rendering the flow a continuous just-in-time flow, a pillar in Toyota production. The SyncLean digitized Andon feature, will ensure in-station quality and reduce rework through a fast response to problems, portrayed in the "House Model" as the pillar *Jidoka*. Some goals of the Toyota Production System, will be made easier to achieve through SyncLean. The Andon feature will push for better quality while the tasks hazards archive feature will ensure a safer work environment. The features of SyncLean will then form a "House Model" of their own, a structurally less complex model, that will hopefully develop to a future model on par with that of the Toyota Production system. This model, will allow for team work through its collaborative nature and ultimately, continuously improve (*Kaizen*).

The survey showed the interest of users in the safety features provided by SyncLean and the 'task and constraints' feature as well. The latter being direct effectors of project safety and performance, it is only natural these features are favored. The survey results also reflected the ease of use of SyncLean by the users, but the targeted survey body was made of students and teachers. The application ease-of-use is yet to be evaluated by different specialists of different backgrounds and positions in the construction industry hierarchy. The results showed that the least preferred feature was the built-in communications feature, which most of the surveyed found unnecessary in comparison to the already available communication features on the mobile platform. More detailed testing will be conducted when a full version of the application is developed.

As for the application itself, Alarcon et al. (2013) state that managing information is critical for organizational performance, and that information networks are vital for value generation (Alarcon et al., 2013). SyncLean, being the center of construction site information sharing will make way for value generation through accessibility to the Last Planner. Not only will the mobile application provide easy accessibility, but also shorter communication time between the site personnel and decision-making entities through its communication features and virtual Andon system. Hamzeh et. al (2012) state that an agile response to unexpected problems is ensured through shortening the previously mentioned communication time. By achieving a more reliable workflow on site, through SyncLean, schedule performance will be significantly affected. Two case studies confirmed the correlation between workflow reliability and schedule performance through quantitative analysis (Olano et al., 2009). Monitoring the schedule through a user-friendly mobile application, will also simplify the data collection process on site, hence facilitating database creation (Costa et al., 2004). The easily accessible constraints will improve the site personnel understanding of tasks, which will in turn effect the effect of look-ahead planning. Even without prior knowledge of Lean philosophy in construction, site personnel will be engaged in making tasks ready and increasing (TMR), which will affect PPC (Percent Planned Completed) positively and reduce the duration of the project (Hamzeh et. al, 2015).

Featuring a task hazard archive, SyncLean will provide workers with detailed hazard descriptions for every task to be executed. Through virtual cloud-based communication, the application will substantially increase levels of safety, knowing the mere daily verbal communication of risks between site personnel ought to affect safety levels significantly (Kines et. al, 2010).

The application being in its preliminary stages, server downtime, application crashing, and any problems related to the IT perspective of this project are being disregarded in this paper.

CONCLUSION

SyncLean, is a mobile application that aims at improving site work, tackling performance, quality and safety. The application promises features that will ensure tasks are done safely, correctly and on time. The user-friendly nature of SyncLean will ease its release into construction sites and will prove its reliability and importance. The proposed application will hopefully result in a fruitful collaboration between Construction, Lean and Information Technology (IT).

The satisfactory survey taken by the prototype application testers reflected how easy to use SyncLean is. The survey targeted the university students that tested the application and the testers were immediately familiar with the interphase and familiarized themselves with the application features immediately. The task hazards feature was particularly praised by the users alongside the automated analytics and metrics feature.

To conclude, the theoretical analysis for the need of SyncLean is but a step in the course of fully implementing this application in a construction project. Much work is yet to be done however, in terms of fully developing this application and testing it on real ongoing projects. Next steps would be to release a final build of the application that would then be implemented into a construction site for study. Full implementation would serve as a case study that would uncover the weaknesses of SyncLean and show through quantitative analysis whether it would benefit a project. The latter would allow testing of the application interphase on a larger community consisting of different disciplines and education levels. Other future steps would be to consider the technical specifications needed to successfully run SyncLean on mobile devices, and studying the costs associated with developing, implementing, running and sustaining the application from the start to the end of a construction project.

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IMPROVING DESIGN COORDINATION WITH LEAN AND BIM, AN INDIAN CASE STUDY

Vaibhav Bhat[1], Jyoti Snehal Trivedi[2], Bhargav Dave[3]

ABSTRACT

Building Information Modeling (BIM) and Lean construction principles have been used independently as significant methods to construction process improvement. Their combination presents challenges and opportunities in implementation, especially when applied in the field.

This study explores two perspectives, firstly identifying factors and issues in design coordination of construction projects; secondly, applying lean and BIM functions simultaneously to overcome some of the problems in design coordination. Relative Importance Index (RII) method was adopted to identify major critical factors of design coordination and their effect on the three categories viz; design management, time management and cost management. Subsequently, BIM and lean functions such as 4D simulation integrated with Look ahead planning, Quantity take off, Clash detection during look-ahead and weekly work planning, to reduce change orders and RFIs for additional value to customer were applied in an integrated fashion. This improvised BIM-Lean process facilitates the design co-ordination during construction phase for all project stakeholders. Finally a matrix is drafted based on previous research that shows integration of Lean Principles and BIM functionalities adopted for the case study.

KEYWORDS

Lean construction, Building Information Modelling (BIM), Request for Information (RFI), Clash Detection, 4D Scheduling

INTRODUCTION

The design phase for any project is characterized by high level of uncertainties in resulting outputs in contrast with design requirements. The problems occurs when the requirements and the resulting outputs both are indistinct. (Maier and Storrle, 2011). BIM

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(Building Information Modelling) and Lean are the two different intellects that are having an influence on the construction industry. Lean is a concept related to production process while BIM is rooted in technology that instead of acting as standalone systems, when mutually applied to the construction projects helps to achieve great results that solves many of the issues prevailing in the construction projects (Sacks et.al, 2010).

Each project involves different stakeholders having their own and joint responsibilities. The process involves detailed inputs from each stakeholder for different building systems complying with norms (Tatum and Korman, 2000). Inadequate coordination gets reflected in form of waste for the projects in terms of design, cost and time. Instead of focusing on value addition, time is spent on resolving coordination issues (Tribelsky and Sacks, 2011). Moreover, communication through 2D information limits the ability of different stakeholders to coordinate, which in turn effects communication during meetings (Fischer et al., 2002).

BIM tools have had a noteworthy impact on effectiveness of the coordination process. Studies reflect the prised and numerous use of BIM for design coordination and conflict detection (Bernstein and Jones, 2012, Eastman et al, 2008). However, research has shown that implementing BIM alone as a technological solution has a limited benefit. To this end, the synergy between BIM and Lean show that many of the design coordination issues identified by previous research can be tackled through simultaneous implementation of these two concepts (Sacks et.al, 2010). This paper attempts to first identify coordination issues in Indian construction projects and subsequently tries to implement integrated lean and BIM tools to overcome these issues.

In this case study BIM was applied in order to improve design coordination between different design disciplines. Model checking was used to control clashes at the time of execution. Moreover the methodology was also implemented to create a 4D BIM that showed the simulation of the construction process over time. 4D BIM allowed the analysis of the proposed design and its constructability that is going to be executed.

The paper is structured as follows: first section outlines main problems with design coordination in construction and their probable solutions found in literature. Second part outlines the problems in design coordination in Indian construction projects through interviews. The next section covers a case study where integrated lean and BIM functions are deployed in terms of: Quantification, Clash detection, Cost Variation, Look ahead and 4D Simulation. Finally, discussion and conclusion are provided along with suggestions for future research. This strategy of design coordination focuses on interaction subtleties and information dispersal to support design teams in improving design course, knowledge change, and value creation while reducing wastes.

LITERATURE REVIEW

Previous research in design coordination has classified design issues in three main categories: design criteria, construction, and operations issues (Korman et.al, 2003), further, the issues were sub-classified into conceptual reasoning and spatial aspects. Also, constraints were identified with underlying reasons for each discipline. (Tabesh and

Staub-French 2006). According to Mehrbod (2015), the issues in design coordination that can be traced are illogical design, multiple systems conflict, trades design conflict and incorrect design details. The most essential design defects identified by Mardones and Alarcon (1998) were: lack of information and wrong information Wang and Leite (2014) argue that the coordination issues emerge due clashes related to Architectural, Structural and MEP designs, which remain undetected during the design stage. While BIM may help resolve clashes through clash detection, the process needs to be managed effectively in order to be effective. This is highlighted by Tauriainen et, al. (2016) who highlighted coordination issues in design as indistinct sharing of duties between designers in the team, lack of communication, insufficient BIM knowledge of design manager, modelling instructions not used for project, compressed design schedule, conflicts between models, frequent changes during design, and no clear scope. Pikas et, al. (2015) mention that delivering better products is the primary aim for design management in a research that identified typical design management inadequacies and possible remedies. The issues determined were variability in projects, poor planning and avoidance of iterations, poor specification of clients, and poor integration of design disciplines.

It emerges that the coordination aspects along with communication and process management are equally (or more) important than the technological solutions (such as BIM) alone. This is highlighted by a study based on ethnographic action research, which suggested that adopting lean practices reduces coordination related issues at the time of execution and paves the path for BIM adoption (Mahalingam et.al 2015).

Literature explains that the key sources of design error are connected to repetitive design cycles that results from unanticipated changes, poor management and communication (Arayici et.al, 2012, Hattab et.al, 2016) disrupt design workflow, subsequently creating waste such as increased cycle times, cost, rework, and errors. Design clashes involves positioning errors where building components intersect each other when the models are fused. To prevent costly rework, resolution of these clashes is important (J.Won et.al, 2016). Recent research conducted by Peansupap and Ly (2015) studied five categories of structural and MEP related design errors but the study was limited to schedule delays and omitted any discussion on how BIM can facilitate error mitigation at the design stages. Research that studied design clashes are grounded on limited scope of analysis.

The above highlights major design coordination issues and helps classify them in different categories and provides underlying reasons behind issues. Lean and BIM solutions can help overcome many of these issues as highlighted by several studies (Sacks et al. 2010; Rischmoller, Alarcón, and Koskela 2006), however not much has been reported on solving design coordination issues through lean and BIM integration on real-world projects.

PRELIMINARY STUDY

The initial part of the preliminary study was based on a questionnaire survey that was divided into several parts: Questions were about the frequency of coordination issues, impact of issues on cost and time, knowledge on concepts of Lean and BIM and these questions were mostly ranking based that helped to get the major critical issues. Further factors were categorized into its impact on design management, cost management and time management.

The data received in the questionnaire survey was from 11 respondents across India (Ahmedabad, New Delhi) whose profiles are: A-Proprietor, B-Senior Manager, C-Project Coordinator, D, F, H-Director, E-Executive Architect, G-Site Engineer, I, J, K-Project Manager.

The data received was analysed by Relative Importance Index (RII) method to determine the relative importance of the issues/factors in design coordination identified by the survey. Some questions were framed to capture background information of the respondents.

The frequency for the questions was measured on the scale of 1 to 5 in which 1=Never and 5=Very frequent. The respondents helped in addressing the majority of design coordination issues happening on site during execution and also contributing their knowledge regarding BIM and Lean. The major critical factors of project coordination issues is mentioned in the below Table 1.

The issues that were found in literature resonated well with those found during the site visit and questionnaire survey.

Table 1 - Categorized factors of project coordination issues

Sr.No.	Issues	Rank	Category
1.	Delayed decisions	1.	Design
2.	Changes in drawing	2.	Design
3.	Issue of RFI and Change orders	3.	Design
4.	Clients requirements changed and caused redesign	4.	Time
5.	Waiting for others to complete their works before the proceeding works can be carried out.	5.	Time
6.	Time in supervising and inspecting the construction work	6.	Time
7.	Time for instructions and communication among different tiers and trades of workers	7.	Time
8.	Changes in input data caused redesign in building services design	8.	Cost
9.	Waiting for the clarification on the site due to changes in drawings	9.	Cost

CASE STUDY

A case study project an IT park in Gurgaon (Haryana) India, was undertaken to study issues regarding design coordination, and apply Lean and BIM solution to try to solve them. The case study was carried over a 2 month period and the issues related to design coordination were studied. Total site area was 100,362 sq. There were total of 9 towers in the complex out of which 5 were already constructed and 4 were under construction. The scope for study was limited to Tower 9 only. Several topics were addressed in design coordination as mentioned in Table 2. The current scenario of the case study related to pre-implementation of Lean and BIM process is explained in Table 8.

Table 2 - Key topics addressed by the case study

1. Design Management	2.Time Management	3.Cost Management
1.1 Clash Detection	2.1 One month Look ahead schedule	3.1 Design changes impact on Cost-MEP and Structure
1.2 Quantity take-off	2.2 4D Simulation	3.2 Extra work
1.3 RFI(Request for information)	2.3 Quantity Take-off-Manual Time and BIM Time	3.3 Quantity Take-off
1.4 Quantity variation with respect to BOQ(Bill Of Quantities	2.4 Look ahead planning	3.4 Variations in Quantity

METHOD

1. Quantification-Quantity Take-off from BIM

Automated quantity take off is more precise as there are less chances of error, hence reducing variability and taking less time with respect to manual calculations. The quantities automatically change if at any time in future design changes. For the purpose of this case study, quantity take-off was taken up for Slab, Blockwork and Column as shown in Table 3 and Table 4.

Table 3-Quantity take off-Slab

Description	BOQ	Revit	Manual
Typical (1st, 2nd, 3rd, 4th, 5th, 7th, 8th, 9th)	2600 m^3	2,703.00 m^3	2,393.00 m^3
Ground floor	350 m^3	339.00 m^3	301.00 m^3

Table 4-Quantity takeoff Blockwork

Description	BOQ	Revit	Manual
100mm blockwork: 39 Nos	2,820.00 m^2	1,829.00 m^2	1,627.22 m^2
200mm blockwork: 100 Nos	11,820.00 m^2	10,091.00 m^2	9,986.89 m^2

There were significant time savings compared to manual take off, as time consumed in BIM Quantity take-off was: 10-15 minutes, whereas for manual take-off it was: 2 hours. For the scope of the entire building the time saving was approximately 88%. The benefits were not just limited to time saving, as the quantity difference between BOQ and BIM showed that, automated BIM based data take-off can reduce the gap of actual consumption vs planned during execution.

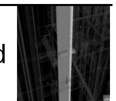
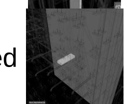
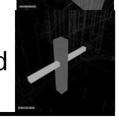
The variation in quantity and cost for the entire project was identified as: Blockwork (100 & 200 mm) -2,155 sq.m, Rs -28,17,800 (~$ -43,062.84) , Column concrete -175 cu.m , Rs -14,38,850 (~$ -21,983.70) and Slab concrete 350 cu.m , Rs 24,51,750 (~$ 37,511.78) . This process helped at the time of billing by comparing and avoiding any discrepancies, hence reducing variability and improving the production and cost control.

2. Clash Detection:

Clash detection helps to track design coordination problems at an early stage. In this case clashes were detected by appending different models in Navisworks and the results were obtained in the form of reports that were resolved before execution started. The clashes were between two models; Model 1-Architecture/Structure and Model 2-

Electrical/Plumbing, where the clash report was generated first between Architecture (Wall/Blockwork) vs. Electrical (Lighting) and second between Structure (Wall/Blockwork) vs. Plumbing (Piping) as shown in Table 5.

Table 5 Clash Detection (a subset is shown)

Clash Type	Number of clashes	Model 1	Model 2	Primary Responder	Reviewer	Review Status	Image
Real	8	Architectural: Wall; Blockwork 200 mm	Electrical: Lighting Fixtures	BIM coordinator	Architect; Electrical	Resolved	
Real	8	Structure; Blockwork 200 mm	Plumbing: Circular Pipe	BIM coordinator	Structure: Plumbing:	Resolved	
Real	8	Structure: Column	Plumbing: Circular Pipe	BIM coordinator	Structure: Plumbing	Resolved	

The clashes detected were mostly regarding MEP. The MEP pipes were clashing with blockwork and columns. The clashes regarding electrical design and architecture were due to fixtures and blockwork that were rectified by just shifting the lights away, but the MEP and Structure clashes were solved by getting detailed drawings and provision of sleeves at the time of designing. The clash detection helped in a way that it paved the path for solving the issues between plumbing and structure consultant in advance by sleeve provision.

But if this process would have not been followed, it would have caused an extra cost of Rs 61, 6400 (~$ 9,449.41) for the entire scope and 1 week instead of a day for detecting clashes manually contributing to waste. The total number of real (solvable) clashes detected for the entire scope were 70.

Coordination between different designers through BIM models prior to construction improved the process and reduced variability at the time of execution. The RFI'S related to plumbing works reduced from 10 to 3 for a particular week i.e. almost 70% reduction.

2.1 Cost Saving by avoiding core cutting:

In continuation with the majority of clashes observed in Table 5 for plumbing and structure the cost implication has been mapped for the process. Following the clashes between the pipes and the structural elements, a potential resolution was to provide sleeves at the time of casting the structural elements. However, since the sleeves were not originally designed, if not detected early, the need for core cutting (in the structural elements) would have emerged. Following the clash detection, the major re-routings were identified and cost implication for core cutting was calculated.

The core cutting diameters range from (102mm-302mm).The variation amounts for the case study whose diameters are (102and127mm) are Rs 4,060 (~$ 62.26) and Rs 4,751 (~$ 72.86). Similarly the cost was calculated for diameters 152,202,302mm core cuts whose variation amount came to Rs 10, 134 (~$ 155.35) , Rs 11, 287 (~$ 173.03) , Rs 9, 920 (~$ 152.07) and Rs 21, 488 (~$ 329.41).

The cost variation report was generated which gave information about savings that was around Rs.61, 640 (~$ 944.94). with approximate time of 1 week for 50 core cuts as per clashes. For the entire scope of the project the cost would have rose to Rs.6,16,400 (~$ 9,449.41) with 500 corecuts.

3. One month look ahead Schedule:

A four week look ahead schedule helped to monitor in advance the challenges that would be faced in the coming month at the time of execution and tried to solve them to save cost and time overruns. The look ahead schedule integrated with BIM tackled two distinct challenges, that of visualization of plan and detailed production planning including resource allocation and commitment management in general.

The activities that will happen in the month of August’17 were pulled from the Master Schedule as shown in Table 6. The main activities related to: Column, Slab, Beam, Blockwork and Staircase were worked upon zone wise. All these zones were defined at the initial look-ahead stages for which the major challenges were identified. It gave major quantum of weekly work planning.

The look ahead schedule helped in the process of solving constructability issues. The input flows such as quantum of work, quantity of material and drawings required for the coming month were identified by adopting this look ahead schedule.

If this process would not have been adopted the issue of constructability would not have been resolved as the same schedule was linked with the BIM model that helped to visualise the process. The duration of activities was reduced from 358 days to 230 days with cost saving of Rs 5, 40,000 (~$ 8,278.20) in terms of shuttering material. So it acted as a step for 4D simulation and simultaneously for production planning.

Table 6 One month Look ahead (partially shown)

Work plan for next four weeks									
Sr.no	**Activity description**	**Area**	**UOM**	**Total planned**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Remarks**
1	Tower area Slab and beam	Ground Floor	Cum	292	-	146	146	-	
2	Tower area Verticals (Columns)	Ground to 1st floor	Cum	131	-	-	-	-	As per available drawings.
2.1	Zone 1	Ground to 1st floor	Cum	- -	49	-	-	-	
2.2	Zone 2	Ground to 1st floor	Cum	-	32	-	-	-	
2.3	Zone 3	Ground to 1st floor	Cum	-	-	49	-	-	

4. Constructability through 4D Simulation:

Constructability through 4D simulation has a link based on clash free model obtained in Table 5 and zoning created for one month look-ahead as shown in Table 6. The schedule was integrated with BIM and a 4D simulation model was generated. The major activities observed for constructability taken for Ground and First floor were Column, Slab, Beam, Blockwork and Staircase.

The columns were distributed into different zones for 2300.61 sq.mt of floor area i.e. Zone 1(Red), Zone 2(Yellow), and Zone 3(Green) .In Zone 1(Red): there were total 15 columns, Zone 2(Yellow): there were total 10 columns and Zone 3(Green): there were total 15 columns. The construction sequence was: 1. Slab and beam 2.Zone 1 Columns 3.Zone 2 Columns 4. Zone3 Columns 5. Staircase 6.Blockwork as shown in Figure 1.This process was repeated for the next floor and was continued till 10th floor. In the above process columns kept on constructing as per the zones starting from Zone1 and ending on Zone 3.

The whole process helped in visualising the activities, their related issues for the coming month and prepare material, labour and drawings ready in advance that will increase the production flow and value when executed.

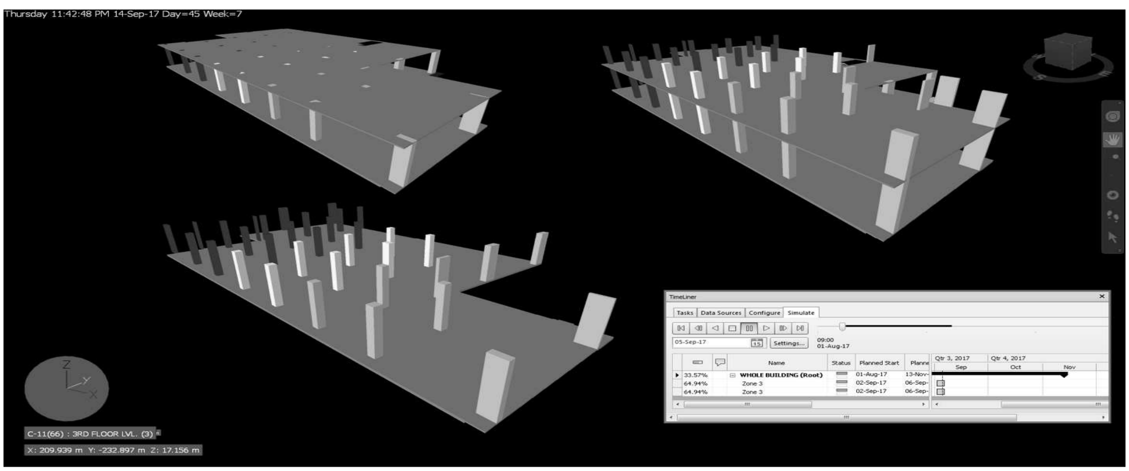


Figure 1 4D Simulation as per linked schedule

DISCUSSION AND CONCLUSION

The study highlighted that there are several design coordination issues that affect the efficiency of not only the design but also the construction process. Lean and BIM if implemented simultaneously can help resolve these issues, however there are major gaps in research when it comes to real-world examples and how they achieve this integration.

Based on the case study and solutions devised, Table 7 was created to demonstrate the interactions that were achieved between Lean and BIM, based on the original study by (Sacks et al. 2010)but the matrix is achieved for limited interactions more interactions can be worked upon and proved practically, and Table 8 gives the explanations for the indexes mentioned in Table 7 and also elaborates the post implementation process of Lean and BIM integration.

This research shows that lean and BIM if applied in an integrated way will help resolve coordination issues during design and construction, however the study is limited to a single project in India and more such studies are needed to create a systemic framework in addressing design coordination and construction management related issues.

Table 7 Interaction Matrix of Lean principles and BIM Functionalities

	Lean Principles			
	Reduce Variability	Increase flexibility	Design the production system for flow and value	Verify and Validate
BIM Functionality	A	B	C	D
Visualization of form	1			
Reuse of model data for predictive analyses	1 2			2
Maintenance of information and design model integrity	3			3
Collaboration in design and construction	1	1		
Rapid generation and evaluation of multiple construction plan alternatives			4	

Table 8 Interaction Matrix: Explanation of Cells

Index	Explanation	
	Pre Implementation	**Post Implementation**
1.	Manual clash checking took 1 week for an area of 23791.11 sq.m with still having manual discrepancies.RFI'S related to plumbing were 10 for a particular week.	The incompletely detailed parts were easily observed in automated clash checking reducing efforts to a day simultaneously RFI'S reduction to 3, almost 70% reduction. This improved design quality reducing variations.
2	Manual quantification of elements for the entire scope of the project took 600 minutes including checking for variations, if any.	The BIM model data used in automated quantity takeoff taking just 75 minutes for the entire scope making work 88% faster. Quantity variations easily tracked with the variation amount tending to Rs 28,17,800 (~$ 43,062.84) for 100&200 mm blockwork reducing variability at the time of billing.
3	No verification/validation of designs before actual execution.	Verification and validation done in terms of clashes detected related to plumbing saving against rework cost of Rs.6,16,400 (~$ 9,449.41) for 500 core cuts for the entire scope.
4	No future thoughts for designing production system for flow, value and any generation of alternatives/visualization for reducing coordination issues.	4D and look ahead helped in reducing issues during production. The duration for the activities was reduced from 358 days to 230 days. Cost saving for the shuttering material due to zone wise planning came to Rs 5, 40,000 (~$ 8,278.20).

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DEVELOPMENT OF AN INTEGRATED BIM AND LEAN MATURITY MODEL

Sajedeh Mollasalehi [1], Ahmed Adel Aboumoemen[2], Anushka Rathnayake[3], Andrew Fleming[4], Jason Underwood[5]

ABSTRACT

The level of Building Information Modelling (BIM) and Lean adoption has been rapidly increased. The benefits of integrating these two approaches have also been identified. However, to achieve the maximum benefits of the interaction of these two approaches, there needs to be assessment tools to analyse their performances collectively. Because understanding and analysing the performances of these approaches would provide value to the entire project in terms of lessons learned, more value generation, and continuous improvements. Therefore, this paper aims to propose an integrated BIM and Lean Maturity Model based on reviewing the literature around current maturity models.

This paper proposes an Integrated BIM and Lean Maturity Model named "IDEAL" which could serve as a basis in terms of assessing the performances of the projects implementing BIM and Lean together.

KEYWORDS

Maturity Models, Maturity Assessments, Lean Construction, Building Information Modelling (BIM)

1.1 INTRODUCTION

In recent years, the application of new innovative and technological approaches has been increased to improve overall project productivity and performances within the construction industry. The most beneficial approaches can be considered to be BIM and Lean Construction which provide benefits to the construction industry. Because of the increased adoption of BIM and Lean approaches, there is a need of having proper assessment tools or models to analyse the performances of these approaches.

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There are different assessment tools and maturity models available for assessing the performances of BIM and Lean individually. However, due to the increased adoption of these two approaches together, there is a need of having an integrated maturity model or assessment tool to analyse the performance of both BIM and Lean together. Providing an integrated BIM and Lean maturity model would enhance analysing the performances of these two collectively together so that subsequently it would enable realising the benefits of both approaches.

2.1 MATURITY ASSESSMENTS

Over the recent years, an interest over maturity models have increased in such way that maintaining a maturity model supports organisations in becoming more mature (Khoshgoftar and Osman, 2009). Andersen and Jessen (2003) definition of maturity is the quality or state of being mature. Jugdev and Thomas (2002) pointed out that the main advantages of a maturity model is that it allows to recognize strengths, weaknesses, and benchmarking information for projects and organisations. However, maturity models also possesses a set of limitations, from a theoretical perspective in specific (Dakhil and Alshawi, 2014; Jugdev and Thomas, 2002). Existing literature shows that a set of maturity models have been used to assess organisations (Khoshgoftar and Osman, 2009). The Software Engineering Institute (SEI) developed the CMM, which is based on a software development process (SEI, 1993). Six models have been created from this development, but lately it has been integrated into a holistic maturity model that has been named by the CMMI. This Model includes 5 levels of maturities which are explained in Table 1 (SEI. 1993).

Table 1: The Software Engineering Institute CMM defined (SEI. 1993)

Maturity level	Definition
Initial / Ad-hoc	Processes are usually ad hoc and the organization usually does not provide a stable environment. Organizations are characterized by a tendency to over commit, abandon processes in the time of crisis, and not able to repeat their past successes again.
Defined	Software development successes are repeatable. The processes may not repeat for all the projects in the organization.
Managed	The organization's set of standard processes is established and improved over time. These standard processes are used to establish consistency across the organisation.
Integrated	Using precise measurements, management can effectively control the software development effort. At this level, organisation set a quantitative quality goal for both software process and software maintenance.
Optimised	Focusing on continually improving process performance through both incremental and innovative technological improvements.

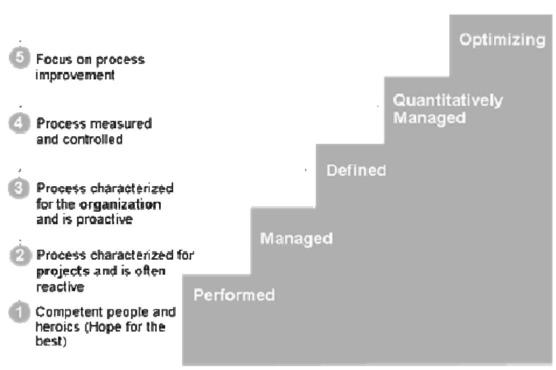

Figure 1- Capability Maturity Model Integration (CMMI) (Chrissis et al., 2003)

There is a need of having an integrated maturity model or assessment tool to analyse the performance of both BIM and Lean approaches together. Since most of the existing maturity models in relation to BIM and Lean have adopted the Capability Maturity Model Integration (CMMI) approach, therefore, CMMI should also be adopted when introducing the integrated BIM and Lean maturity model (Chrissis et al., 2003). Based on the CMM levels, an evolution of a maturity model was developed which includes 5 levels as explained in Figure 1 (Chrissis et al., 2003). By reviewing literature, the authors have selected only a few BIM and Lean maturity models which are most relevant to the context of this study.

2.2 BIM MATURITIES

According to Eastman et al. (2011, p.16) "BIM is a fundamentally different way of creating, using, and sharing building information lifecycle data". BIM provides many benefits to the whole projects lifecycle as "BIM facilitates a more integrated design and construction process" and thus this "results in better quality buildings at lower cost and reduced project duration" (Eastman et al., 2011).

Even though, BIM provides many benefits, to gain the true benefits of its adoption, individuals along with organizations should have the right knowledge to first use it and then to assess their performance of its usage (Smits et al., 2016). Additionally, due to different size and/or project types of companies, the BIM implementation level in organisations vary from one to another. Therefore, organisations need to consider the importance of adopting BIM maturity models and assessments based on the current available BIM maturity assessments (Chen et al., 2014; Succar, 2009).

There are many different BIM Maturities. Nevertheless, Most of the current BIM maturities follow the CMMI, since it is more relevant and related to the background of BIM than rest of the maturity types (Aboumoemen & Underwood, 2017, Dakhil & Alshawi, 2014). Bilal Succar (2010) defines BIM maturity as a state of the quality, repeatability and degree of excellence of a BIM model within a BIM capability. Succar developed a ranking system, namely Building Information Modelling Maturity (BIMM) that incorporates the essential parts for delivering BIM applications through an operational process. Several models have been developed by Industry practitioners and academics to assess construction industry's BIM performance and implementations (Giel and Issa, 2013; Nepal et al., 2014; Succar, 2010). BIM maturities are developed to measure efficiency of BIM competencies and capabilities across a set of construction industries (Aboumoemen & Underwood, 2017).

A discussion on a selection of BIM maturity assessments is presented in this section. Since there has been a vast variety of BIM maturity assessments, the researchers have selected the two main ones that are more relevant in the context of this paper.

2.3.1 Bilal Succar BIM Maturity Matrix Index

The BIM Maturity Matrix Index- (BIMMI) has been developed by Succar (2009) that is driven from the CMM. BIM framework components are combined on an information tool through performance improvement measurements, which justifies reason for development of the BIMMI. BIM Maturity levels can be demonstrated from Figure 2 below.

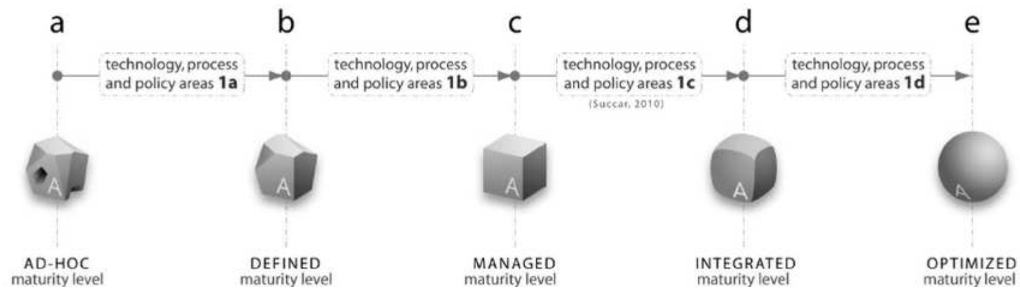

Figure 2 - The Five Maturity Levels (Succar, 2009)

2.3.2 The U.S National Institute of Building Sciences BIM Model (NIBS)

The U.S National Institute of Building Sciences (NIBS) developed the interactive BIM standard Capability Maturity Model (CMM), which incorporates areas of a BIM model such as Data richness, and the information related to its area of interest. A weighting importance is provided to each area of interest to distinguish them, which are classified consequently. A description of the maturity level is given to understand what they mean so the users expected to complete the assessment are to select the necessary levels, and then a score is given to each interest area that adds up to deliver the total sum of the maturity level. A certification level is demonstrated and points required to be achieved is displayed which allows organisations to see which maturity levels they fall under, where if it did not reach the minimum level, then how many points are required to reach the required level (NIBS. 2007) as shown in Figure 3.

The Interactive BIM Capability Maturity Model

Area of Interest	Weighted Importance	Choose your perceived maturity level	Credit
Data Richness	84%	Data Plus Expanded Information	4.2
Life-cycle Views	84%	Add Construction/ Supply	2.5
Change Management	90%	Limited Awareness	2.7
Roles or Disciplines	90%	Partial Plan, Design&Constr Supported	4.5
Business Process	91%	Some Bus Process Collect Info	2.7
Timeliness/ Response	91%	Data Calls Not In BIM But Most Other Data Is	2.7
Delivery Method	92%	Limited Web Enabled Services	4.6
Graphical Information	93%	3D - Intelligent Graphics	6.5
Spatial Capability	94%	Basic Spatial Location	1.9
Information Accuracy	95%	Limited Ground Truth - Int Spaces	2.9
Interoperability/ IFC Support	96%	Most Info Transfers Between COTS	4.8
	National Institute of BUILDING SCIENCES Facilities Information Council National BIM Standard	Credit Sum	40.0
		Maturity Level	Minimum BIM

ADMINISTRATION

Points Required for Certification Levels		
Low	High	
40	49.9	Minimum BIM
50	59.9	Minimum BIM
60	69.9	Certified
70	79.9	Silver
80	89.9	Gold
90	100	Platinum

Remaining Points Required For:	Certified	20.0

Figure 3 - Relation of Interactive model, and points required (NIBS. 2007)

3.1 LEAN MATURITY

In the past 20 years, the construction industry has recognised the importance of adopting new approaches and principles to reduce waste and thus improve overall project productivity and performances (Egan, 1998; Latham 1994). Lean construction is recognised as one of the key approaches to improve the construction productivity by reducing waste (Egan, 1998; Mollasalehi et al., 2016). It was stated by Lehman & Reiser (2004) "lean construction is a project delivery system based on Lean Production Management process, which is aimed at improving value by satisfying customer needs and improving performance". However, to understand the potential benefits of Lean and to achieve its true value, organisations need to measure and assess their lean implementation performances. This could be done through Lean maturity assessments and models. In recent years there is an increased level of interest in lean maturity models (Becker, et al., 2010). Lean Maturity models aim to manage the major revolution changes by defining directions, prioritising improvement opportunities, and guide cultural changes (Nesensohn, et al., 2014). Based on the review of Lean maturity assessments by Urban (2015), there are different types of Lean maturity assessments which adopt different approaches to assessing Lean maturity. These studies include: Lean Enterprise Self-Assessment Tool (LESAT) by Nightingale & Mize (2002), Lean Production check-list by Sánchez & Pérez (2001), Lean Construction Maturity Model (LCMM) by Nesensohn *et al*. (2014), Lean Manufacturing Performance Evaluation Audit by Donovan (2015), and Lean Index by Ray *et al*. (2006). Based on the above mentioned studies, two Lean Maturity assessments have been chosen in this paper which are most relevant in this context.

3.1.1 Lean Enterprise Self-Assessment Tool (LESAT)

Massachusetts Institute of Technology (MIT) assessment tool is one of the broadest system in business level invented by "Lean Aerospace Initiative" (Nightingale & Mize, 2002). As a supporter for MIT assessment tool, Enterprise Level Roadmap as shown in Figure 4, was developed to complete overall process of lean implementation. Entry/Re-entry cycle, Long Term cycle, and Short Term cycle are the main activities in the transition road map which support lean transformation.

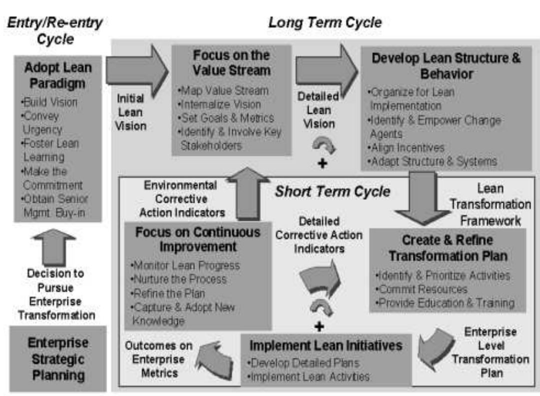

Figure 4 - Enterprise Level Transition to Lean Roadmap (Nightingale & Mize, 2002),

To complete the model, LESAT was proposed by LAI to support the model. There were five maturity statements in the LESAT Maturity, ranging from least capable (Level 1) to world-class (Level 5) (Nightingale & Mize, 2002). Main characteristics of each level has been described in Table 2 below.

Table 2 - LESAT defined (Nightingale & Mize, 2002)

Maturity level	Definition
Level 1	Some awareness of this practice; sporadic improvement activities may be underway in a few areas
Level 2	General awareness; informal approach deployed in a few areas with varying degrees of effectiveness and sustainment.
Level 3	A systematic approach/methodology deployed in varying stages across most areas; facilitated with metrics; good sustainment.
Level 4	On-going refinement and continuous improvement across the enterprise; improvement gains are sustained.
Level 5	Exceptional, well-defined, innovative approach is fully deployed across the extended enterprise (across internal and external value streams); recognized as best practice.

Although there are several models available for lean management, the completed model is developed by Lean Aerospace Initiative (LAI) which clearly defines principal activities and leading tasks as well as helpful enablers and instruments. The analysis of Hallam (2003) indicated that, thirty-one UK and USA industries have implemented LESAT. LESAT helps them to determine the current status of lean through an assessment process. However, like most of other available lean models, LAI's assessment relies on internal and external relations and strategic issues from the enterprise perspectives. A template of LESAT Maturity matrix is shown in Figure 5.

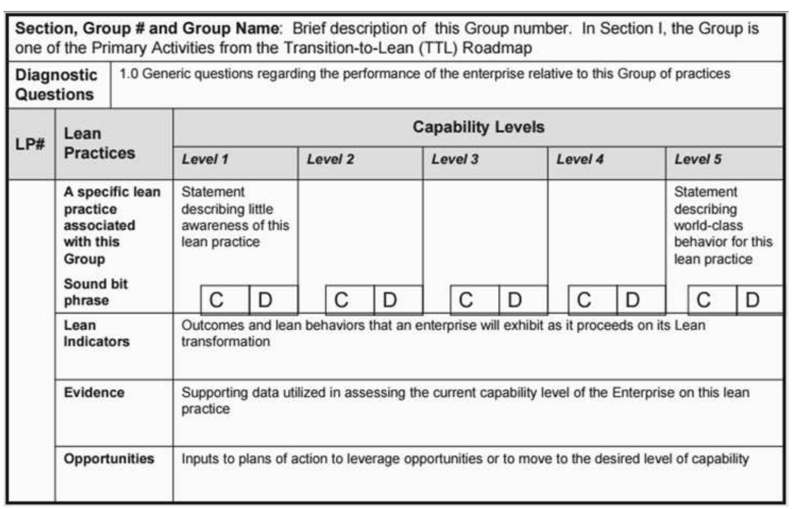

Figure 5 – LESAT Maturity Matrix Template

3.1.2 Lean Construction Maturity Model

Lean Construction Maturity Model (LCMM) was developed based on the CMMI model and its maturity levels. So, it comprises of five levels of maturity, 11 key Attributes, ad

60 defined Behaviours, Goals & Practices with 75 Ideal Statements to measure the maturity within organisations, which would provide essential support and guidance to the lean adoption in organisations (Nesensohn *et al*., 2014). Five maturity levels that are shown in Figure 6 measure the deviation between the Ideal Statement and the current state of the assessed organisation (Nesensohn *et al*., 2014). Each maturity level is defined in Table --- which are used to assess the project.

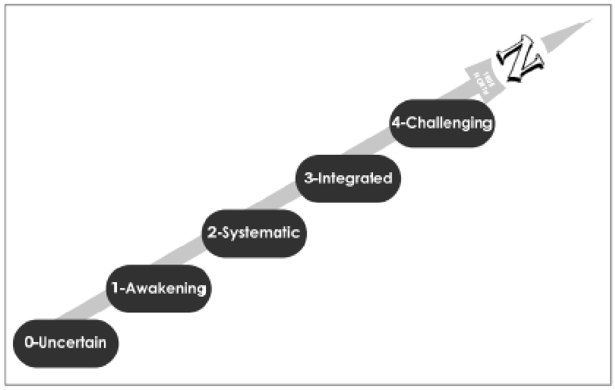

Figure 6 - Maturity Levels of the LCMM

Table 3 - Definition of the Maturity Levels

Maturity level	Definition
0-Uncertain	The Ideal Statement is hardly evidenced in action
1-Awakening	General awareness exists and the Ideal Statement is inconsistently evidenced in action
2-Systematic	The Ideal Statement is systemically evidenced in action
3-Integrated	The Ideal Statement is interrelated as a whole and happens automatically
4-Challenging	The Ideal Statement is status quo which is challenged to improve further

3.1 AN INTEGRATED BIM AND LEAN MATURITY MODEL (IDEAL)

BIM and Lean approaches provide many benefits to projects in many different ways when impalement individually. However, the integration of these two approaches would maximise the benefits and will result in better overall productivity and performance improvements (Mollasalehi et al., 2016). As the construction industry is realising the benefits of the interactions between these two approaches, there is an increased level of adoption of these approaches together (Mollasalehi et al., 2016; Sacks et al., 2010). Therefore, there needs to be an integrated maturity model to assess the level of BIM and Lean performances in projects that these two approaches have been implemented together. This paper proposes an integrated BIM and Lean Maturity Model which includes five main stages as shown in Figure 7. This model is based on critical reviewing of BIM and Lean maturity models which have been discussed in previous chapters. At each stage of this maturity model, the maturity levels of BIM, Lean and integrated BIM and Lean are defined. This integrated BIM and Lean Maturity Model which is called "IDEAL" Maturity Model, not only considers the level of BIM and Lean maturities individually, but it also considers the maturity level of these approaches collectively together. Firstly, by reviewing BIM and Lean maturity models separately, the authors extracted the main features and beneficial aspects of each model. Then, based on the findings from reviewing the maturity models and also the interaction between BIM and Lean approaches, the IDEAL model was developed. Each level in the IDEAL maturity model is described and defined in detail in relation to Figure 5 which can be demonstrated from Table 4. This IDEAL maturity model would enhance analysis of the projects' performances where BIM and Lean approaches are implemented together. Therefore, the performance of these two approaches would be analysed and assessed to better realisation of their benefits.

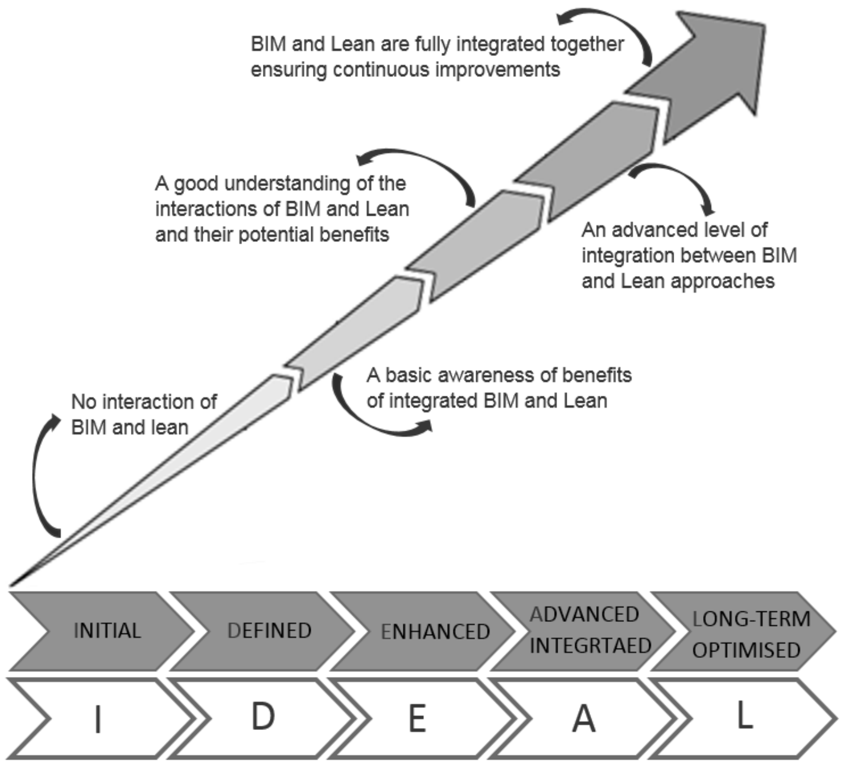

Figure 7 - IDEAL Maturity Model

Table 4 - Definition of the suggested IDEAL Maturity Level

Maturity Level	Approach	Description
Initial	BIM	There is not a defined systematic processes and policies in terms of BIM implementation. Therefore, BIM is not fully implemented and there is a lack of consistent support from the management team. Also, the use of software is not fully systematic and embedded amongst team members. Thus, there is no true collaboration between project members.
	Lean	There is some awareness of few lean practices or tools, but lean is not fully implemented. The philosophy of lean thinking is not well understood and adopted. Therefore, some activities in terms of lean adoption may be underway in a few areas but not to the full extent.
	Integrated BIM and Lean	As BIM and Lean approaches are not fully implemented, the potential benefits of interaction of BIM and lean are not recognised and fully understood. Even though, there might be few BIM and Lean activities undertaken, but they are not in line.
Maturity Level	**Approach**	**Description**
Defined	BIM	The management team is driving the BIM implementation but there is still a lack of true BIM knowledge, BIM software skills, and true mind-set. There are basic documentation of processes and policies, but due to lack of fully effective collaborative environment, BIM is not fully adopted. However, there is initial steps towards mutual trust/respect among project participants which intends to follow the BIM processes
	Lean	There is a general awareness in terms of Lean practices. Some informal approaches deployed in a few areas and some of the Lean tools are used.
	Integrated BIM and Lean	As BIM and Lean approaches are not fully implemented, the potential benefits of interaction of BIM and lean are not recognised and fully understood. Even though, there might be few BIM and Lean activities undertaken, but they are not in line.
Maturity Level	**Approach**	**Description**
Enhanced	BIM	There is a well understanding of BIM implementation vision by the majority of project participants. There is a BIM implementation strategy which is linked with the action planned that are in details. BIM is acknowledged not only as a tool, but a combination of technology, process, and people. Therefore, there is an advanced level of collaboration amongst project members.
	Lean	There is a systematic approach of Lean implementation in varying stages across most areas. The philosophy of Lean thinking is well understood and the lean principles and tools are being adopted within the projects.
	Integrated BIM and Lean	There is a good understanding of the interactions of BIM and Lean and their potential benefits. Some of the adopted BIM features are in line with the Lean principles to achieve the benefits of integrated BIM and Lean. For example, Last Planner System (LPS), as one of the lean tools, is implemented in line with BIM features, such as visualisation and collaboration.
Maturity Level	**Approach**	**Description**
Advanced Integrated	BIM	The requirements and processes of BIM implementation are fully integrated into organisational, strategic, managerial and communicative channels. Modelling deliverables are well synchronized across projects and tightly integrated with business processes. BIM standards and performance benchmarks are incorporated into quality management and performance improvement systems. Therefore, Productivity is now consistent and predictable in the BIM collaborative environment.
	Lean	Lean is fully implemented and there is on-going continuous improvements across projects. The philosophy of Lean thinking is fully understood and the Lean principles and tools are fully practiced towards continuous improvements.
	Integrated BIM and Lean	There is an advanced level of integration between BIM and Lean approaches. These approaches are working in parallel and towards same goals. So the interaction of BIM features with Lean principles are fully understood and the BIM and Lean implementation is practiced in line with those interactions.
Maturity Level	**Approach**	**Description**
Long-Term Optimisation	BIM	BIM vision is actively achieved. The implementation of BIM strategy and its effects on organisational models are continuously revisited and realigned with other strategies. Selection/use of software tools is continuously revisited to enhance productivity and align with strategic objectives. Collaborative responsibilities, risks and rewards are continuously revisited and realigned. Benchmarks are repetitively revisited to insure highest possible quality in processes, products and services.
	Lean	The lean philosophy is embedded within the organisational level and the lean principles and tools are fully implemented. The lean practice is repetitively revisited to insure highest possible quality in processes, products and services.
	Integrated BIM and Lean	BIM and Lean are fully integrated together towards achieving the highest possible quality and productivity of the project and processes. Therefore, BIM features are implemented fully in relation to Lean principles to ensure continuous improvement of projects.

CONCLUSION

It has been recognised that there is a need for an integrated BIM and Lean maturity model to assess the performances of projects that implement both BIM and Lean together. As the aim of this paper was to propose an integrated BIM and Lean maturity model, a review of the existing maturity models and assessments were conducted for BIM and Lean individually. Thus, this paper adopted some of the initial concepts of the current BIM and Lean maturity levels and then through looking at the interaction of the BIM and Lean, an integrated BIM and Lean maturity model was proposed.

This paper proposes a maturity model named "IDEAL" which aims to assess and analyse the performances of the projects that are implementing BIM and Lean together. This IDEAL model comprises of five main levels which are in line with the level of integration of BIM and Lean. Therefore, the performance of these two approaches could be analysed and assessed through this proposed model to better realisation of their benefits.

This paper proposes this model, but the next stage of this study is to then validate this proposed model in a real-life construction project. So, the authors of this paper would recommend the use of the IDEAL maturity model in construction projects to both validate the model and assess their performances in relation to the adoption of integrated BIM and Lean. Also, it is recommended to examine and investigate the usage of the IDEAL model amongst the projects to better identify its benefits.

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APPLICATION OF 4D BRIDGE INFORMATION MODEL AS A LEAN TOOL FOR BRIDGE INFRASTRUCTURE PROJECTS: A CASE STUDY

Aneetha Vilventhan[1], R. Rajadurai[2]

ABSTRACT

Construction projects require the coordination of multiple organizations. The production flow of these projects is often hampered through sources of wastes such as improper utilization of the skills of the labours and lack of coordination with the multiple organizations involved in these projects. Bridge information modelling provides a powerful platform for visualizing work flow and collaboration between organizations throughout the life cycle of the project.

In this paper, 4D bridge information models for a concrete bridge (flyover) construction project was built through integrating 3D BrIM model with the schedule. The developed 4D bridge information model enabled value addition through improved visualization, co-ordination and communication among project participants. This study provides a practical contribution by showing that project stakeholders can use 4D BrIM models as a lean tool to prevent undesirable situations and reduce the overruns, rework and improve the effective utilisation of labours in Bridge construction projects.

KEYWORDS

Lean tool, bridge information modelling, visualisation, coordination, 4D BrIM model.

INTRODUCTION

Construction projects involve multiple participants where they execute independent and mutually exclusive goals, often resulting in poor coordination, rework, and incorrect work. Lack of coordination and communication were considered as one among the factors attributing to generation of construction wastes (Gill 2012). Lean concepts provides a way to minimize waste and maximises value of the system (Koskela 1993; Hosseini et al. 2011). Lean concepts considers 7 types of waste namely overproduction, inventory, extra-processing, motion, travel, defects and waiting in a process flow (Dubler et al. 2010). Though lean concepts were originally developed for manufacturing industry

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and the construction industry incurs high level of variability, lean principles of flow design were common for both manufacturing and construction processes (Koskela 1993). The reduction in wastes can be achieved through adoption of lean tools and techniques like Last Planner System (LPS), Concurrent engineering, work structuring, Value Stream Mapping(VSM), daily huddle meeting and many others. The implementation of lean methodologies in construction imparts significant improvements in workflow and overall performance of the process (Castillo et al. 2015) and improves coordination and communication among project teams in construction (Castillo et al., 2015; Mahalingam et al., 2015).

As like lean concepts, Building Information Modelling(BIM) also shares a common platform of coordination and collaboration throughout the projects lifecycle (Porwal and Hewage 2013). Unpredictability in the construction were being the source of waste and disrupts the performance of the process (Yu et al. 2009). The adoption of BIM helps to visualise the process, coordinate and communicate information's for the better performance of the project. (Chen and Luo, 2014; Mahalingam et al., 2015).

Though BIM and lean construction differs, research states they share significant synergies and efforts were taken in literatures to integrate lean and BIM in construction process (Dave et al. 2010). This paper adopts 4D BrIM models to improve coordination and communication among project participants in an ongoing bridge construction project in India. This paper tries to minimise the lean wastes associated in the construction process of the bridge construction project through the application of 4D Bridge information models(BrIM). The BrIM models were used to improve the coordination and reduce the uncertainties in the workflow.

LITERATURE REVIEW

REVIEW ON THE APPLICATIONS OF BIM

Building information modelling (BIM) is generally referred as both technology as well as a process (Mahalingam et al. 2015). BIM has changed the traditional way of work with respect to design and execution in architecture, engineering and construction (AEC) industry (Cheng et al. 2016). Currently around 122 BIM software systems are present and are being used in different domains of construction industry namely the architecture, structural engineering, building services, project management/design coordination, facilities management, sustainability and geographical information systems-BIM (Kumar and Mukherjee 2009). The use of BIM has been practiced in various stages of construction and different purposes like visualisation, estimation, coordination, monitoring and control, asset management, rehabilitation and risk mitigation.

Given the success and benefits of adoption in BIM in AEC of building projects, BIM has also been adopted for infrastructure projects like bridges and tunnels and was referred to as Civil Information Modelling(CIM) (Cheng et al. 2016). The studies suggest, the adoption of BIM in infrastructure generates value creation, enhance coordination and communication through common data exchange platforms (Kumar et al. 2017).

Application of BIM in bridges, also called as Bridge Information Modelling(BrIM) (Marzouk and Hisham 2014) were studied by various researchers. Augmenting object and its parameter as openBriM standards to facilitate interoperability on information were studied (Jeong et al. 2017). These OpenBrIM neutral schema were mainly applied to perform engineering analysis of bridge structures (Jeong et al. 2017; Xiao; et al. 2017). As like the uses of BIM in building projects, the BIM on bridge structures offers various applications like 3D modelling, Visualisation, clash detection, structural analysis, Quantity Estimation, Project monitoring and control, Risk Assessment, Assets maintenance (Kim et al. 2011; Marzouk and Hisham 2014; Fanning et al. 2014; Zou et al. 2016; McGuire et al. 2016; Xiao; et al. 2017). The use of BIM on bridge infrastructure were proposed in different stages in construction like preconstruction, post-construction, construction.

However only limited studies like visualisation, setting out of site boundaries (Chong et al. 2016), cost control (Fanning et al. 2014), earned value analysis (Marzouk and Hisham 2014) and schedule management via telepresence (Kang et al. 2016) were presented during construction stages, while other applications were proposed on preconstruction stages.

REVIEW ON THE INTEGRATION OF LEAN AND BIM

Though there exist differences in processes between BIM and lean, they both share some set of concepts in common. Studies have indicated the synergies existing between through matric interactions and have identified the existence of 56 constructive interactions between lean and BIM (Sacks et al. 2010). Khanzode (2010) addressed the interaction of VDC (Virtual Design and Construction) and lean in the name of IVL (Integrated, Virtual Design and Construction and Lean) to develop a pull schedule and improve the coordination of MEP systems in a project. In a study, Zhang and Chen (2016), considers BIM as one among the lean tools and techniques to eliminate wastes in the system. Further studies have proposed the use of BIM and Lean concepts in case studies to find how BIM facilitate the adoption of lean in construction and concludes by sighting the benefits of increased value and waste reduction by them (Gerber et al. 2010). In contrast, studies were also made to investigate the mediation of lean practices for BIM adoption and argues lean enabled effective BIM adoption (Mahalingam et al. 2015). Interaction of BIM and lean were discussed to develop an integrated BIM simulation framework to produce reliable plan and minimise waste in the construction process (Jeong et al. 2016).

The collaboration of lean and BIM concepts were proposed as solutions for improvement and overcoming the problems in design management practices (Tauriainen et al. 2016). Several recommendations like target value design, big room were made to improve the flow of information and communication among participants. In another study the concepts of information technology and lean were combined in the form of simulation game called RBL(RFID/BIM/Lean) and were developed as a learning tool for production of prefabrication housing, where metrics of PPC, productivity index were used to evaluate the simulation (Li et al. 2018). The study of lean and BIM was also applied for the operation and maintenance processes to enhance integration and sharing of information and reduce waste via pull planning (Shou et al. 2014). Likewise, the use of BIM and lean is also incorporated in infrastructure projects. Lean and BIM concepts of LPS and visualisation respectively were mainly integrated to develop a software named VisiLean to control projects (Dave et al. 2010). Though Dave et al. (2010) proposed a way to apply lean and BIM for infrastructure projects, the idea of application in infrastructure projects to control project performance remain unexplored.

RESEARCH METHODOLOGY

A constructive research methodology is adopted in this paper. The Constructive research as a methodology provides strong grounding in identifying a practical problem from practice, complemented by related literature and the identified research problems are solved by developing or constructing a solution which will be operationalised to determine its workability and appropriateness (Oyegoke 2011). This kind of research pertains to creating and testing an artefact. Case studies allows investigators to understand and analyse the holistic and meaningful characteristics of contemporary events (Yin 1994). This paper considers an ongoing bridge project as a case for study, identifies associated problems and develops 4D bridge information models to minimise the problems faced during construction.

The study considers direct interviews, site drawings and site documents as the source of evidences for data collection. The study captures contemporary events of the case considered and performs modelling activities. The research methodology adopted to perform the study is shown in figure 1.

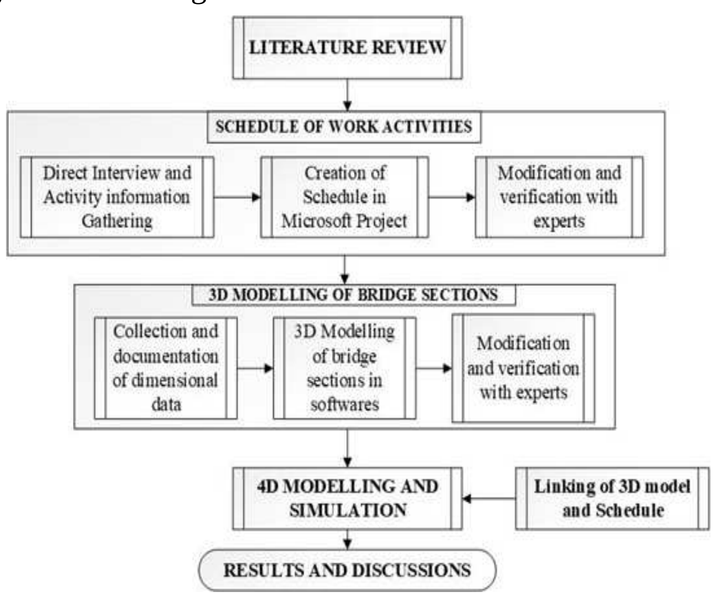


Figure 1 Research Methodology

BACKGROUND OF CASE STUDY

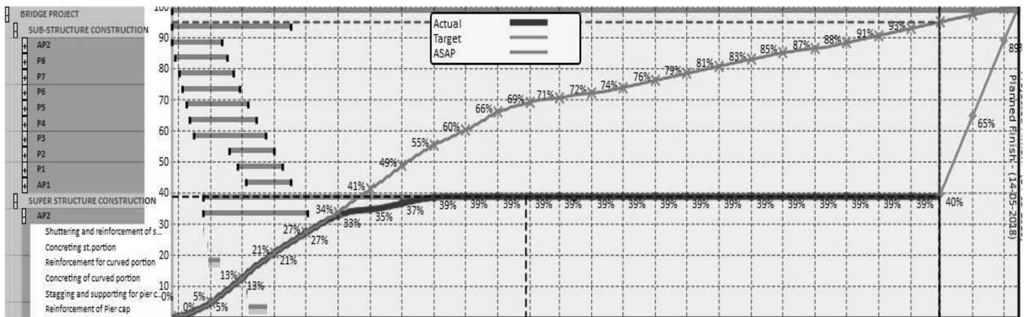
The paper considers an ongoing bridge construction as a case study for the application of lean and BIM concepts. The bridge spans to a total length of 711 metres with two approach roads, 10 piers and 9 spans each of 30m length. The width of the bridge is designed to support 6 lane provision. The duration of completion was estimated to be 2 years and is currently ongoing. The project considers traditional method of project management and do not use lean and BIM concepts in design and execution stages. The details of the project are tabulated in table 1.

Table 1: Details of Case study

Content	Description
Project Title	Construction of flyover at the junction of NH-45 and Vandalur
Location	Vandalur, Chennai
Estimated budget	55crores
Estimated duration	2 years
Purpose	To reduce traffic congestion at Vandalur junction

DEVELOPMENT OF SCHEDULE

A schedule representing the entire sequence of activities from the planned start date were developed. The project site uses a schedule in an excel format, however they were not shared due to confidentiality issues. Hence a new baseline schedule as per the sequence of construction in site was developed in Microsoft Project 2016. From direct interview with the project manager at site, details of construction activities like duration of activities, start date, resource required and sequence of activities were collected and a working schedule was prepared. The developed schedule was reviewed by the project manager and necessary modifications were incorporated. The developed schedule was then used for tracking the performance of the project. The baseline was set and the tracking of progress was performed. The S curve profile for the planned and actual progress were determined using the software. This enabled the project team members to find out exact delay incurred and other performance matrices. The developed s-curve is shown in figure 2.



Planned	94	243	398	526	648	795	939	1064	1158	1269	1328	1356	1386	1418	1464	1508	1550	1595	1636	1661	1697	1739	1785	1825	1869	1909	1...
Actual/Target	94	243	398	526	628	668	707	740	746	746	746	746	746	746	746	746	746	746	746	746	746	746	746	762	1245	1710	1...
Planned %	5	13	21	27	34	41	49	55	60	66	69	71	72	74	76	79	81	83	85	87	88	91	93	95	97	99	1...
Actual/Target %	5	13	21	27	33	35	37	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	40	65	89	1...
Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	M...
Year	2016										2017												2018				

Figure 2 Developed S-Curve

DEVELOPMENT OF 3D MODELS

Though use of 3D BIM models were used in AEC industry, still 2D drawings were used for design and construction for bridge infrastructure projects (Lee et al. 2012). The case project used only 2D drawings for design and construction. The printed 2D drawings of the bridge was studied carefully and were used to design the elements in modelling software Autodesk Revit 2018. Use of geometric and parametric 3D models of bridge elements were adopted in the study. The structural elements like column, footing, beam, slabs were modelled as 3D Revit family members. The parametric model of footing family of bridge and the geometric model of longitudinal girder families are shown in figure 3.

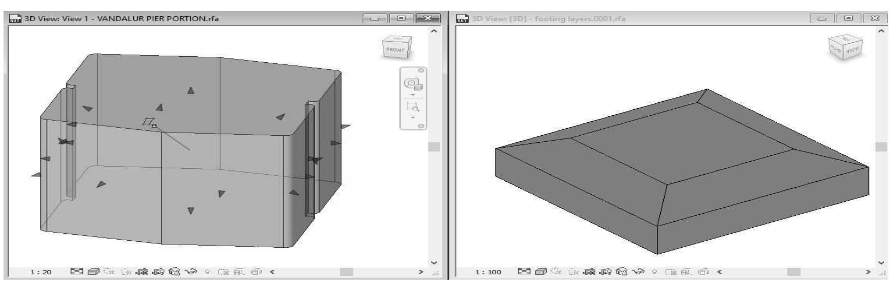


Figure 3 Representation of developed Revit family members

Use of opinions from the expert in the field of modelling were considered for developing the models. The bridge information like material of the section, strength of concrete and other properties were given as input in the 3D models. The necessary modifications in the models were made as per the review and discussions with the project manager at site. The developed 3D model is shown in figure 4 below.

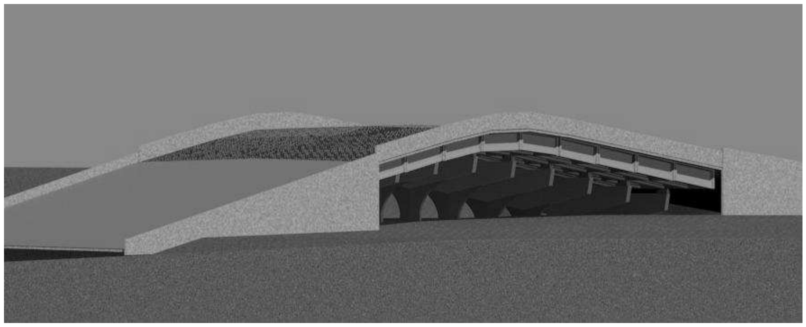
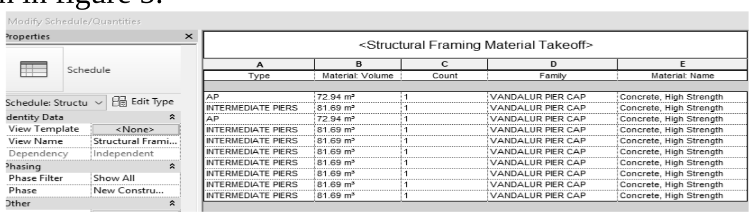


Figure 4 3D Rendered Image of the bridge

From the developed 3D models, the estimation of quantities of materials was performed. This enables the participants to estimate the work activities in short duration of time. The project members were then trained to use a collaborated platform where they can visualise, estimate quantity and perform analysis. The sample estimate of pier cap portion is shown in figure 5.



<Structural Framing Material Takeoff>

A Type	B Material: Volume	C Count	D Family	E Material: Name
AP	72.94 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
AP	72.94 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength
INTERMEDIATE PIERS	81.69 m³	1	VANDALUR PIER CAP	Concrete, High Strength

Figure 5 Quantity take-off from 3D models in Revit

DEVELOPMENT OF 4D MODELS

The schedule and the 3D model were then linked together to develop a 4D model in Naviswork (figure 6). The 4D simulation was presented to the project participants in their weekly meeting. Along with the simulation of entire construction process, comparison of planned progress and actual process through simulation was also performed. This helps the participants to have a clear virtual real time idea of how far they were lagging and what they have to accomplish in future periods.

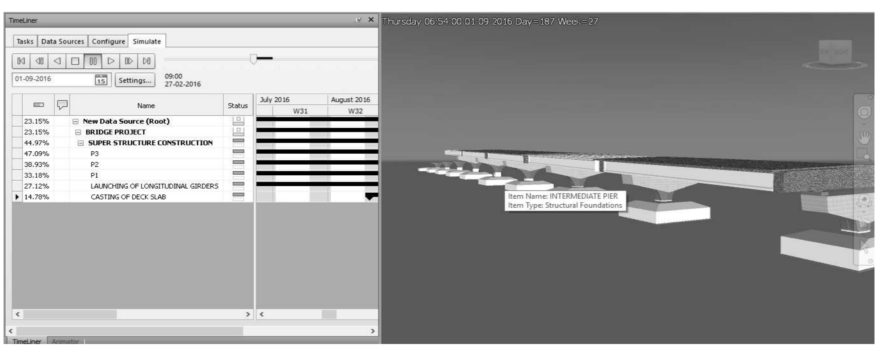


Figure 6 4D simulation of the bridge

From the obtained S-Curve, the actual completion status of the project was found to be 50%, while the planned completion status has to be 94%. The major factor contributing to the delay and non-achievement of planned targets is poor coordination between the contractors and sub-contractors. This results in underutilisation of the efficiency of the labours in site. The BrIM models were then presented to the project team and they have been explained to the project team by the authors. It further created a space to share individual's ideas and opinions about the progress of work and the problems faced. The visualisation of 4D simulation of activities enabled the participants to visualise virtually the problems during construction and to suggest an effective way to implement the activities to complete it within the planned target dates. This enabled collaboration and coordination among different crews present in the process. As a result, the project team was able to understand their lacking potential and places where they can improve their potential with the available resources in hand. It helps to effectively use the potential skills of the labours thereby reducing the waste of underutilisation of the skills of the participants in the project. It was clearly observed that the project team was interested to work on these platforms through their conversations and discussions. The participants at the meeting were enthusiastic to further discuss about the development of models. Thus 4d Brim Models were used as a lean tool to reduce rework and overruns in the project. The sequence of construction simulation is shown in figure7.

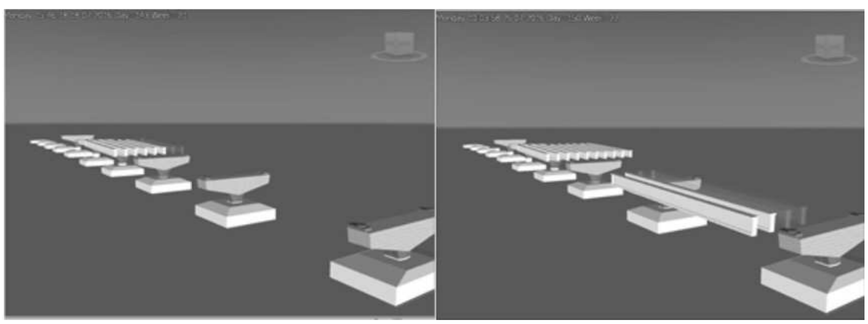


Figure 7 Simulation of construction sequence

LIMITATIONS OF THE STUDY

Though the study applies BrIM as a lean tool in a bridge infrastructure project to reduce rework and overruns, the paper fails to identify the combined effect of lean and BIM in the study.

CONCLUSION

Study of the application of 4D BrIM models are limited in literature. This study develops simulation 4D BrIM models for an ongoing bridge construction project to enable visualisation of entire construction process. The simulation of planned performance and actual performance were performed. The project team used these models for their discussion to make effective decision to improve their further performance. The models and simulation enabled collaboration and coordination among the different labour crews in the construction process. Thus the study concludes that application of BrIM as a lean tool enables value addition through improved visualization, co-ordination and communication among project participants. However, further studies are needed to explore hidden opportunities underlying the application of lean and BrIM in infrastructure projects.

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WHAT IS *LEAN CONSTRUCTION:* ANOTHER LOOK - 2018

Alan Mossman[1]

ABSTRACT

There is no agreed definition of lean construction. This is a problem for some and not for others in the lean construction community and beyond.

Answers to the question "***what is lean construction?***" from a simple survey reported here, on the web and in the formal and informal literature reveal a diversity of views. The purpose of the survey was to get a sense of the definitions-in-use in the lean construction community.

Some of the implications for the community are outlined and suggestions made for further study.

KEYWORDS

lean construction, lean, definition,

INTRODUCTION

> "*there is no universal accepted, explicit definition of lean construction*
>
> Dauber 2003: 29

> "*a multifaceted concept that defies universal definition* Green and May 2005

> "*Various parties within construction … have different explanations of what lean construction means. There are inconsistent definitions and little agreement among practitioners.* Leong et al 2015

> "*Lean does not have an agreed definition, it has numerous, …, this is the subject of discussions between academics, and professionals. Not having a specific definition has not stopped Lean from being successfully applied in motor manufacturing".*
>
> O'Neil 2016

> *The first problem in introducing Lean Construction in Japan is that its definition is not clear.* Inokuma 2017

Some suggest there should not be a definition. Others argue that there should. The stimulus for this paper was reading this definition in a recent PhD thesis:

> "*A combination of original research and practical development in design and construction with an adoption of lean manufacturing principles and practices (i.e.,*

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> *Toyota Management System) to the end-to-end design and construction process. Lean construction is concerned with the alignment and holistic pursuit of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging and recycling. Austin 2016*

Even though the literature is littered with definitions, I looked in vain in the PhD for sources for this definition (this study has shown the first sentence is virtually identical to the one offered by Wikipedia, the second draws heavily on part of the AGC definition).

WHAT IS A DEFINITION?

"*An exact statement or description of the nature, scope, or meaning of something*" Oxford English Dictionary [from Latin *definitio*(n-), from the verb *definire* 'set bounds to'].

This raises questions about what is meant by ***nature***, ***scope*** and ***meaning***. There is not space here to discuss that.

An **operational definition** defines the subject of the definition in such a way that it can be measured (Deming 1985; 1994, 150). As Leong et al (2015) note: 'An operational definition puts communicable meaning into a concept. … lean thinking & lean construction are concepts and there is a great deal of confusion in industry regarding these concepts.'

WHAT ARE THE CRITERIA FOR A GOOD DEFINITION?

Greg Howell's criterion for a successful definition of lean construction (that practitioners of traditional construction should ***not*** be able to assert "*we do that*" ***and*** be able to ground their assertion) is an example of a simple yes/no metric (Howell, personal email).It is very, very difficult to learn when you already know (or just think you know). Common retorts to attempts to define or explain Lean Construction begins with:

> *"Oh, we do that already";*
> *"there's nothing new here, it's all common sense";*

Both comments indicate that the individual has decided that there is nothing new to learn and illustrate why Howell's criterion is so important.

A definition of lean construction could reasonably be expected to:

- **differentiate—** and therefore exclude those who practice traditionally
- **be operational —** in Deming's sense
- **be concise —** *as simple as possible and no simpler* as Einstein may have said
- **reduce communication difficulties** (Dale & Plunkett 1991 in Boaden, 1997 quoted by Petttersen 2009).
- **simplify education** on the subject (Boaden 1997 quoted by Petttersen 2009).
- **make research easier** (Godfrey et al 1997; Parker 2003) - although Boaden (1997) states that this is not essential(all quoted by Petttersen 2009)[2].

[2] This and the previous criterion begs the question "*what is the definition of traditional construction?*"

- **make it easier to define overall goals of the concept** (Andersson et al, 2006 quoted by Petttersen 2009).

BUT/AND

If, as I believe, one of the presuppositions about lean and lean construction is that "*nothing is so good that it cannot be made better*" any definition can be improved. As Bertelsen notes (see below) *our understanding has changed and continues to change*.

Howard Ashcraft wrote (email)*:I think that you need at least 2 definitions. One to illustrate how Lean differs from traditional practice (gatekeeper definition) and one that illuminates its essence (philosophical definition).*

ADVANTAGES OF A DEFINITION OF LEAN CONSTRUCTION

- To increase the chances that researchers and writers are researching & writing about the same topic (c.f. Green & May 2005, Green 2011; see Mossman 2012)
- Green (2011) suggests it will increase chances that lean construction will consistently live up to the claims made for it– [I'm not sure how that works]
- make it easier to evaluate its application and its effectiveness (Leong et al 2015)
- remove an obstacle to adoption by contractors (Gao and Low, 2013; Stevens, 2014).

ADVANTAGES OF NO LEAN CONSTRUCTION DEFINITION

I feel the lean construction community is similar to a religious community. If that is true:

- reduces potential for bitter rivalries and schism arising from defining' *one true way'*
- the different images of lean construction implicit in the variety of definitions that already exist offer a richer set of ideas and possibilities, than one single view could.

A SELECT CHRONOLOGY OF DEFINITIONS

The term *lean construction* appears to have been coined in 1993 in time for the first IGLC meeting.

At IGLC in 1999, Howell presented "What is lean construction" concluding: *Lean construction results from the application of a new form of production management to construction. Essential features of lean construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design to delivery.*

In 2002 Lauri Koskela, Greg Howell, Glenn Ballard & Iris Tommelein (p.211) defined it as *"A way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value."*

At the 12th IGLC in 2004 Luis Alarçon is reported to have said "*We started the discussion about what we mean by lean construction in 1993 in Espoo, a discussion we have had since then. And we still do." [personal email from Sven Bertelsen in 2010]*

In a CII report, Diekman*et al* (2004) wrote "*the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project*."

In 2005 there was a discussion in the IGLC yahoo group "*Should we answer the question "What is lean construction?"?*"

Both Court 2009 and Sayer & Anderson 2012 quote LCI's definition: "*a production management based approach to project delivery, a new way to design and build capital facilities.(c.f. later LCI definition below)*

In LCI's *Transforming Design & Construction- a framework for change* (Seed 2010) the five-page chapter titled "Lean construction defined" offers: *a respect- and relationship-oriented production management-based approach to project delivery—a new and transformational way to design and build capital facilities.*

By 2012, in presentations, Glen Ballard was using "An application to construction of a management ***philosophy*** defined by the ***ideal*** it pursues,the ***principles*** followed in pursuit of the ideal, and the ***methods*** used to implement the principles." Greg Howell was using this same wording by 2013.Ballard continues to use that form of words (e.g. at the Dec 2017*Lean in the Public Sector* meeting). In a 2012 IGLC paper Ballard defined what he understands the words in bold to mean.

At IGLC in 2012 Pekuri*et al* reported *"… it is still difficult to define exactly what the term "lean construction" means."*

Abdelhamid's website (2013) includes"*A holistic facility design & delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic & continuous improvements in contractual arrangements, product design, construction process design & methods selection, the supply chain and the workflow reliability of site operations*."https://msu.edu/user/tariq/Learn_Lean.html 19nov17

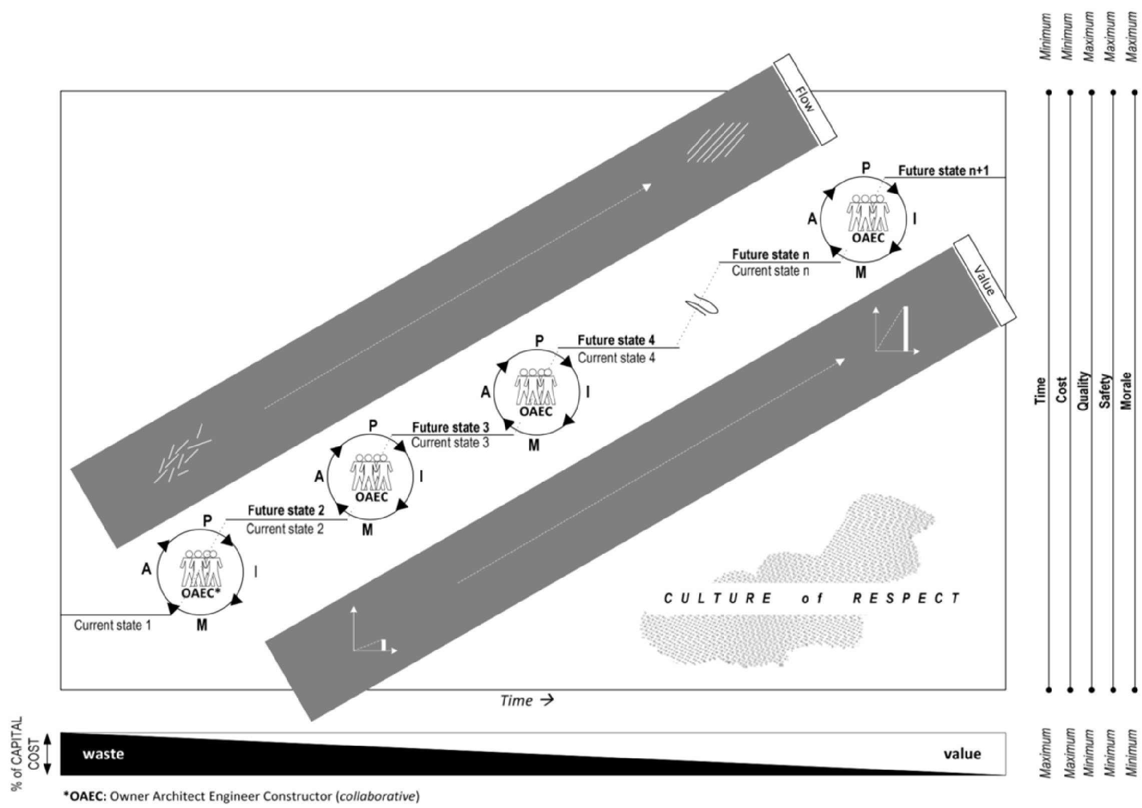

Figure 1: The "who, what, where, how, when and why" of lean construction.
Source: Rybkowski 2012

In 2013 Rybkowski*et al*. presented "On the Back of a Cocktail Napkin: An Exploration on Graphic Definitions of Lean Construction". Their conclusion is shown in Figure 1.

Two years later Leong et al (2015) sought an 'Operational Definition of Lean Construction Onsite'. The authors conclude "*In order to [*test the leanness of construction projects*], we must first have a robust and defined methodology and operational measures of what lean construction is, i.e. a standard measure of lean application (leanness).*"One of the authors told me that a tool to test the leanness of construction projects exists (and is valued by users) but there is no robust operational definition of lean construction *per se*.

The latest P2SL glossary equates lean construction and lean project delivery: "Lean Construction, Lean Project Delivery = Application of lean thinking to the designing and making (or delivery at large) of capital projects (or projects in general).

The LCI website, quoted by Gao & Low 2014, offers "*A production management-based approach to project delivery …[that] is particularly useful on complex, uncertain and quick projects*."

The Integrated Project Delivery Collaborative website includes "*a production management based approach to project delivery – a new way to design and build capital facilities*. http://ipdfl.net/processes/ipd-lean-construction/ 19 Nov. 17

METHOD

From time to time we all have to answer this question: "**What is lean construction?**" I wanted to know the favourite answers used by members of this community. So, using a virtually identical request, I asked the community via a number of overlapping channels:

- LinkedIn article. That article was "reposted" 3 times by others.
- Posting a 'discussion' on 2 lean construction groups on LinkedIn
- Email to the IGLC yahoo group, copied to selected individuals.
- I also took definitions from the first 20 results from Googling the question.

Altogether, within a period of six weeks I received 42unique 'definitions' via email or via comments on LinkedIn from 39 authors – yes, some people submitted 2 or more definitions. In addition, I have considered 26 definitions retrieved via Google search on the term 'what is lean construction?' This is not a systematic review of the literature.

WHAT IS LEAN?

According to the Lean Enterprise Institute http://www.lean.org/WhatisLean (14Apr16) *lean = Creating more value for customers with fewer resources.*

Chauncey Bell suggests that lean is not definable. He put his thoughts on the subject into the *Forward* he wrote for Hal Macomber's recent book *The Pocket Sensei*:

> *"Most of those who employ this word [lean] today think that they are pointing intelligibly to coherent, valuable practices, tools, and methods – whether originally derived from the Toyota experiences or not – that will move people and organizations toward some cohesive path of improved action. However, the word* lean *itself does not reliably indicate any particularly organized direction of thinking for improving a difficult situation, despite what we might guess from reflecting on old jargon such as* lean and mean*. There is no stable method or approach called* lean*…. …. Unfortunately, what the word lean points to today is little more than what the word* modern *indicates.* (*Macomber 2017, xiv*)*"*

In an email Chauncey wrote*:*

> *"I am a serious critic of the current enactment of … lean …. It misses the mark for many reasons. …. … it is a slogan used by all manner of people, some of whom are serious people, and too many are shallow wannabe's looking for the latest fad.*
>
> "*For me, the lack of a heart of the matter is not a bad thing.*
>
> "*Lean as we watch it today, is an American tradition built by consultants and writers attempting to say sexy things that come out of the wake of what Ohno and colleagues did at Toyota. Their observations were idiosyncratic, fragmented, without ANY attention to the heart of the matter which has to do with cultural traditions and language. The discourse failed at all of the big 3 automotive companies, has produced a collection of important practices in manufacturing in the West, and is busy failing in construction in the West.*

> “***I think that we'll all be better off if what we call lean is replaced, soon, by some new exploration.*** *[my emphasis].* *Chauncey Bell, email*

In an email unconnected with this study Koskela wrote something similar:

> *there is no robust explanation for lean. This makes it easier to reject lean. (17Nov17)*

SURVEY RESPONSES: WHAT IS LEAN CONSTRUCTION?

Sven Bertelsen emailed (Sven’s emphasis):*This seemingly simple four-word question is hard to answer, not least because our understanding has changed over the years and is still changing. …. The most important thing is that Lean Construction is based on theories about the project’s nature. Originally the Transformation-Flow-Value theory* [Koskela 2000]*, …. In practical terms, this implies that the client and his satisfaction is the guiding light and the schedule is more important than the budget in the day to day management. …. A later theory … is* ***complexity theory*** *... This makes Lean Construction accept and deal with the construction projects’ natural complexity and dynamics, and treat it as an adaptive system existing on the edge of chaos. …. Finally, Lean Construction stimulates and improves* ***cooperation between trades*** *in the daily operations, and thereby further stimulates the learning process. [Thus] Lean Construction is:*

> *1. “A new way of managing projects based on two theories, The Value-Flow-Operations theory that puts schedule & logistics before budget & work, and chaos theory that introduces pull logistics through Last Planner.* *Sven Bertelsen, email*
>
> *2. “A management principle that stimulates continuous learning and improvement and supports cooperation.* *Sven Bertelsen, email*

Sven is not the only person with 2 or more offerings. John Rooke offered three:

> ***1. lean = the design of slack****. (Slack being the amount of redundancy that a complex system requires in order to sustain itself. Too little slack leads to breakdown, too much is waste. The problem, then, is to distinguish between waste and necessary slack. This is coherent with a Flow perspective)* *John Rooke, email*
>
> *2. principally the management of learning and commitment* *John Rooke, email*
>
> ***3. (favourite)*** *the elimination of waste, particularly waste of time.* *John Rooke, email*
>
> *“A collaborative, proactive, transparent, and involving environment, focusing on an optimal production flow for the end product, systematically and visually using combined work and plan processes, cross-functionally keeping the bigger picture in mind.”* *Hans Thomas Holm, Linkedin*
>
> “*a way of thinking to create more value for the customer with fewer resources; focus on flow, continuous improvement and value for the customer.* *Anon, email*
>
> *“exactly what the customer wants, exactly when they want it, with nothing in store.* *Kristen Parish, email*

*Kristen Parish added:*Clearly, you can't perfectly do this in construction (hence, strategic buffers), but I tell students and professionals alike that we should strive for this.

"synchronised harmony *Christine Pasquire, email*

Christine Pasquire explains: *this I believe covers every aspect of lean construction when you unpick the meaning of each word and their combined use. There is no way prevailing practice can make any claim under either word ….'*

*Shang Gao*offered both the Koskela*et al* 2002 and the above LCI definition commenting*:both acknowledge LC is a production system for projects. The first one also highlighted three goals of a production system - deliver project, minimize waste and maximize value. The second one points out what kind of projects are suitable for LC*.

All the definitions received and others found on the web (together withan analysis of the concepts included in or alluded to in each of the definitions) are in an appendix published elsewhere [on Researchgate.net at https://bit.ly/2KYPDsT]. The analysis of the 68definitions submitted is summarised in Table 1:

Table 1: summary of definition analysis – most frequently mentioned concepts + #

Concept	**#**	**Concept**	**#**
Value, customer need	35	Flow	8
Waste reduction	17	Thinking, lean thinking	8
Collaboration, team work	16	Lean manufacturing, TPS	6
Delivery, outcome	15	Lean principles	5
Production Management	14	LPS or ref to key features of LPS	5
Less input, resources required	13	Reliable	5
Continual/continuous improvement	11	Faster and other refs to speed, time	5
Process or system	10	Efficiency	4

Other concepts identified in the content analysis were: new (4), whole process (4), operational strategy (3), action (2), commitments (2), learning (2), philosophy (2), respect for people (2), TFV (2), tools, techniques (2), trust (2) – 7 others were mentioned once.

Should the lean construction community be worried that there is so little agreement?

THE PURPOSE OF LEAN &LEAN CONSTRUCTION

Perhaps the easiest way to think about lean is in terms of its purpose. What we now know as lean was developed **to enable Toyota to shorten the time between making a vehicle and being paid for it**.

An early statement of IGLC's purpose was "*to better meet customer demands and dramatically improve the AEC process as well as product. To achieve this, we are developing new principles and methods for product development and production management specifically tailored to the AEC industry, but akin to those defining lean production that proved to be so successful in manufacturing*." http://cic.vtt.fi/lean/index.htm 12jun05

Ebbs 2017 wrote "*The purpose of Lean is to provide every customer's value in the most efficient and effective manner possible*." Like the purpose of lean suggested above there is no end, no destination for this purpose — it is, in Womack and Jones' words, a pursuit of perfection and that pursuit can have no end. But note: this too fails the Howell criterion.

Stafford Beer was fond of asserting that the purpose of a system is best assessed by studyingwhat it does (e.g. "a system is what a system does" (e.g. 2003)

Sacks *et al* (2017) describe the evolution of lean construction and what it does:

> *Lean construction can be seen as a progression not simply from craft and industrialized construction, but also from mass construction. Figure* [2below]*shows Lean Construction as derived from the three other classifications (craft, industrialized and mass construction). It inherits concepts from all three, as well as from Lean production.*

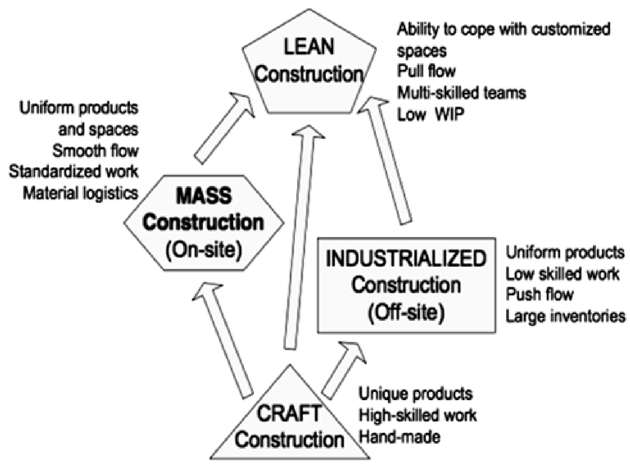

Figure 2: Evolution of construction production systems. *Sacks et al 2017*

DISCUSSION

Rybkowski et al (2013) report that when ZofiaRybkowski asked Greg Howell why the question "What is Lean Construction?" never goes away, he responded: *"Is-ness is the problem for me. This is a computer, this is door. ….**It surely would be better if we dropped the term lean.**…."* (personal communication 2010) [my emphasis].

A number of respondents suggested that their definition depends on who is asking, or on the context. Rybkowski et al (2013) report that Alan Mossmantold one of the authors: *"If someone asks 'What is lean construction?' I start by trying to find out why they want to know and what they already know. Then I have some ideas about how to respond. I feel that you are making a problem where none exists. Live with the ambiguity and help your students to do that too"* (personal communication 2010).

Perhaps this explains why Iris Tommelein, custodian of the LCI Glossary entry above, wrote (2018) "*Lean construction is systems thinking, respecting people, pursuing continuous improvement, and so much more.*"

CONCLUSION

This brief study has revealed the diversity of views about the nature, scope and meaning of *lean construction*.

My own conclusion from this small study is that "lean" is *a practical collection of theories, principles, axioms, techniques and ways of thinking that together and severally can help individuals and teams improve the processes and systems within which they work*. I don't believe that this meets the Howell criterion, nor is it an operational definition.

Until we have an alternative to "lean construction" there is plenty of opportunity for further work in this area. The quick and dirty content analysis (summarised in Table 1) might be reviewed and a more systematic collection of ***published*** definitions be made.

In the meantime, I wonder if it would be more helpful to focus on defining the purpose of the system that we call 'lean construction'.

ACKNOWLEDGEMENTS

I am grateful to all who responded to my question – those who wanted to be,are named with their contribution.

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A LEAN E-GOVERNANCE APPROACH TO MITIGATE CORRUPTION WITHIN OFFICIAL PROCESSES IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

Delays in construction projects lead to litigation-related issues and waste of money, in addition to rescheduling task and deliveries to fit the newly delayed plan, which is no easy task to accomplish given the hundreds of activities on a typical construction site. One of the factors that subject the schedule to delays is the official processes performed at the public sectors. Lebanon is a country that has been plagued by corruption; official processes run at suboptimal levels and delay the day-to-day activities of citizens and projects across all industries. The concept of applying lean methods to mitigate this corruption is promising; as this is the first study in Lebanon to address this issue by employing a lean perspective. The aim of this paper is to analyze, assess, and formulate frameworks of official processes based on interviews conducted with professionals in the field who have experienced unexplained delays in their construction documents. In addition, this study develops a tailored e-governance strategy that would effectively lead to a lean revamp in the public sector in terms of service quality, transparency, and reliability. Moreover, it serves as the theoretical foundation for the transformative shift in the official processes in the Lebanon.

KEYWORDS

E-Governance; Lean IT; Work flow; Standardization, Work Structuring.

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INTRODUCTION

Lean is minimizing waste and maximizing value to ultimately reach a perfect value-creating process containing zero waste (LEI, 2017). Lean cities are those who apply lean principles to maximize citizens' value-added services and eliminate waste from their processes (Quintana, 2017). "Lean Governments are part of a growing trend of management tools designed to lower costs and improve the efficiency of government operations" (Scorsone, 2010). Lebanon is a country with high corruption rates that are magnified by the inefficient systems that are present, especially since corruptive actions have become embedded within the mentality of people (Awada, 2014).

This paper discusses corruption in Lebanon, and how the implementation of lean methodologies into its governmental sectors can prevent corruptive actions, achieve efficiency, and consequently save time and decrease unnecessary costs on construction projects.

The concept of lean cities is already being implemented in some countries. In Minnesota, for example, they have offices that are dedicated to continuous improvement that develop new ways for inspection that save on money and introduce new tools into their departments (Minnesota Government, 2017). Colorado is another state where the concept of lean governments was successfully implemented. The state's approach is made up of three pillars: cross-functional process improvements, localized process improvements, and everyday ideas and respect for people. This in turn led to remove 23 on-value adding steps and issuing permits quicker with fewer errors. Moreover, the transition that the Colorado Department of Transportation did to become paperless saved it $18,000 a year as a consequence of digitizing the government and integrating lean applications to its IT (Codot, 2017). Another example would be the Connecticut Department of labor where they saved 119 steps, eliminated 1181 cycle time hours and saved $500,000 in staff time over a year (Johnston, 2013). All the aforementioned figures were to highlight the positive correlation between applying lean practices and reducing waste.

Lebanon was the 136th least corrupt nation out of 175 countries, costing the state an estimated $800 million a year. Moreover, it scored 28/100 in a corruption indicator that ranges between zero (highly corrupt) and 100 (very clean), which is worse than the overall Middle East and North Africa's average score of 38/100 (Transparency International Corruption Perceptions Index,2016). This highly corrupt score was associated with the absence of presidential elections where corruption has extended to almost all governmental institutions with rare supervision (Lebanese Transparency Association, 2016).

A messy queue of people holding thick folders of official documents behind a counter is a familiar scene for anyone who goes to ministries or state intuitions in Lebanon. In light of the Lebanese bureaucracy, the experience of requesting any kind of official document could be confusing and annoying as people struggle to access basic governmental services. "Our system feels like it's still the same since the time of the Ottomans," Bassem Deaibess, a 35-year-old musician, told The Daily Star. "I lost my passport in 2011 and the entire process, to get a new one, took over a month."(Nashed,2016).

Bribery is a critical aspect of corruption that exhausts not only the government treasury but also the citizens' money. Corrupt officials plunder the government treasury through processes' fees of legal and illegal transactions in the governmental departments (Beirutie, 2015). The reasons behind citizens' bribes reveal that 49 percent of Lebanese people offer bribes to speed up transactions, 19 percent pay bribes as gifts, 16 percent pay for cheaper services, and more than 16 percent perceive it as the only way to get the service done. When it comes to reporting corruption cases, more than half of Lebanese would prefer to stay silent rather than report a corruption incident in fear of becoming victims for reporting. Also, they believe that reporting such incidents will not make perpetrators get punished (Awada,2014). In addition, "the Lebanese developed tools such as Wasta as methods that can assure trust in their daily transactions (Harfouche& Robbin, 2012). "Wasta" comes from an arabic root conveying the idea of "middle" and a wasta is someone who acts as a go-between and use intermediaries. The intermediaries in case of wasta must be someone with influence but not necessarily a relative or even a close friend (Whitaker, 2009).

In the light of the problems mentioned above, e-governance via digitizing governmental system provides a tool that enables the control over the process and allows the integration of lean principles. This tool is a first step of applying a long term strategy that adds value to the customer and removes wastes, thus providing the philosophy foundation of the 4P model (Liker, 2013). E-governance also allows more transparency in the system, limiting both "Wasta" and bribery and improving the second step in the 4-P model called process (Alawadhi& Morris, 2009). Moreover, this clear and transparent process will raise problems to the surface and will challenge employees to think outside the box and provide creative solutions (Liker, 2013). This is the third part of the 4-P model that includes growing leaders that live the philosophy. The last step is Kaizen, meaning continuous improvement, and is ensured by an E-government since it would be the first major change implemented to move to a better system.

The increasing rate of corruption in the Lebanese government makes it more urgent to introduce lean techniques into the public sector. Just as it has been implemented in other cities for more than 15 years, the time has come to start implementing lean methodologies in Lebanon. Therefore, this paper introduces a lean IT strategy that aims at creating a flowing balanced process that provides transparency and supervision to prevent corrupt intentions by employees.

METHODOLOGY

This paper summarizes exploratory research about corruption within official processes in Lebanon and the impact of applying lean tools on reducing the incurred document delays. Research involves both a survey of available literature about existing lean cities and short interviews to determine the current process steps and the impact of document delays on the construction projects. Interviews were conducted with construction engineers and a document tracker that has been working in the field for more than 30 years. The document tracker's experience reflects the situation of Lebanese official centers in general since he has worked in several districts across Lebanon.Interviewed personnel were asked about the delays they encountered, the reasons behind these delays and possible solutions to prevent them.The problem with the current governmental practices was found to be its high dependency on human decisions and acts as well as its lack of supervision.

The strategy proposed involved an arbitrary document of "Type X" from start up until completion. The research process comprised the following steps: evaluating current practices in completing documents as well as developing a lean IT strategy that aims at improving the latter practices. The strategy methods include the achievement of a more efficient process with transparency that allows the citizen to view the status of his documents. Moreover, the document has both a time tracking system to determine if it is being delayed and an online payment mode to prevent any form of bribery.

This research reflects guidelines for improvements in Lebanese official document processes through adopting a lean IT approach and accordingly do not pertain to any practical testing or application of these guidelines.

CURRENT STATE

The typical procedure for issuing a construction permit includes 3 major entities. It is first submitted to the order of engineers where it takes about two to three days to be reviewed and signed by a mechanical, electrical and executive engineer. After their approval it would be taken to the urban planning office where it is signed by the 3 engineers as well, each has to go over the drawings. This process usually takes 10 days. Finally it is taken to the municipality of that area, where they conduct weekly meetings to review submitted requests of that week. However, if they find any problem it is put on hold for further check to be discussed again in next week's meeting.

The average time for issuing the permit is found to be two months, since other that these mentioned durations the document might be delayed for corruptive reasons waiting for "gifts" to speed up the process. After the construction phase, residential permits must be issued to register apartments for the owners. The official time for this permit is stated as ten days, where it passes through five stages to check that the constructed facility coincides with the designs and that prices are adequate.

One can clearly notice from the steps listed above that the process is vulnerable to manipulation by the employees performing it; especially when supervision is absent. And a great proof of that is the fact that it can be performed within one day if a bribe is offered.

F.H. is a document tracker who has been in field for over 30 years. He believes that bribery has become the guaranteed path to perform any service in a much shorter time, and that employees in public sectors manipulate their positions for personal interests. He stated that sometimes they might fabricate illegal intentions or even claim that a document is missing just to provoke the owner to offer a bribe for him. The following table presents the results of short interviews conducted with engineers with their experience with construction project delays due to corruption in official processes.

Table 1 Survey of Governmental Inefficiency Effects

	Process affected by governmental procedures	Types of waste	Root Cause of problem
1	Request to connect to municipal pipe network for water in a new construction site	Time, money (employee keeps on delaying the service until contractor offers a bribe)	No proper supervision, government employees have the power to delay work and get bribes

Table 1(cont'd): Survey of Governmental Inefficiency Effects

	Process affected by governmental procedures	Types of waste	Root Cause of problem
2	Negative iterations in the approval process of project design	Time, design resources, rework	Unclear guidelines (wicked), intentions of engineers to trigger designers to pay them to stop drawing refusals
3	Municipal permits required for bank loans	Time, money	The municipality was tight on budget, exploited its authority by delaying the process till contractor pays them money
4	Getting permits for construction	Time, money (If one employs a person from the inside, it would take half the time)	Inefficient process, with lots of inventory, variability, and bureaucracy
5	Permit to modify an existing facility	Time (the document requires one week but extended to a month)	No supervision or transparency, the employee manipulated his job for personal issues with the engineer

The first step in solving the problems stated above is to establish clear simple guidelines that cannot be manipulated. Second, processes must be digitized to enable the control over them and the introduction of lean principles to make them more efficient. Therefore, a strategy must be followed to mitigate corruptive actions, make the process more efficient, and subject it to further improvements.

DEVELOPING A STRATEGY TO MITIGATE CORRUPTIVE ACTIONS

In order to develop an effective strategy to mitigate the effect of corruption within official processes, two strategies must be followed to illustrate the methods in which an impactful change can be achieved.

BEHAVIORAL STRATEGY

The first is a behavioral strategy that aims to positively shift the mindset of public employees, making them potential agents of change in terms of the quality and reliability of the public services they perform. Before attempting to change anything, one must acknowledge the fact that change does not come easily; people are, by nature, afraid of change, and become unconsciously resistant to any idea that is forced on them without their personal approval and against their personal interests. This strategy is not the contribution of this paper; however, it is important to state it since it covers one of the 4P's of the Toyota Way model, which is investing in people in such a way that the organizational philosophy becomes incorporated within their contributions at work.

LEAN IT STRATEGY

Moving on from the lean behavioral strategy, we reach the second part of the "lean revamp" that aims to mitigate the effects of corruption in official processes. A lean IT strategy is proposed to block the means for bribing and the unlawful delay of a document request. It provides transparency that enables the citizen to monitor the progress of his/her document, track delay, and report it. It also aims at monitoring the progress of each employee and helps apply the rewards/penalty system.

FOUNDATIONS OF LEAN IT

It is important that one develops a proper infrastructure that will be the foundation for the Lean IT strategy that will be discussed later on. This foundation is in the form of an Enterprise Resource Planning (ERP) System that breaks down barriers in terms of information silos and enables the swift and real-time transfer of information between different governmental entities involved. Lebanese ministries always have interdisciplinary work among them that requires them to connect with each other in an efficient manner, so an ERP system would be essential to maintain a proper flow of information among them.

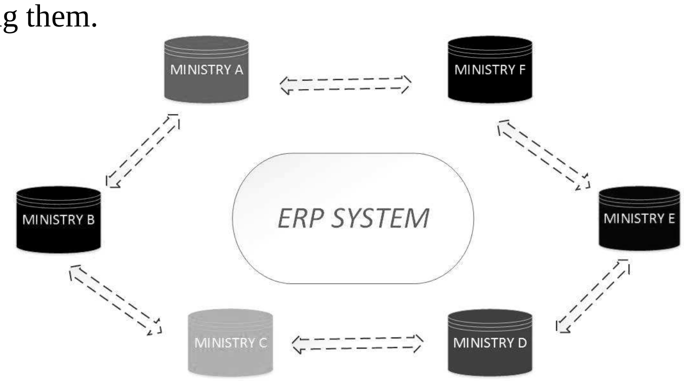

Figure 1: Enterprise Resource Planning (ERP) System

To properly illustrate this section, we will take a case study pertaining to how corruption within official processes affects the construction industry and create a Lean IT strategy that, once implemented, will tend to the issue of mitigating corruption. This case study involves tracking the passage of an arbitrary document "Type X" in the following proposed Lean IT system as it moves from station to station to be completed and handed over to the customer.

PHASES OF LEAN IT

The lean IT strategy is comprised of two phases, the first ensures that all prerequisites for submitting a certain document are ready and the second phase ensures that no document is delayed beyond a specified allowable time frame. Both phases will be thoroughly discussed in the following sections.

Phase I:

As shown in figure 2, a new, arbitrary construction document request of “Type X” is generated online and the system gives the user an order number. This request will enter the proposed system and will pass through two checkpoints. The first checkpoint is the “Document Checker” that makes sure that he has all prerequisites ready, i.e., all associated documents that are required to fully process his request. Such items include, for example, his ID as well as project information about the project (municipality permit, ownership contract, electricity and water permits…), size of the project, and so on. If any document is missing, a notification will be sent to the user telling him to submit the missing document(s) for his request to be considered, or else it would be discarded. Once all documents are ready, the request passes by the second checkpoint: the online payment.

Online payment is of utmost importance because it will block the means to get a physical bribe. The system will detect only a certain amount of credit that has to be satisfied. If the customer pays less, a notification will be sent to him to pay the remaining amount, and if he pays more, the system will not accept it. After payment is complete, the document enters the second phase of the system, Phase II.

Phase II:

The document will now enter into a one-piece flow, First-In-First-Out (FIFO) Queueing System. Considering the example of the arbitrary construction document “Type X” above, assume that this type of document usually takes around seven days to complete and passes by two checkpoints, annotated in figure 3 as Checkpoint A and Checkpoint B. (These checkpoints represent the different entities that the document passes through and might not necessarily be in the same place; checkpoint A may be the Ministry of Labor and checkpoint B may be the Ministry of Transportation, for instance). These seven days are split as follows: Part of the work requires three days at Checkpoint A and four days at Checkpoint B. Document requests are sent to Checkpoint A in the aforementioned manner. One can take the scenario that there is only one workstation available to process documents. These documents will be tracked according to the number of days they spend at a workstation; three designated zones are present to account for the time spent in processing: The green color (designated as G) tells us that the time spent in a workstation is acceptable, the yellow color (designated as Y) tells us that the time spent at a workstation is fair, and the red color (designated by R) indicates that the document has spent more than it should have at the workstation. Now, assume that document requests are spending more than they should have at workstation 1 of Checkpoint A. This tells management that there is a bottleneck at that point of the process, hence proper action must be taken to remove this waste, especially since we will have an increase in amount of work waiting on workers, which according to lean, is waste. However, given governmental budget constraints, one can opt to either provide extra training to the worker(s) involved at the station or can add to the number of workstations available to increase the processing rate of document requests and overall efficiency of the checkpoint itself. The same logic applies for any other existing checkpoints involved in process, regardless if these checkpoints belong to the same ministry or not. The system records the productivity of workers to assess their contribution to the checkpoint in order to have a continuous assessment of the system's performance and the possibility of improvement.

One can draw out an analogy between how tellers at a bank operate and how documents are processed in the proposed system. A bank teller is expected to complete, for example, no less than 30 requests per day assuming there is an infinite amount of customers available in the queue to be serviced. When management records the amount of requests completed versus what was expected of them to complete, they have to identify the source and nature of the error and correct it accordingly in the case of suboptimal performance, and reward those who have proven themselves competent over time.

From the customer's end, they can check the status of their documents online to see whether they have been processed or not. They simply enter their document order number given to them at the start of the process and an output screen will appear showing them a real-time tracking of their application and how many tentative days remain until their document is ready for collection. This estimated time of completion will change based on the overall productivity of checkpoints which are detected automatically by the system.

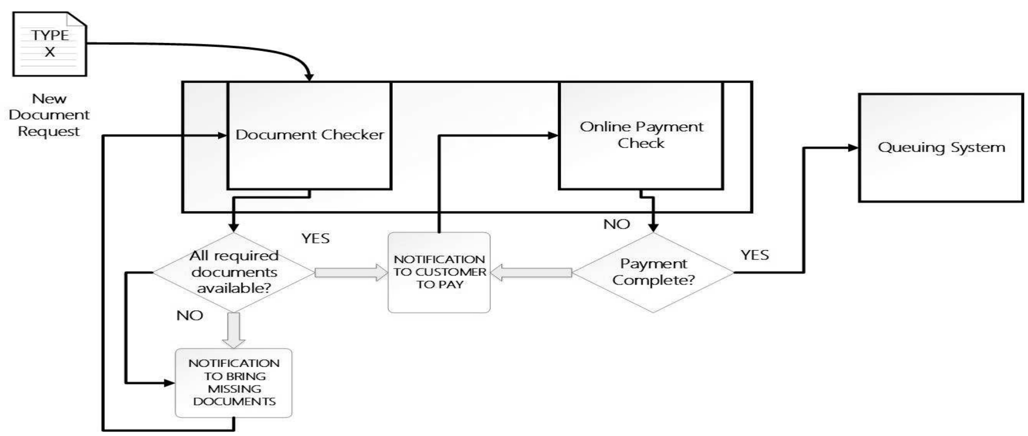

Figure 2: Phase I of the Lean IT Strategy

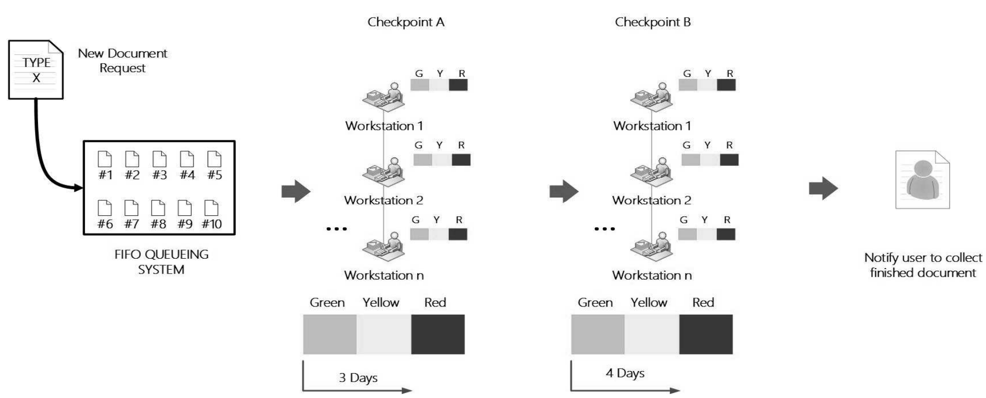

Figure 3: Phase II of the Lean IT Strategy

DISCUSSION

Employees in the public sector come from a variety of backgrounds, cultures, norms, mindsets, and levels of qualification. Some believe that since they are Lebanese official employees, then they should perform at the same level the government does, which in this case, is very much underperforming and corrupt. This, in turn, will encourage them to negatively exercise the power their positions give them by demanding or accepting bribes or gifts in exchange for a quicker service. Furthermore, the role of "strong connections" to authoritative people and intimidating leaders has its role to play in terms of who gets which position and with what salary. It cannot be assumed that this will completely end just by applying an IT strategy because practically speaking, it will not. Hence, it is also very important to take into consideration the design for a lean behavioral strategy that will institutionalize a cultural change. This would be like watering the trees of a garden. A garden would not be fruitful just by placing trees into its pots; however, it requires watering and proper care to have it sustained. Employees need methods for a behavioral strategy to be able to grow. Proper care and follow up are essential as well to prevent any disease from plaguing the present environment.

Therefore, a global approach must be taken to enable the creation of a behavioral strategy that aims to positively shift the mindset of public employees, making them potential agents of change in terms of the quality and reliability of the government services they perform.

Moreover, let us look at this behavioral strategy from another perspective using the 10-10-10 Rule (Welch, 2009). The 10-10-10 Rule will tell us to think of this strategy as follows: *What effect will this behavioral strategy generate in 10 minutes, in 10 months, and in 10 years?* In 10 minutes, it is obvious that if you approached a public employee with this strategy, he/she would tell you that you can try to implement it but no one will take it seriously. Now, imagine if this idea was being applied for 10 months. 10 months is not a sufficient time for implementing such a strategy, but one thing would be certain which is that at least part of the lean principles would be absorbed by employees, and an incremental change will definitely be visible in terms of overall performance. In 10 years of incorporating this value-adding, lean behavioral strategy, and taking into consideration the number of new employees that would have entered into this partially-shifted, new positive-mindset environment; a definite change would be noticeable because this culture will be integrated and handed down from one generation of employees to the next as it is being implemented. This paper would open up the possibility for more detailed research to implement effectively a strategy that targets the behavior of Lebanese governmental employees.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, it is fair to say that change will not come easily when it comes to changing the culture and mentality of Lebanese government employees, but it is only in adopting and staying committed to long-term lean strategies that will give us the opportunity to mitigate the amount of corruption in official processes. These strategies will start by removing inefficiencies of current procedures to end with improved processes that would keep improving with time. By that, we would elevate the standards and transparency within the Lebanese Construction Industry in a way that would motivate other industries to adopt such a lean mentality, and in return, advance at both a personal level as well as a country-wide level through promoting a sense of reliability and authenticity of work.

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FACTORS AFFECTING IMPLEMENTATION OF LEAN CONSTRUCTION

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ABSTRACT

Research has shown advantages an organization can obtain by implementing lean methodology. However, when implementing new philosophies like Lean Construction, there are always some challenges to overcome. Examples could be lack of basic knowledge about the theory/philosophy behind lean, lack of willingness to change, implementation process in an organization, lack of clear objectives/visions with the implementation and top management involvement.

The authors of this paper have worked with implementation of lean principles in a Norwegian contractor company. The contractor is split into several sister-companies, acquired over the past 40 years. Some of the sister-companies have succeeded in implementing lean, while others have not succeeded well. The authors will evaluate how the organization have planned to implement lean in an efficient and sustainable way, and what factors that have affected the implementation. The research methodology used is case study, where the different sister-companies are the cases. Research from the case study of lean implementation will give a better understanding for similar cases. It will also address how to overcome challenges related to the implementation process in similar cases.

KEYWORDS

Lean construction, Implementation, factors of success, organizational transformation

INTRODUCTION

Lean Construction have recent years received more and more attention. Large Norwegian project owners and contractors have started implementing lean principles and tools. Among the most common applied principles, you can find Last Planner System (LPS) (Ballard, 2000). Principles like Integrated Project Delivery (IPD), Target Value Delivery

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(TVD), takt-time planning, Set Based Design (SBD), and Choosing by Advantages (CBA) are also getting increased attention in the industry.

There will always be challenges to overcome when implementing lean principles and tools. Bygballe et al. (2014), Chesworth (2015), Neto et al. (2007), Howell et al. (1998), Höök et al. (2008) and Arbulu et al. (2006) have addressed different challenges. Some example of challenges are lack of conceptual understanding of the philosophy and theory, urgency to change among individuals (Mann 2014), implementation approach, and lack of lean culture.

The purpose of this research is to identify factors affecting the implementation of lean in a construction contractor holding company, and its underlying sister companies. This will help us understand implementation in different cases. We aim todescribe challenges with implementation and how they were met in specific situations in the sister companies. The research questions to be answered are; What challenges occur when implementing lean? How could these challenges be met when implementing lean in a fragmented construction company? This research will be based on Lean Construction literature, and use a case study to answer the research questions.

TRANSFORMATION PROCESSES AND LEAN CONSTRUCTION

Kotter (2007) points out eight critical factors every organization have to deal with to handle a transformation process. The first four steps are establish sense of urgency, forming a powerful guiding coalition, creating a vision and communicating the vision. The first four steps are meant to dissolve status quo in the organization. Then the implementation and use the new methodology, tools and/or philosophy should start. The next four steps are then empowering others to act on the vision, planning for and creating short-term wins, consolidating improvements and producing still more change and finally institutionalizing new approaches.

An implementation process may take several years before the future state becomes the new status quo. Organizations need to keep up the hard transformation work, in order not to lose the momentum (Kotter 2007). During such a phase of transformation, it could be preferable to hire or relocate dedicated individuals with experience in order to enhance the progression. The new standard achieved after earlier steps should now be in place. However, even though the conceptualities of the future state are now well established in the organization, the top-management needs to constantly focus on the future state going forward.

The interest for lean methodology in construction have evolved trough two different interpretations (Koskela et al. 2002). One interpretation relates the use of lean production methods in construction, and the other is what today is addressed as Lean Construction ("LC"). LC have used lean production theory as basis to evolve in order to become an independent theory-based methodology. There are still some common factors practitioners focus on, which are to eliminate waste, maximize costumer value and pursue continuous improvements. (Koskela, 1992; Womack & Jones, 2003). Even though the road to achieve these factors varies.

Since the introduction of LC, the approach of research has been focusing on difficulties and challenges with implementation of a lean practice in construction companies.

Many organizations have tried adopting lean into their daily operations, but not all have accomplished to sustain it. In Knudsen (2016), a LC-expert was asked about challenges, and her response was that the killers were lack of leadership together with no strategic plan or vision. Further, she comments that organizations need to start out small and test their ideas within a specific project. A good ambassador is preferable, in order to get other employees on-board. When momentum is created and you start deploying ideas and initiatives, results will come along. However, it requires commitment from everyone involved. When you have satisfying results, it is crucial to communicate these out to other parties in the organization.

Arbulu et al. (2006) proposed a lean transformation approach in construction, which maintains current state operations while the transformation process rolls out on designated projects. This gives the organization time to adjust its leaders and project teams, and prepare them for the transformation. The organization will also have good control on when and where the break point between current state and future state will occur. This, along with top-down leadership support is a preferable approach.

Moreover, research has also shown that in order to achieve a successful implementation these five key elements need to be in place; (1) Vision, (2) Skill, (3) Incentive, (4) Resources and (5) Action Plan. If all elements are in place, a change will be possible. Lack of one or more will probably result in an unsatisfying result (Larson 2003).

Höök et al. (2008) points out it is not enough just implementing and start using lean tools and principles without striving after a common lean culture among the employees. A lean culture is not achieved overnight; it takes a lot of practise and doing, before it is a natural extent of any employee. A proven way to engage employees to become more involved and empowered could be done, according to Diekmann et al. (2004), with a tool that gives employees daily feedback on their actual improvement. To move towards a lean culture, it is important to have proper arena to talk about improvement. A combination of involving parties, talk about problems, root causes and further find solutions as a team will persuade others to join the effort (Tillmann et al. 2014). If the top-management pursue and focus on sharing knowledge and experience throughout the organization, the organization itself will be even more capable to handle and challenge the status quo. Hence, the company should strive to create an organizational culture where the focus is to seek continuous improvements (Chesworth, 2015).

"Without a Lean management system in place to support the new physical or procedural arrangements, people are left to rely on their old tricks for fooling the system, using familiar workarounds to get themselves out of trouble", Mann (2014).

METHODOLOGY

The purpose of this paper is to identify factors affecting the implementation of lean construction and how to succeed with implementation of lean in a fragmented contractor company. The research questions to be answered are what challenges occur when implementing Lean Construction, and how we can overcome the challenges when implementing Lean in a fragmented construction company. Yin (2013) states that choice of research method in a large part depends on your research questions. The more your questions seek to explain some present circumstance (e.g. how and why some social phenomenon works) the more that case study will be relevant. Hence, a case study described by Yin (2013) could fit with this kind of research questions. Two master students contributed to the research through their work with their master thesis (Knutsen 2016 and Rønneberg 2017), and their research results are merged into this paper.

The contractor company consists of a holding company with 12widely geographically spread subsidiaries (each a "division", collectively "divisions"). The divisions are acquired over a period of 40 years. The divisions are responsible for their day-to-day operations.

To answer the research questions, the first one is firstly addressed through a literature review, thereafter by a case study. The case study includes interviews and a questionnaire to identify factors affecting the implementation in the specific situations. The last question on how to overcome the challenges with implementing lean in a fragmented company is addressed through the same case study.

The case organization is currently in the middle of an implementation process with lean and lean is already well anchored in the company's strategy. The top-management want a lean approach to their daily operations in their organization, because they believe it will help them realise their goal on every end product, which is zero personell injuries, zero need for rework and seven percent profit margin (the 007-goal).

The case study is based on a prior literature review, as well as interviews, observations, a questionnaire, document studies and informal conversations with people involved in the process, both internally and externally. To get knowledge about the implementation process in the holding company, the first step was in-depth interviews with 3 key stakeholders in the holding company and with the external consultant, an expert on lean implementation involved in the implementation process. To get knowledge about the situation in the sister-companies, a questionnaire together with in-depth interviews with key personnel in the company was performed. The questionnaire was sent to seven sister companies that already had started implementing lean. 151 persons were asked to answer the questionnaire, where 123 answered the questionnaire. The questionnaire included questions regarding the employees' knowledge about the implementation process, its goals, information about the implementation from the management, how satisfied the workers were with the implementation and the effects of the implementation. The interviews were performed with 4 of the companies. In the interviews, the top management of the sister companies were asked questions regarding the implementation process; Why the organization wanted it, how to ensure a sustainable future state and other questions relating to implementation process were asked. Informal conversations with key-personnel involved in the process supported the findings from the interviews.

FACTORS AFFECTING THE IMPLEMENTATION OF LEAN CONSTRUCTION

The results summed up in this section are based on the literature review, the interviews and the questionnaire.

HOLDING COMPANY FINDINGS

The final decision to start implementing lean construction in the organization was by no means an impulsive decision. After some careful consideration and consulting, the organization`s top-management believes that daily operations based on lean philosophy is highly preferable. Increased demands from both private and public owners have led them towards taking benefit of the advantageous that comes with lean philosophy. The transformation is not highly needed, but rather a strategic move to position themselves for the future. This helped create some kind of urgency, which is preferred to get the transformation process going. Further key-personnel have taken on necessary training to handle uncertainties that may arise, like questions from concerned individuals. This will, and has in the case helped calm down strong individuals, which have resisted the change process from the beginning.

The aim of the organization is that within 2 years, lean construction should be the way they do things. Due to absence of any desperate need to change, the organization has the possibility to progress in a healthier manner.

The organizaiton faced lack of internal competence on lean construction. Therefore, a consultant company was hired. The consultant company developed a roadmap for the implementation process. The purpose of the first steps, outlined in Kotter (2007), is to dissolve status quo in the organization. Going forward, the roadmap is like a guiding tool to finally transform the organization into a self-driven one, which always searches for continuous improvements. During the work with the case, several commonalities with Kotter's eight steps occurred.

SISTER COMPANY FINDINGS

After the anchoring within the organization leaders, the process takes a step down. When continuing the transformation process into this division-level of operations, it is highly important to get manager's and key-personnel's attention. They are not supposed to create a new vision, which already is enacted. Rather show commitment and ownership to the transformation taking place. The consulting firm maps out, in consolidation with internal users, on which process they should start their improvement work. To help them locate urgent problem areas they use a process-mapping tool. When an improvement project is chosen, an A3 is drafted and further executed. Getting proper training and conceptual understanding among employees is important to keep the process going, and certainly when the consultants start backing off after 4-6 months.

One finding, which most likely reflects the managers vision of status quo and/or their point of view of lean as a production theory, is that some of the divisions showed much greater interest in starting the implementation process, others have been waiting for results from one of the early adopters. The questionnaire shows that the two companies with most successful implementation processes thus far both have had a feeling of urgency for change. According to Mann (2014), a feeling of urgency to change is one-step to a successful organizational change. In these two companies, we also observe that they have an internal driving force behind the implementation process, which also is according to Mann (2014).

Another important challenge that occurred was to communicate a proper vision throughout the whole organization from the holding company down to the sister companies. The feedbacks from divisional managers were positive. Hence, it has shown that even though managers responded positively to the implementation, not all of them understood the extent of the process. Further, the road to success demands a lot of involvement and commitment.

Before the process rolled out to the divisions, an indicative progression was mapped. The estimated time each of the divisions were supposed to get help from the consultants, was estimated to about four months. Reality has shown that all of the five divisions that have been through the process with support from the consultant company, have exceeded the estimated timeframe. For the sister-companies, the cooperation with the consultant as an external facilitator have been very important. This also is in line with Womack and Jones (1996) and Ballard and Kim (2007).From the questionnaire, 51 % of the employees are very satisfied or satisfied with the cooperation with the consultant, while 4 % is dissatisfied with the cooperation.

One factor for successful implementation of changes is according to Arbulu and Zabelle (2006) resources. Lack of resources to support the implementation will lead to frustration in the organization. The holding company has supported the implementation both economically and by resources, through the external consultant company. From the questionnaire we can observe that two of the sister companies would like more support from the holding company. One of these companies still state that they have had successful implementation, the other have had challenges with the implementation.

PROJECT LEVEL FINDINGS

After a couple of A3 improvement projects have been going on at respective division-offices, the improvement work carries out on construction projects. The purpose is to get proper anchoring within the division-management and further withstand the improvement work at project-level. When the improvement work starts out on construction projects, it is important not to “forget” to keep working with the improvement within division-management; this is carefully monitored by the consultants. Typical improvement projects out on construction projects where planning, and involvement of parties to reach a common goal. At this level, the Last Planner System is implemented.

From the questionnaire, 90 % of the employees agree or partly agree that they know why Lean Construction is implemented in the organization. Around 15 % of the employees partly or fully agree that they did not have enough information about Lean Construction prior to start of the implementation process, where there are sister-companies where up to 12 % of the employees fully agree that they did not have enough information about Lean Construction. When asking about whether the employees had enough information about the implementation process, around 20 % disagree that they had enough information about the implementation process. There are variations between the sister companies, where in one company all agree that they had enough information about the implementation process, while in one of the companies 32 % disagrees that they had enough information.

From the questionnaire, 51 % of the employees agree or partly agree that the implementation of Lean Construction have been successful for their respective company. In this respect, there are large variations between the companies, from 84 % in one company to 20 % in another company. The questionnaire shows that the company where projects became more productive after implementing Lean are the same companies that most often use Lean Construction elements in their organization and projects.

DISCUSSION

A big responsibility to succeed lies with the top-management, especially when the consultants starts backing off. From that point, the top management and the division management and other key-personnel are going to be the superior, and all questions and reporting are going to end up in their lap. The work with the in-depth interviews revealed that the top-management had not gone through the implementation process before the first division had. This caused some ripple effects at the early adapters, because they did not have proper backing from top-management. Another finding was the absence of common forum for managers to talk about lean across the divisions and to exchange learnings and experiences.

The implementation process has to be seen as a simultaneously top-down, bottom-up implementation approach. This because the transformation seeps downwards from the top-management into the organization, throughout each division and further to projects within the divisions. What is seemed to be beneficial from this approach is that even if the transformation process doesn't carry out as planned, the transformation will keep going. This because the process will have all necessary backing from higher up the organization.

A problem met is actually caused by the top-down implementation. Individuals affected by the transformation have felt that they are the root cause, not the top-management. Even though that is not the case. In spite of this, a lesson is that the holding company itself should have done more of the improvement work internally before any of the divisions.

The holding company aim to change the culture in the company. Changing an organizational culture is not done overnight. This is supported in both the literature and case findings. It will probably take years of practice before the chance of major setbacks is gone. Strive for a solid lean culture among the employees requires first dedication from every party involved. Further, you need a good conceptual and theoretical platform to work from, and key personnel with executive power as ambassadors. The consultant company was aware of this challenge, so they were not only focusing on implement just leantools and practises. They also tried to involve and engage employees to strive for improvement at all levels. A challenge the consultants have met is that the employees does not raise any questions, and that is definitely not because everything is very clear, rather a cultural challenge.

One of the consultants believes that the challenge is not only to implement new things to an organization, but to get rid of old habits. A consistent finding was that employees, which came straight out of school, had less problem adopting a lean mind-set. This is most likely because they possess no earlier experience related to the current state of daily operations.

Due to the highly fragmented organizational structure, several strategic challenges were raised. One central challenge is that the holding company does not have any direct executive power over all the divisions. In other words, the holding company cannot force a division to start the process, but the twist is that key personnel have seats within every company board. So a challenge has been an absent consequence culture between the holding company and the division. Even though, this challenge has been coped with to a certain extent with success stories from other cases, and a general belief that the change will contribute to the strategic 007-goal of the organization.

During the implementation process, the divisions get supervision twice a week. This will prevent the consultant's resources from being stretched thin, since there are constantly two divisions involved. A typical challenge with a third-party transformation is the fact that the third party actually does not have any direct executive power over employees within an organization. In other words, a consultant cannot in the given case tell and decide what the employees should do. Therefore, their approach is more directed into encouraging people to do it. This should be safeguarded by satisfying educational training, as well as adequate anchoring within top-management. It is a false impression when the consultants do not see any kind of improvements from week to week, and the consultants carry out all the improvement work. In some cases, it has been the reality. A triggering factor has been lack of commitment from key personnel, like the manager for a division. It is his or her responsibility to encourage his employees to seek continuous improvement, and actually check if they are succeeding. Especially after the consultant's work is done, if there is no following up or any kind of reporting system throughout the organization. In addition, especially within every division, the relapse to old habits is closing in.

Further responsibilities are to designate a champion. A champion is a person, which first is dedicated and truly believes in the future state. Further, he takes over the consultant's role, which includes the following up of all the improvement-projects. A good system for reporting needs to be initiated, and the top of the reporting chain have to care. The preferred system for reporting is by A3, this makes it clear for every party where they stand, what is needed, and at last what they have accomplished.

CONCLUSION AND RECOMMENDATIONS

In this paper, the authors have addressed how a general contractor implements lean throughout their organization, from a holding company, through its sister companies and down to the project level, and what factors affect the implementation. One main finding is that the implementation should follow the line from top organizational management, down to its divisions and further into construction projects. Although early adopters could give positive impact on others, the implementation process should follow this line. We have revealed how the consultants work with the organization to achieve their goals, and the similarities to Kotter (2007). The final goal is to have an organization that continually strive for continuous improvements.

Further, the authors found the implementation plan/strategy, developed in collaboration between the consultants and the holding company to be satisfying. Yet, there are still challenges rising, which need to be handled correctly. For instance, the fact that the transformation period has exceeded in most divisions. This might be caused by the absence of a burning platform or lack of ownership among key personnel. Even though, the study confirms that top management support and anchoring is an important factor for successfully implement and sustain the new behaviours.

Moreover, findings in the case are backed up by the literature, with exception of a consultant driven lean implementation process. Even though a consultant driven process seems to be the right choice for the organization, due to lack of internal lean resources. An outcome has been challenges concerning the handover from the consultancy to the organization, after their process is finished. Therefore, designated champions will get the consultants responsibility of following-up on ongoing and future improvement projects.

Lastly, we found out there was not any forum for discussion of lean across the divisions. Moreover, no common arena for exchanging valuable experience and learnings from their improvement work. After all, despite the fact that the road to fulfil the vision is long, the organization seems determined to do so. Therefore, to establish learning forum across the organization is highly recommended.

Through literature search, interviews with the holding company, the questionnaire and interviews with five of the sister companies, important factors for successful implementation were identified. For successful implementation of Lean Construction in a holding company with its sister companies, the following factors are important;

- implementation starts with the holding company with top management support through the sister company and its management and down to the projects
- information and communication around the implementation and the lean principles, from the holding company, through the sister companies down to the project level is important
- showing success from early adopters in the implementation is important
- if use of external facilitator, support with resources both from the holding company and the sister company is necessary, building internal competence to use when the consultant company is no longer there.
- marking of victories and recognition of successes along the way, both at holding company level, sister company level and at the project level is important
- establishing a forum for exchange of experiences between the holding company, the sister companies and the projects will give good support on all levels

Some of the divisions have, prior to the consultant driven process, taken sporadic use of lean tools and principles. Further, it would be interesting to compare the lean-ness in such division with a division where consultant driven implementation is the case.

Moreover, it was found that one of the most successful divisions, in term of revenue, have not officially gone through an implementation process. Therefore, it would be interesting to do research what their best practice is, and compare their behaviour to lean principles.

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EVALUATING WHY QUANTITY SURVEYORS CONFLICT WITH COLLABORATIVE PROJECT DELIVERYSYSTEM

Sa'id N. Ahmed[1], Christine Pasquire[2], and Emmanuel Manu[3]

ABSTRACT

The recurring poor performance and lack of collaborative culture in the UK construction industry has been a topic of debate for many years now. This has triggered an industry wide demand for performance improvement and innovation in the construction sector. Several studies over the years have reported and linked these concerns to fragmentation, deep-seated cultural resistance and negative commercial behaviours among project participants. Traditionally, Quantity Surveyors (QSs) within the UK system are popularly known for their commercial management functions i.e., contract advice and cost related roles. But, the lack of evidence on collaborative practice across the commercial roles often performed by the QSs in practice has revealed a separation within the construction model where QSs are formulated outside the core project production team (client, designers, and constructors). This continues with further practical implications like process waste, value loss, conflicts among others. However, recently, there were calls for industry-wide modernisation with an appeal specifically on QSs to create positive link within the value chain as against being a burden to it. Based on a literature review and a case study approach, the study further discovered other commercial factors deterring collaborative practice that is emanating from QSs position outside the production system. These factors among others are: commercial background &training, customer &safeguarding practice, excessive monthly reporting & commercial governance and balancing standards with innovation.

KEYWORDS

Lean construction, collaboration, collaborative production system, quantity surveying.

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INTRODUCTION

The UK construction industry has seen plethora of reports and recommendations from government, practitioners and academia, calling for performance improvement and modernisation. According to Cain (2004) the first commissioned report raised concerns in 1929, with obligation to improve efficiency and remove waste within the construction processes.

Subsequent reports such as the Latham and Egan both challenged the industry to adopt collaborative practices, and streamline construction processes. Accordingly, Farmer (2016) also lamented on this, stating that the industry needs to modernise and replicate manufacturing advances – stressing that delivering construction in a collaborative production fashion is required. In response to the Egan and Latham recommendations, a construction strategy was launched by the government in 2011, in an attempt to modernise procurement approach through the introduction of newer models such as the cost-led procurement model, integrated project insurance and two stage open book (Cabinet office, 2014). This was a move to curtail the lack of transparency in costing activities, collaboration and generally the wastes in construction projects.

However, these advances were only partially applied in the UK system, and do not fully allow the practice of collaboration (Pasquire et al, 2015). This has invariably left the prevailing system 'dualized' where one stream focuses on actual production (building the project to completion) and the other stream revealed a separate role that is mainly concerned with overcoming transactional governance that uses risk as a criterion to influence construction procurement (Pasquire et al, 2015). This position has often been criticized in literature as having a profound influence on production creating barriers and inefficiencies in construction (Ghassemi and Becerik-Gerber, 2011; Eriksson and Laan, 2007; Hawkins, 2012; Cox, and Thompson, 1997). Consequently, this other stream (cultural system) has been observed and is related to the role played by the QS's outside the production stream advising clients and providing means for safeguarding practice through cost and risk management functions that forms a bigger part in the system widely known but unacknowledged (Love, Davis, Ellis, and Cheung, 2010).

The need to modernise the conventional system, incorporating QSs into the collaborative domain has become essential. The generally used lean system is a collaborative paradigm known for achieving reliable value for customers with less wastes in construction (lean construction institute, 2012). More importantly, lean support a holistic collaboration through the integrated project delivery system and transforms design & construction, against the prevailing system where QSs/commercial team have been allowed to practice outside the production team that repeatedly amount to more waste and adversarial relationships. The importance of a holistic collaboration among construction stakeholders is key to this transition, which has been emphasised in literatures (Xue et al, 2010; Yeomans et al, 2006). The need to invigorate other actors (QSs) on how to collaborate and create a positive link within the value chain have been emphasized(Farmer, 2016).However, there are no empirical evaluation as to whether QSs functions is likely to be different and/or similar to their potentials working in a collaborative system. In view of these, this study would evaluate why QSs functions outside production is conflicting with collaborative practice in both lean and conventional system.

RESEARCH METHODOLOGY

The study adopted an exploratory qualitative approach using multiple case study technique. This provides an opportunity to investigate in-depth and real-life context (Pratt 2009; Yin 2009) to collect the data over sufficiently long periods of time, for clarifying key aspects of pivotal practices (Miles and Huberman 1994). It also addresses the 'how and why' questions and the influence of the social context (e.g., how QSs are established in a collaborative system)on practices within human dimensions (Maxwell 2005). The criteria for selecting the cases where based on (1) the research focusing on collaborative production system and the relationships with the commercial team (2) the commercial challenges affecting collaborative practices. Two cases were examined comprising of water and rail infrastructures. All the projects are from a public client and were procured using alliancing and joint venture arrangement. Multiple source of data such as semi-structured interviews, documentary analysis and observation were utilised to improve the quality of findings and conclusion (Yin, 2009). Overall 18 participants were interviewed across the two cases that lasted for 50-60 minutes involving: client, directors (commercial, alliance & procurement), designers, contractors, consultants, QSs/estimators, lean practitioners, and suppliers. Early costing and design activities were observed and documentary materials were analysed to assess in detail the CP in each case and how commercial teams were maintained.

The unit of analysis on this research is on CP and how commercial teams are embedded. The data were first analysed from within-case to determine the distinctive pattern in each case (Eisenhardt 1989b) and secondly, cross-case analysis was used to determine the differences and similarities among them. The characteristics of the case studies is illustrated in table 1 below.

Table. 1 Characteristics of the case study projects

Project Attributes	CSPA	CSPB
Nature of project	Water Infrastructure	Highways infrastructure
Location of project	East England,	East midlands England
Nature of works	Design & construction of water recycling treatment plants	Upgrade of motorway to smart motorway
Type of client	Public client	Public client
Mode of partners/SC selection	Alliance, framework	JV/framework
Proposed project duration	60 months	24 months
Procurement arrangement	Alliance, centralized procurement system	Join Venture
Contract sum	£1.2 billion	£120 million

LITERATURE REVIEW

LEAN - A COLLABORATIVE PROJECT DELIVERY SYSTEM

Lean is generally known as a philosophy that focuses on identifying waste and optimising value stream, from organisational level, down to the supply chain management (Scherrer-Rathje, *et al*., 2009). But it has also transcended beyond the ordinary waste removal in processes to a production philosophy that brings more innovative advances into the construction industry (Koskela, 2000). Hence, Koskela in 2000 established the theory of production to construction which further contextualised the definition of lean construction to a production-based management approach that support an integrated project delivery system. This then brings in the perspectives of transformation, flow and value propositions (TFV). These views, reveal how resources are transformed from inception to completion. They also identify how flow are viewed and maintained within the interrelated activities and across the entire project spectrum. Value is revealed and focus from the customer's dimension which satisfies the needs. Despite this, the classical assessment of production from the traditional system remain unchanged (a transformation of resources towards a finished product). A view that has failed to consider production as an integrated process for delivering value from inception to completion.

Traditional construction has also failed to grasp the full philosophy behind lean system, because the norm has been to target principles without fully optimising other aspects like planning, control, and commercial relations (Picchi and Granja, 2004; Alves and Tsao, 2007; Pavez and Alarcon, 2008). Lean system has been adopted in the UK to improve supply chain management (Ballard and Howell, 2003; Green and May, 2005 and Emmitt, 2009). But, Hook and Stehn (2008) cautioned that this move is problematic because the traditional approach to construction is still contract-based and does not focus on continuous improvement, nor the integration of project performers or building team relationships. Vrijhoef and Koskela (2000) also concurred that this view within the UK construction is flawed which typified the level of fragmentation especially the separation between the design and production processes. It is worth mentioning that, understanding this view by QSs/commercial team in the conventional system must be improved. This is a move that can replicate the concept of partnering through an increased integration and collaboration to eliminate wastes that are derived from sub-optimisations and adversarial relationships.

HOW LEAN APPROACH COMPLEMENT COLLABORATIVE PROJECT DELIVERY SYSTEM USING FIVE BIG IDEAS

Five big ideas are principles that lay emphasis on a holistic collaboration in construction which was developed by lean project consulting in 2006. It reveals five overriding values that galvanized a new way for project delivery and maintain collaboration which has proven successful in the Sutter health's projects (Lichtig, 2010).According to the lean project consulting group, the principles includes: *(a) collaborate; really collaborate, throughout design, planning and execution (b) increase relatedness among all project participants (c) projects are network of commitments (d)optimize the project, not the* *pieces and (e) tightly couple actions with learning.* Fischer et al, (2017) further analyzed these ideas to mean:

1. Involving downstream players in upstream decisions from outset to provide more avenues for resolving series of problems, using the art of conversations to explore possible solutions.
2. Establish relationships based on trust.
3. Projects are always viewed as processes but not as entire network of commitments – hence the need to work together and maintain these commitments.
4. Acting on what's best for the project rather than what is the least cost.
5. Participants contributing throughout the project process should align with the clients demand with an opportunity to learn while in action.

These concepts form a foundation for innovation in project delivery system and approaches in construction through proper collaborative practice. However, traditional approach for procuring and delivering project is still unchanged (Bertelsen, 2002). Evidence suggests that clients often take the lowest price in operation from advice by their QSs believing that, it's the safe option and will lead to an optimal value. The rationality of flow management (optimizing the whole process) is a logic that eliminate activities that are not adding value, thereby enhancing the value adding ones. However, non-adding value activities are now more embedded in construction. This has shifted focus from value optimisation to value reduction. The current system indeed harbours quite a lot of non-adding value activities. The study of Sarhan et al, (2014) gave an account on how the institutional system and the structural arrangements supports these wasteful activities in construction. This also revealed how commercial teams(QSs) in procurement and cost management contributes to these wastes in construction.

Similarly, through the current system, construction is often perceived as a service providing industry. The final project is usually assembled through the combination of trades. However, projects are not well defined, and there isn't a tradition that considers what true value is on the final product (Bertelsen, 2002). The value constraints of clients are not clearly visible from the start nor their realisation being examined systematically within the project spectrum. It can be argued that the lack of wider understanding of waste within the current system by the QSs is detriment to achieving optimum value and is conflicting with collaborative project delivery system (Pasquire et al, 2015).

THE UK PREVAILING CONSTRUCTION SYSTEM

The UK construction industry and its project delivery approach has been criticised in several literatures. Often, it has been considered to be confrontational, risk-averse, with lack of trust and limited capacity for modernisation (Zaghloul and Hartman, 2003; Rooke et al, 2004; Eriksson et al, 2008). These also contribute to the following factors: adversarial and hierarchical structure (Ghassemi and Becerik-Gerber, 2011; Sarhan and Fox, 2013); fragmentation (Egan, 1998) and cost driven environment (Bresnen and Marshall, 2000). Osipova and Eriksson (2011), posited that these challenges emanate from the prevailing system in construction, while Eriksson and Laan, (2007) added that these has adversely affected the extent of collaboration and trust among project participants. Similarly, Egan and Latham (1998 & 1994) have called for the substantial attention and improvement in the areas of collaboration and trust in the construction environment. However, Matthews et al, (2003) argued that value maximising and waste minimising in construction is a challenge, because the contractual structure inhibits collaboration, stifles cooperation and innovation, and rewards individuals for reserving good ideas or optimise performance at the expense of others.

Despite these criticisms, there seems to be a project delivery mind-set embedded in the institutional fabric within the industry that prevails regardless of the attempts to address these shortcomings (Sarhan et al, 2017). Commentators have argued that better collaboration among participants in projects could remedy most of these challenges in construction (Eriksson et al.; 2008; Xue et al.; 2010; Sebastian, 2011; Walker et al.; 2017). But, because clients are still allocating risks and safeguarding their project assets from opportunism, by deploying various control mechanisms contained within the contractual arrangements (Pasquire et al, 2015), and they invariably, do so by seeking advice from their lawyers (QSs) whom are familiar with the construction contracts and laws (Sarhan et al, 2017). This is an implication that now revealed a deviation within the delivery system along with several issues which has been highlighted above. Increasingly, QSs are not part of the production team, but are being used traditionally without proper integration. Arguably, this arrangement is also in conflict with their commercial functions, which leaves them with options of optimising their parent companies at the expense of the project that leads to more cost overruns. Seemingly, from this point of view the system is not encouraging them to collaborate, and clients also don't seem to understand the implications of excluding QSs from the core team is prompting into more value-loss in projects (Doloi, 2011).

HOW QSS POSITION IS CONFLICTING COLLABORATIVE ARRANGEMENT IN CONSTRUCTION

Quantity Surveyors have always been an integral part of the UK construction industry. Their evolution began from the 17th century and were established as a practice by the royal institute of chartered surveyors (RICS) in 1864 (Seeley and Winfield, 1999; Ashworth et al, 2014). Traditionally, they offer cost advice and assist with alternative design solutions as well as on cost implications in design and procurement using the techniques of elemental cost planning and cost checking (Kirkham, 2007). QSs other duties include post contract cost management activities such as valuation, change management and valuing variation to final account (Ashworth, 2014).

However, their ability to provide optimum value in projects, and collaborate with other construction participants has been challenged (Ashworth; Marsh, 2003). The current delivery approach, and their isolated roles in costing and design has posed tremendous challenge in providing more upfront input in construction (Olanrewaju and Anahwhe, 2015). For instance, under the prevailing system, QSs are only involved when strategic decision is taken i.e., when designers & engineers are appointed, briefing conducted and technical drawings reaching completion if not completed (Olanrewaju and

Anahwhe, 2015). Figure 1 revealed how they are separated from the production stream. This is also similar in their traditional cost planning function, where they are involved late for input on after-the-fact-costing (design-estimate-redesign) process.

This separation indicates a gap and disconnect that contributes to project delays, conflicts, waste and barriers to collaboration (Doloi, 2011; Kashiwagi & Savicky, 2000). QSs position outside production has not only hampered their value addition to the project team, but has allowed inefficiencies (termed wastes in lean) in their roles and across the project spectrum. For instance, QSs are not the main users of a contract, however the complexity in which they interpret the onerous document encouraged opportunistic behaviours among parties that leads to severe disputes (Sarhan et al, 2014; Rameezdeen and Rodrigo, 2013).Similarly, how they apportion risk using disclaimer clauses attracts about 8-20% project cost as contingencies(Zaghloul and Hartman 2003). Thus, this creates more rigors that stifle collaboration with a persistent focus on individual party functions, that build more distance among the participants encouraging lots of adversaries (Eriksson, Nilsson and Atkin, 2008). These behaviours stem from the prevailing system that lead teams away from trust to self-seeking interest i.e., opportunism (Pasquire et al, 2015).

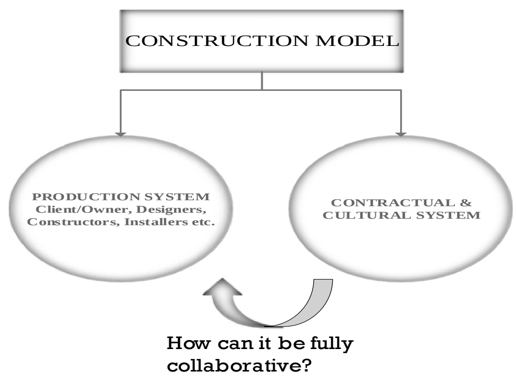

Figure 1: UK Construction Model

EMPIRICAL FINDINGS FROM THE CASE STUDIES

In this section, empirical findings captured from a multidisciplinary practice (lean-like approach) within the UK construction industry are presented. These findings explore on the commercial challenges affecting collaborative practices in projects and programmes.

COMMERCIAL CHALLENGES AFFECTING CP IN PROJECT AND PROGRAMMES

There are various commercial challenges that were discovered across the two cases that continue to undermine collaborative practices. These challenges are mostly associated with QSs and their commercial functions, the common ones among all the cases were: customer/safeguarding practice, QSs background/training, excessive reporting/commercial governance, and balancing standards with innovation.

a. Customer and safeguarding practice

Customer practice is a fundamental barrier associated with the QSs in practice. Some of the interviewee respondents were quick to comment on this saying: '*QSs are transforming well here under the commercial model, but how they persist with their due diligence is driving certain behaviours and inconsistencies in their approach especially with the SC'* [commercial manager, CSPA]. Another respondent also observed saying: '*Reflective of their siloed viewed, CP is still an influence in terms of how QSs operate which is served by a win-lose mentality (game theory type) of behaviour, and we still witness that here. For them is a kind of doing what their role is asking them to, proving their worth to the client'*. [Procurement Director, CSPB].

b. QSs background and training

Some of the respondents were of the view that QSs backgrounds & training is affecting the collaborative arrangements. The procurement director stated that: '*QSs often behave around the contract with the need to protect an organisation/client at all costs, and traditionally most often the only way they can maintain profitability for an organisation is through constant aggressive stance*. *And this is dictated by the market they came from affecting how we operate'*[CSPB].This demonstrates commercial challenge that stems from safeguarding practices, developing inconsistencies even in a collaborative environment. This is also a reminisce on how their background is (interpreting contracts) with a bounded culture on protecting client/organisation at all costs. Arguably, this can be attributed to lack of knowledge and collaboration that is contributing on how they behave in practice. Consequently, this view has brought about a short-term spotlight with a rigid mind-set (win-lose mentality) that continued to stifle their collaborative views.

c. Excessive reporting & commercial governance

Another barrier is how clients persists with commercial governance, excessive monthly reporting in project teams even in a collaborative setting. This of course, typifies how QSs are used to mount pressure on the project teams through bureaucratic processes that often doesn't add value to the project nor on the QSs roles. A procurement director and design manager both observed saying: *'clients even here have strong governance with the believe that the team needs to be more efficient. But certainly, this puts more pressure on the team, and I think this process should be optimised – allowing the QSs to contribute more value in other sense'* [PD, CSPB]*'One of our challenge here is focussing on what we need to do to deliver the project, but there is a lot of commercial assurance, and our QSs are so entrenched in these processes that sometimes can't give any degree of detail back to the delivery team for them to understand financial implications'*. [Design Manager, CSPA]. Again, this further illustrate how QSs position will continue to stifle CP, reiterating the need for them to be in a position beyond interpreting contracts but to contribute more value for the overall project. The much reliance on data to measure performance leaves a huge hole through redundant monthly reporting process that arguably could be better balance towards the project teams themselves. It can be argued that these persistent rolesare preventing QSs from understanding project values and wastes, as their competencies being used ineffectively – hence, the continued escalation of cost and time overruns in projects.

d. Balancing standards with innovation

This challenge still lingers, where commercial team are struggling to embed new ideas. But, because they are not entrenched upfront with the project team their innovative thoughts goes unacknowledged. A cost intelligent team leader lamented on this connoting that: *'this might be information asymmetry and because we don't sit together with designers, a lot of the time people don't critique the delivery of most solution and often this are left unchallenged'* [CI, CSPB].This indicate that because of the interface and fragmentation, the commercial team leader can only talk to the PM to pass on new ideas onto the designer, but the designer might argue and stick to what he/she knows and the PM wouldn't know otherwise or be able to test the true legitimacy of that claim because the designer is looking at maximising an eloquent solution, whereas the commercial team comes from an efficiency perspectives. The implication here is that, because they're disconnected and often sit outside the production team - the ability for a scheme to take such efficiency idea on-board remain a challenge. This shows how far-wide the commercial team are compare to the designers in the production team, despite the efficiency knowledge commercial team can offer, it goes unacknowledged and standards often prevail which defeat the idea of knowledge sharing and collaboration.

DISCUSSION

The observations made on this empirical case studies brought some new insights that describe how CP is being affected by some commercial functions in the UK construction industry. These implications show why QSs starting from the prevailing system are hesitant to collaborate or support its ethos in practice. Systematically, they're brought up differently and at different times in projects – hence, they continue to stick to customer practice. More so, the nature on how they are assessed (PQS)i.e., utilised based on the project profit rather than their input on the projects. Arguably, this stance is one of the biggest barrier to CP. The study has discovered other instances in collaborative setting like, excessive reporting and commercial governance. Majority of these activities are filled with efforts and time that adds no value, i.e., managing transactional interfaces from upstream down to the supply chain level. Currently, this is where QSs are placed now either to agree or protect a commercial position for their employers and clients (Farmer, 2016). Inevitably, this implies that QSs roles are overshadowed and led by an adversarial transaction with a combative effort to interpret project costs and risks which isn't allowing CP to flourish.

Another, implication revealed that intensified customer practice and other factors is how their background& training is conflicting with CP. This is evident specially when clients decide to buy designs, multiple number of QSs are engaged to fight battles with the contracting side, QSs are often deployed and they come in with different objectives and agenda. This a strategy that also shows how they're utilised for commercial assurances. So, distinctly here, you have QSs with different motivation, and a client paying exorbitant amount which they cannot guaranteed the project outcome, and part of their role is to get more (QSs) for safeguarding purposes. This explains how client's perceptions are on the QSs in construction, which typifies their behaviours when it comes to CP. Arguably, this approach has discouraged QS's attitude for not being part of the integral team to deliver a project, but being regarded as service-based providers to subdue the adversaries between parties. Invariably, this tactic appears not to be working, as it further revealed how they're reluctant to take the risk of being paid to save money in projects, but can only subscribed to being paid on a cost-plus-fee basis.

Hence, this shows that without properly incorporating QSs into the production domains or into a relational arrangement, these barriers to collaboration will continue to resurface despite adopting alliancing or JV frameworks. More so, all the stakeholders need to feel a sense of ownership in order to influence behaviors and achieve the desired outcome.

CONCLUSION

The aim of this study is to evaluate why QSs commercial functions is conflicting CP in both lean and conventional system within the UK construction industry. In doing so, the study has established that QSs, are structurally separated from the production system. It has also established some relational challenges engendering their status-quo, and how these commercial challenges affect collaboration in projects and programs. There were certain factors discovered also from the cases that are hindering the practicality of achieving CP. These factors among others are: QSs background/training, excessive reporting & commercial governance and balancing standard with innovation. These challenges are associated with the QSs in both conventional and multidisciplinary setting. Similarly, the standard form of contract deployed in practice is contributing immensely to most of the problems identified above, and partly the reason why professional QSs are mostly concerned with protecting a commercial position for employers and clients. It is clear now why traditional QSs might struggle under the lean setting, because of these persistent practices, inefficient procurement approach, and the narrowed views on collaboration. The next steps for this research will be to further understands the factors required that can support QSs and their commercial functions in a lean setting to enhance collaborative practice in the UK construction industry.

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LEAN FORMWORK

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ABSTRACT

Formwork materials and worker payments are one of the main expenditures in reinforced-concrete structures. Formwork engineering is thus one main factor impacting project success. In current practice, formwork construction including non-value-adding activities results rework and inventory waste. The aim of the paper is to adopt the lean manufacturing ideas to reduce unnecessary waste in the formwork engineering. A lean formwork construction model is developed to achieve this goal. In the lean formwork construction model, an on-site quality control culture is established by using Andon. Using the Andon system, form workers could receive support right away when problem occurs. Moreover, using Andon, operations in formwork engineering are pulled using the Kanban system to lower mold inventory level and create a continuous formwork construction flow. To validate the feasibility of the lean formwork model, a real case is tested. Experimental data demonstrate the developed method could banish unnecessary worker-hours in the formwork's operational flow and enhance formwork's value.

KEYWORDS

Formwork, lean manufacturing, kanban, andon.

INTRODUCTION

Formwork operations depend heavily on teamwork. However, ageing workers may deteriorate productivity. This worker structural problem directly impact project delivery, quality, and cost (Sutherland 2005; Chang 2007). To improve the aforementioned problems, scholars have suggested alternative materials, such as paper, fabric, fiber, Fiber-Reinforced Plastic (FRP), metal, compound, and composite materials to substitute wooden molds (Arslan et al. 2005; Yip and Poon 2008; Veenendaal et al. 2011; Spottiswoode et al. 2012).

Lean manufacturing is a management philosophy adopted by enterprises for improving work flow in recent years. Construction industry introduced the lean production concept named Lean Construction since 90's (Koskela 1992). Various studies

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have proven that lean construction could provide the construction industry with an alternative management philosophy (Koskela 1992; Ballard 2000; Ko and Chen 2012; Ko 2011). Lean construction could break through the limit of the traditional construction cost and time trade-off (Best and de Valence 2000). The purpose of this research is to applying the lean manufacturing to eliminate waste in formwork engineering. This paper first introduces background information of the study. Kanban and Andon systems are explained. Formwork construction practice is then discussed, followed by the development of a lean formwork construction process. Finally, a practical construction project is used to validate the feasibility of the lean formwork model. Conclusions and direction for future research are finally documented.

BACKGROUND INFORMATION

Andon and Kanban have been regarded as lean tools to reduce inventory level and create continuous flow. Both methods are briefly introduced as follows.

KANBAN

Kanban, in Japanese, refers to signboard, billboard, bulletin board, and card in general (Liker 2003). Kanban originates from the stamping production line of the Toyota manufacturing site (Li and Yang 2009a). The post-supplementary production pursued by the stamping production line is regarded as the production signal according to the level of material consumption. The most direct manifestation is to decrease the inventory in the storage yard. Three categories of the Toyota Production System's Kanban are described as follows (Li and Yang 2009b):

- Production Kanban

This is a tool used between the finished goods storage yard and production line. The production Kanban plays a role of triggering the production in the post-supplementary production system.

- Material withdrawal Kanban

This kind of Kanban is used by workers to retrive required parts from the storage yard. In this Kanban, the item and corresponding number of parts to be retrieved is recorded.

- Mark and management Kanbans

This Kanban is a static board put on the production site, and can be divided into two types. One is used for displaying information for everyone. The other is mainly used for displaying managerial data.

ANDON

Andon originates from the automatic loom invented by Sakichi Toyoda. The loom stops and the alarm lamp lights up when the device detects the broken yarns. Toyota Motor uses this concept in quality control. An error sensor is installed in the production equipment, and this equipment stops automatically when the sensor detects a fault. Toyota Motor also authorizes workers to press the button or pull the Andon Cords to stop the production line when they find a problem or need help to solve problems. Nowadays this alarm system represents the signal needing assistance (Liker 2003).

FORMWORK OPERATION PROCESS

Formwork operational process includes the following 10 steps, namely: 1) planning and designing, 2) shop drawing preparation, 3) material preparation, 4) mold machining, 5) setting out, 6) formwork assembly, 7) inspection, 8) monitoring and remedy of concrete pouring, 9) stripping, and 10) re-supporting of formwork, as shown in Figure 1 (Shen 1996). The general contractor designs the formwork system. Subcontractor then prepares the shop drawing and materials according to the formwork system. Mold inventory and hardware fittings are also enquired by the formwork subcontractor. If the inventory is insufficient, the subcontractor re-orders the required materials from material suppliers. Mold positions are set out before assembly. Formwork subcontractor has to verify the correctness of setting results, therefore molds can be machined and then assembled. Formwork assembly is carried out alternate with third parties, i.e. piping, rebar, and wiring. During pouring concrete into the mold, the formwork subcontractor must send a formwork engineer on site to avoid formwork support collapse and to handle emergencies in case of formwork exploded. Molds are stripped according to building codes. The stripped molds are reused in the site for the forthcoming formwork. Otherwise, they are shipped to the next project or mold storage yard.

Defective formwork systems may result in collapse or structural deformation. The main reason could be imputed to poor quality control, resulting in waste of making defective products. Workers do not fix problems once they have been found may cause formwork collapse or structural deformation when pouring concrete. These problems may cost more finance and manpower to repair and may interrupt production flow. The additional handling procedures and the consumption of time, energy, and costs are waste.

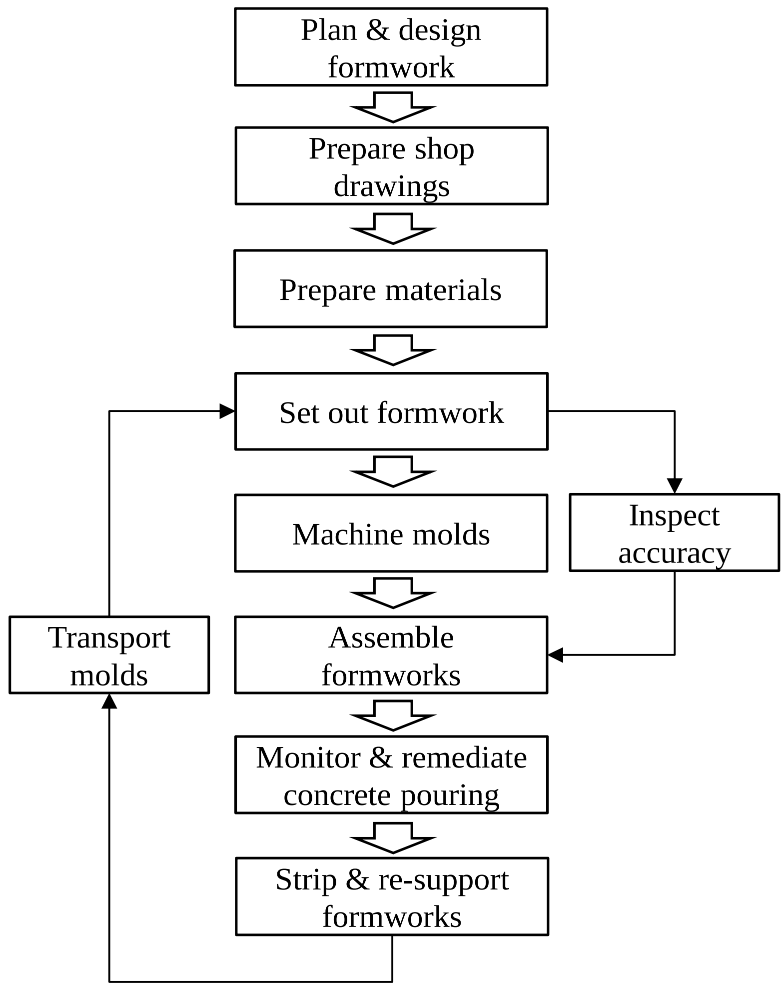

Figure 1: Formwork Operational Flow

LEAN FORMWORK

Formwork system is constructed according to the design conducted by general contractor. Current practice rarely emphasizes the formwork construction quality, or works out a method for improving the quality based on the formwork nature. As a result, the quality of formwork may be various. Poor formwork system may bulge or even collapse. Furthermore, the arbitrary piled up molds in the storage yard increases the time required to search for and handle them (Peng 1998). In order to improve these problems, this study uses the Andon and Kanban systems to establish the lean formwork construction model. Andon is mainly used for establishing the quality control culture, and the Kanban system is used for reducing material inventory (Ko and Kuo 2015). The framework of the lean formwork construction model is shown in Figure 2. In the figure, Andon and Kanban systems are working independently but coherently. The whole production is driven by Kanban system, while the Andon system is implemented within the Kanban system to improve its quality control.

The Toyota way attaches importance to the establishment of the quality control culture. When problem occurs in the production system, the production process is stopped immediately until the problem is solved (Liker and Meier 2006). In the proposed model, Andon culture is adopted to help formwork workers stop working and ask for help when problems occur. When establishing this culture, formwork workers are educated that support is available and no one will receive penalty when problems occur. Because workers do not need to worry about penalty, the performance improvement becomes a cooperative altitude. The use of the Andon culture is to develop a quality management system that focuses on doing the quality right at the very beginning. The culture can also help project stakeholders (i.e. general contractor, formwork subcontractor, third parties) identify and solve problems. However, suspension of the formwork progress puts pressure on project delivery and costs. The construction team should jointly look for methods for solving problems. Otherwise the suspension causes excessive waste. Another reason this study adopted Andon culture is that the suspension of production can effectively control the spread of problems. Formwork subcontractors generally attribute mistakes to the workers. By the contrast, in the lean formwork construction model, all mistakes are assumed causing by the improper work system, flow, and methods. When the formwork workers are educated with this culture, the team members can then endeavor to formulate a more effective system rather than defending themselves.

The Kanban system is used for changing the traditional way of orally releasing construction orders. This method can respond customer demands and banish the potential waste of the materials in the storage yard. In addition, the Kanban system can be used as a base for communication and jointly solving problems among superintendents, formwork foreman, and workers. The continuous formwork construction flow can therefore be created for controlling the formwork progress.

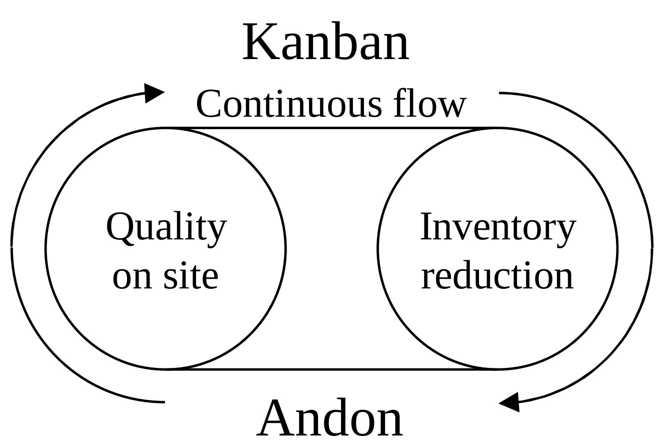

Figure 2: Lean Formwork Schema

CASE STUDY

In this paper, a real construction project is used for explaining the feasibility of the proposed lean formwork construction method. The studied case has one basement with four stories. Total floor area of this building is 2185.3 square meters. This study uses the formwork construction in the second floor as an example. The formwork area in the second floor is 1646 square meters. Shaped steel, steel tube supports, wooden supports, and wooden molds are used. Besides above subcontractors, this floor has scaffold, steel bar, electromechanical, and concrete engineering. The formwork worker-hours in this floor are summarized in Table 1. In the table, worker-hours were measured by the time to complete the formwork with design quality.

Table 1: Formwork Construction Worker-Hours

Activity	Workers[1]	Worker-hours[2]
Set out	0.5	4
Prepare storage yard	2	16
Assemble and machine mold	140.5	1124
Strip mold	26.5	212
Arrange mold	14.25	114
Transport mold	35	282

[1]1 worker = 1 worker works for 8 hours.
[2]worker-hours = Workers * 8 hours.

In assembling and machining formwork, motions i.e. measure, pull, cut, pass, nail, and mend are categorized as value-adding activities whereas walk, search, and wait are waste. The move motion in the transporting mold produces value; however, waiting to be transported is wasteful. An appropriate site layout can reduce the non-value-adding motions, such as walk and wait in assembling and machining formwork and wait in transporting molds. As a result, work efficiency can be enhanced.

Elimination of the non-value-adding motions of walk, search, and wait in assembling and machining formworks and wait in transporting molds can reduce 570.24 worker-hours (i.e. 71.28 workers). The proposed method can reduce 437.28 worker-hours waste (54.66 workers) in assembling and machining formworks; the productivity increases from the initial 11.72 up to 19.18 square meters per worker per day. Regarding transporting molds, the productivity increases from the initial 46.7 to 88.35 square meters per worker per day. Comparisons between before and after improvement are shown in Figure 3.

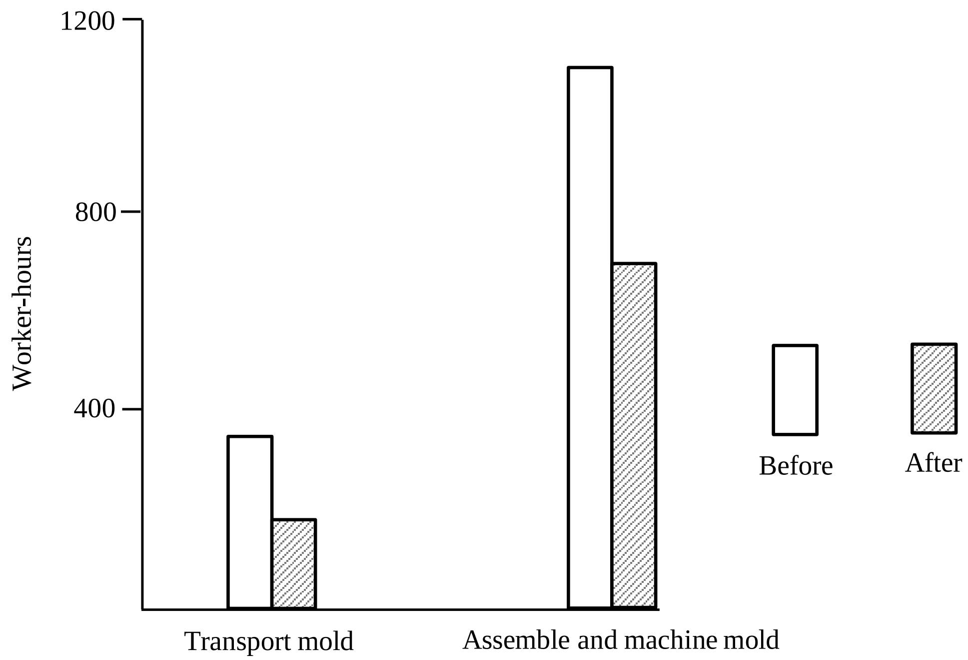

Figure 3: Worker-Hours Improvement

Currently the general contractor, formwork subcontractor, and third party of the project work individually. Such team work culture without an integral plan results waste of waiting between subcontractors due to poor coordination. Analyzed results show that the current formwork construction flow contains waste of motion. Main reason is that the formwork foreman does not plan the construction site layout ahead. Therefore, the waste of motions such as walk, search, and wait occur while assembling, machining, and transporting molds. Furthermore, the construction instruction is orally expressed by the formwork foreman. Formwork workers may receive incomplete production information. Moreover, the formwork team generally lacks of on-site quality control concept. Assistance cannot be obtained when workers have doubts in the construction process. These reasons may generate waste of making defective products.

CONCLUSIONS

Current practice in formwork assembling, machining, and transporting have much waste. This research uses the lean manufacturing to establish a lean formwork construction model, a formwork production system based on reducing waste while increasing customer value. The formwork construction signal transmitted by Kanban system is then pulled to reduce mold inventory.

Improving formwork quality depends on continuously learning and improvement attitude. The Andon culture and Kanban system can then be used to eliminate the non-adding-value waste. However, when transforming lean into formwork construction process, foremen and superintendents also should take the resistance of change into consideration. Lean education is necessary when implementing the lean formwork construction model. Since managerial philosophy between the lean formwork construction model and the current practice is different, workers may resist changing.

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MAPPING OF BIM PROCESS FOR TEACHING LEAN

Shobha Ramalingam[1]

ABSTRACT

Value Stream Mapping (VSM), a Lean tool and Building Information Modelling (BIM) are two contemporary approaches that aim to reduce waste and enhance collaboration in the realization of construction projects. While the principles and practices of both are found to benefit construction processes; there are limited studies that elucidate their synergies and demonstrate the value for teaching lean in construction management programs. VSM visually maps a process and identifies areas for possible improvement. However, it is directly applicable on assembly line operations in a manufacturing industry, an environment which the civil engineering students may not be familiar with, and therefore require experiential learning. To this end, the process of conversion of 2-dimensional (2D) design drawings to a 3D building information model of a construction project was foremost captured through VSM technique in an experimental study consisting of 4 student teams. The action learning methodology allowed the teams to generate the current state map, identify wastes in the process and aim for an ideal future state through kaizen efforts and brainstorming sessions. The experiment helped to reinforce the VSM technique in teaching lean and allowed the students to present appropriate opportunities for improvement. Lessons learnt can further act as a stepping stone to benefit professionals in actual practice.

KEYWORDS

Value stream, Process improvement, Lean construction, Action learning, Teaching

INTRODUCTION

Over the years, the benefit of Lean practices in the construction industry has promoted teaching Lean in the curriculum of construction management programs world-wide. The principles and philosophies of Lean construction are, however, imbibed from the manufacturing industry and as observed by Lobaugh (2008), students with background in civil engineering ‘may not be familiar with the manufacturing processes and process flows, let alone the complexities associated with them’. Tsao et al. (2012) identify different methods that Lean educators adopt to facilitate learning for university students

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including: lectures, tests, assignments, discussions, case-studies, simulations, activity-oriented games and field trips. However, researchers including Nofera et al. (2015), Pellicer and Ponz-Tienda (2014) argue that construction engineering and management students, find it difficult to grasp the abstract concepts of 'waste', 'value', 'process', 'conversion' and 'flow' of activities that are analogous to Lean manufacturing. Hence, for effective teaching and learning to take place in construction management programs, experiential learning becomes essential.

To address this concern, a synthetic experiment was conducted through post graduate students with background in civil, mechanical and electrical engineering, for one of the modules of the course on Lean construction at a leading Construction Management Institute in India. The course on Lean construction (3.5 credits), covered most of the key topics on the subject. However, this experiment focussed on integrating Value Stream Mapping (VSM) tool with Building Information Modelling (BIM) process to standardize operations and minimize waste. This was considered necessary as VSM is process oriented and unless students are part of the process, they may not be able to apply the technique in actual practice, as also opined by Lobaugh (2008). The objective of the study was two-fold: to enable the students to 'learn by doing' and to develop leadership and team capacity building skills. The following section provides a brief overview of VSM and BIM, leading to the research question.

LITERATURE REVIEW

VSM is a powerful diagnostic Lean tool that maps the entire production process graphically, from end-to-end, including flow of material and information to reveal opportunities for minimizing waste, which when improved can induce flow without interruption and enhance productivity (Rother and Shook, 1998). Thus, this tool aims at improving the system, by streamlining individual process steps and identifying areas of waste. In lean manufacturing, any activity that does not add value to the product, is considered as a 'waste' such as: overproduction, waiting, transportation, inappropriate processing, excess inventory, excess motion, defective products and rework (Womack and Jones, 2003). Tapping et al. (2002), proposed a 5 process step for implementing VSM that include: a) determining the appropriate process to improve, b) creating the current state map of the process, c) determining the appropriate metric for improvement, d) creating the future state map of the process, and e) determining improvement methods to bridge the current and future state and initiate action plans.

Some of the recent studies that discuss the application of VSM in construction include: Fontanini et al. (2013) for concrete slab in residential buildings and DantasFilho et al. (2016) for virtual construction process of multi-family housing. All these studies, in common have shown to identify the bottlenecks in the process and have attempted to minimize the wastes. In education, studies by Hadzialic and Weigel (2016), Oberhausen and Plapper (2015) demonstrate the application of VSM through laboratory experiments and student teams. However, there are limited such studies and this triggers further interest to use VSM technique as a demonstrative tool for teaching Lean.

Li (2015) argues that VSM is not as widely applicable in construction, due to absence of repetitiveness in activities, as in a production line assembly. BIM is a collaborative tool that acts as an interface between design and construction. Modelling is often repetitive in nature. For instance, conversion of 2-dimensional (2D) drawings to 3D models and further on to 4D BIM models for large scale infrastructure projects or high-rise buildings, requires sequence of repetitive actions. The benefits of using BIM in design and construction is well documented and include reduced conflicts on site, more coordination amongst the various stakeholders, little delay, minimized re-work and wastage(Eastman et al., 2008). For instance, a study on return-on-investment by Won et al. (2013b), showed a total of 709 errors recorded during design validation of 6 small to medium high rise buildings using BIM. While the Government in developed countries have made BIM usage mandatory in construction projects, it is still not an obligation in developing countries (Kumar and Mukherjee, 2009).However, to aim for BIM maturity in the global market, one need to identify the process improvement steps in BIM. To this end, the research question probed to understand: How does VSM enhance the production of 3Dbuilding information model from 2D design drawings?

RESEARCH SETTING AND METHODOLOGY

The synthetic experiment was conducted for 3 weeks to model a multi-storey residential building project consisting of G + 6 floors. Each floor typically consisted of 5 dwelling units with 2 staircases and a lift shaft. The ground floor comprised of car parking lots and the total area of construction was approximating 20,000 square feet. Four team of students with 3 members each comprising of a civil, mechanical and electrical engineer, were given the task of converting 2D design drawings into 3D BIM in the first week of the experiment using Revit® Architecture and MEP. In the second week, they had to generate 4D BIM from the 3D model using Autodesk Navisworks and the construction sequence of the project in Microsoft Project (MSP). In the third week, they had to optimize the model with respect to cost and time.

VSM implementation followed a structured process (Tapping et al., 2002): In the first step, *choosing the value stream*, the target state to be improved was logically identified as the first phase of generating 3D model, considering the size of the value stream map, the sequencing relationships of activities, competency of the participants and the total available time. Hence the scope of the study was limited to mapping the 3D BIM process as a single product family. The students were given instructions to produce a 3D design model, including all the information required for downstream activities (for 4D modelling), without defects and as efficiently as possible in a week's time. The 3D model comprised of five macro-tasks including foundation, framing with roofing, interiors, plumbing and electrical.

In the second step, the *current state map* was generated using universal symbols, icons, data boxes and different types of arrows. In the third step, *Lean metrics* and *value parameters* were determined. Some of the Lean metrics used in this study included: Takt time, cycle time, process time, lead time, defective rate and total value added time, which are defined and explained in the subsequent section. Two output value parameters were desired for the study, namely, improved process efficiency and quality. The fourth step involved generating the *future state map* by minimizing wastes due to inefficiencies, non-value added activities, defects, rework, errors and omissions through kaizen efforts and brainstorming sessions. In the fifth step, induced *interventions* such as providing descriptive *know-hows* for intermittent processes and *action plans* to enable producing within the Takt time were implemented.

Two additional members were assigned to monitor each team and track the production process. Data to map the current and future state was collected through stop-watch and photographs. After the current state map was generated, the time required to complete each task was plotted and shown to the teams to understand the steps each team undertook and the resultant variation in activity times. The teams were then explained the Kaizen approach to improve the process, following which they committed an afternoon session on brainstorming areas for improvement, in order to achieve an ideal future state. Four topics were identified to initiate Kaizen discussions that included: productivity, exchange of information across disciplines, rework and optimization techniques. The entire methodology was action-based learning (Stringer, 1999), wherein, each team was involved in the process of solving a practical problem and using a feedback system, evaluated alternatives and implemented an action for future improvement.

RESULTS AND FINDINGS

The five macro-tasks in the 3D modelling process included foundation, structural framing, architecture and interiors, plumbing and electrical. As a thumb rule, VSM is applicable to process not containing more than 12 tasks (Tapping et al., 2002). Each of these macro-tasks represented a work package comprising of 5-6 sub-tasks. For instance, Foundation required levelling and filling, reinforcement layout, concreting, fixing utilities, plinth beam. Structural framing required developing columns, beams including roof slabs, lift shaft, stairwell and head rooms. Interiors included developing internal walls, doors, windows, tiling, parapet and railing.

MAPPING THE CURRENT STATE

In order to map the current state, the teams foremost discussed to understand the concepts of Takt and cycle time. For instance, with the given 1 week timeline for 3D modelling, and assuming 5 working days and an 8 hour shift, the total given time = 40 hours (2400 minutes) per week. However, with the academic routine, the students could only devote 3 hours per day (15 hours = 900 minutes per week) during the afternoon sessions with an intermittent break of 20 minutes for the experiment. Hence, the total available production time was 800 minutes (3 x 5 – 0.33 x 5 = 13.33 hours) per week. Figure 1 below shows the current state map of the process using predefined icons of VSM. The information recorded in the data box includes the Average cycle times for each task in minutes.

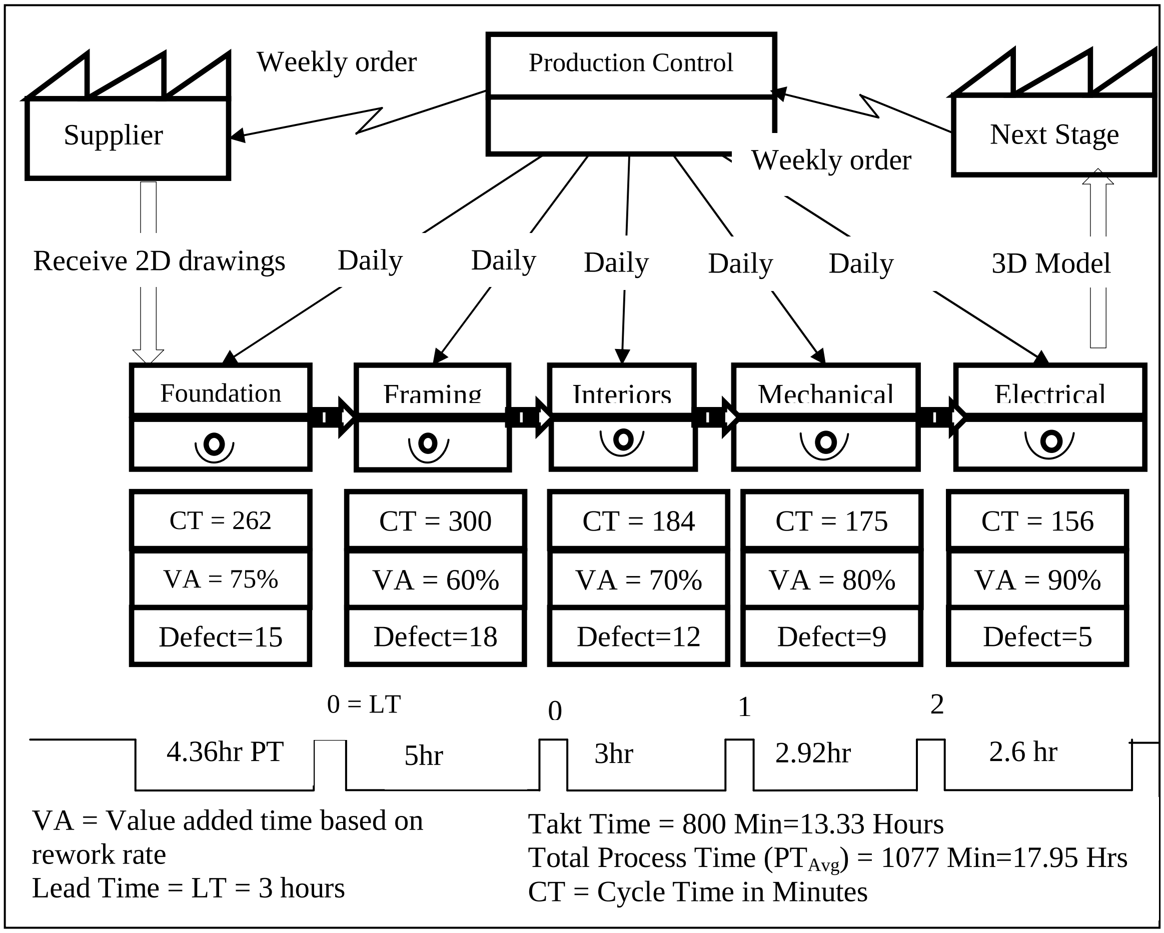

Figure 1: VSM - Current State Map of 3D BIM Process

The current state VSM metrics included:

- Cycle Time (CT) - the duration required to complete the work package. The CT in the current and future state map, is the average of cycle times of the 4 teams.
- Lead Time (LT) - the time elapsed between the task completed and before the start of the next task. LT acts as a buffer to shield downstream activities from upstream variability
- Process time (PT) – the overall cycle time of the sequence of activities.
- Value added (VA) – Value added time
- Takt Time (TT) – the rate at which the 3D model must be built to satisfy the customer demand. Here, Takt time = total available production time, as the demand was 1 3D BIM model in 13.33 hours (800 minutes) for each team
- Rework rate – Number of times a task was required to be performed in an iterative/rework prone process. This allowed to estimate percentage of VA time.
- Defects – Errors, Omissions leading to rework.

Figure 2 below shows the output of architectural building information model generated with plumbing and electrical services.

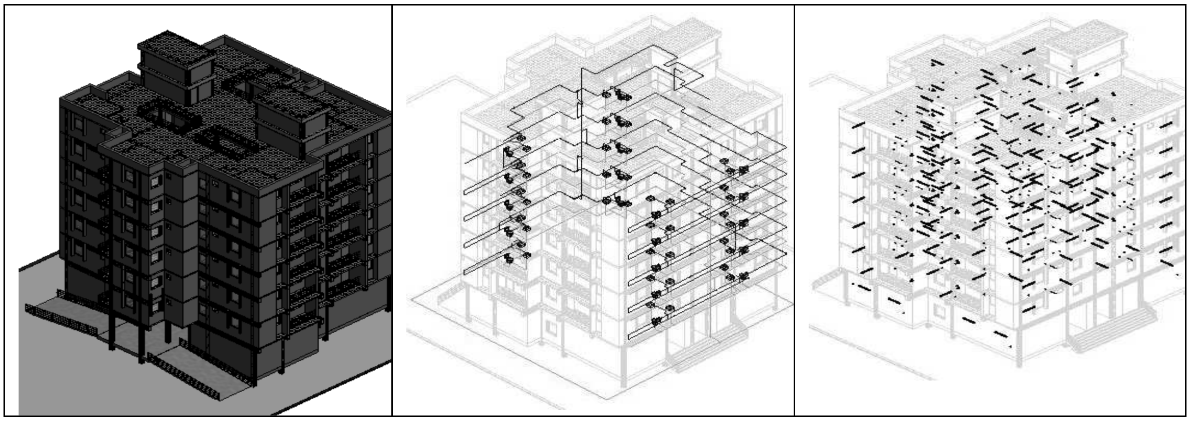

Figure 2: 3D Building Information Model – Architecture, Mechanical and Electrical

Following observations were evident from the current state map. Foremost the teams developed the 3D model in about 17.95 hours (overall production time), exceeding the Takt demand time by nearly 4.6 hours (34.6% increase in time). The process time was equal to the cycle times as there was only one resource assigned for each work station. While the civil engineer executed the first three task, the mechanical and the electrical engineer took subsequent turns. The four teams however showed high variability in the production process. For instance, while one team completed the model in 8.4 hours, another team took nearly 25 hours to complete (see Figure 3a). Hence, the average cycle time for each task was noted in the current state map. Further, the total lead time available was 3 hours, but only for the second half of the sequencing process that included incorporating Plumbing and Electrical fittings in the model.

Task	Sub-Task	Team-1	Team-2	Team-3	Team-4	Average
Foundation	Filling	30.00	15.00	43.00	55	35.75
	reinforcement	64.00	23.00	70.00	48	51.25
	concreting	105.00	56.00	80.00	100	85.25
	fixing utilities	86.00	33.00	60.00	45	56.00
	Plinth beam	70.00	35.00	45.00	30	45.00
Framing	Columns	60.00	30.00	72.00	80	60.50
	Beams	50.00	28.00	86.00	50	53.50
	Roof Slabs	30.00	12.00	60.00	33	33.75
	Lift shaft	24.00	10.00	56.00	30	30.00
	Stairwell	15.00	10.00	45.00	60	32.50
	Exterior walls	20.00	10.00	45.00	30	26.25
Interiors	Partition walls	30.00	23.00	70.00	40	40.75
	Doors	45.00	20.00	80.00	80	56.25
	Windows	45.00	20.00	90.00	50	51.25
	Tiling	56.00	15.00	40.00	40	37.75
	Railing	37.00	10.00	55.00	39	35.25
	Parapet	30.00	10.00	45.00	28	28.25
Mechanical	Plumbing lines	86.00	30.00	60.00	60	59.00
	Fixtures	32.00	20.00	65.00	40	39.25
	HVAC ducting	30.00	30.00	60.00	60	45.00
	Water sprinkler	20.00	20.00	30.00	30	25.00
Electrical	CCTV ducting	10.00	10.00	49.00	30	24.75
	Lighting	50.00	10.00	45.00	60	41.25
	Fan	20.00	10.00	45.00	42	29.25
	Power sockets	10.00	7.00	65.00	37	29.75
	AC wiring	10.00	7.00	40.00	40	24.25
Total Time (Min)		1065.00	504.00	1501.00	1237	1076.75
Total Time (Hrs)		17.75	8.40	25.016	20.616	17.945

Figure 3a: Time taken by Teams

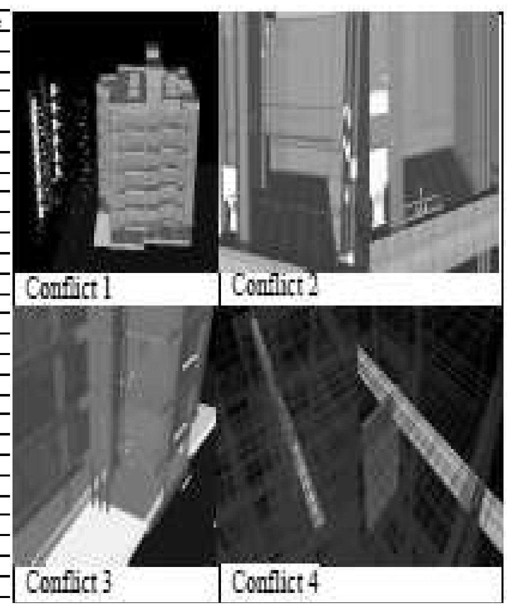

Figure 3b: Structural Conflicts/Errors

KAIZEN WORKSHOP AND TEAM REFLECTIONS

Mapping the value stream, it was evident that more number of defects occurred in the first three process stations leading to rework (refer figure 1). For instance, the amount of value added task during framing was only 60%. This required identifying the cause of rework by the teams through brainstorming session in the Kaizen workshop to identify the bottlenecks as listed below:

- *Incomplete information* in the 2D drawings/plans - led to *waiting* period.
- Prior to executing the foundation task, the *review time* was observed as a *non-value added but necessary activity*.
- *Structural clashes* in stage 2, such as column in the ramp and staircase (see figure 3b), led to *rework*. *Lack of constructability checks*- led to rework. *Lack of version control* also led to *rework*. This could also be due to member inexperience.
- Lack of coordination between the actors led to *redundant information exchange* and discontinuity in the flow. For instance, the initial practice included transmitting information on civil related query only to civil members. This also led to lack of understanding of concurrent processing capabilities.
- Reflecting that the entire sequence was push based rather than being *pull-based*.
- Expected *level of detail* varied amongst the actors due to a tendency to over design (*over production*) and the need for a common guideline was necessary – this emphasized the need for standardization of operations. A descriptive know-how was then developed to minimize this wastage in the future state such as on railings, doors and window details. This reduced the time in the future state by nearly 2 hours for the teams.
- All the teams concurred that the BIM model was heavily front loaded – a situation of *excessive processing*. Any change in the design due to mechanical or electrical conflict led to remodelling the civil works as well. The teams again voiced the need to work in parallel on a skeleton model, wherein, each actor would develop independently and juxtapose in the end.
- Some of the *non-value added tasks* (such as the coordinate system) were due to incorrect information or badly formatted information (see figure 3b).

In summary, the observations identified kaizen burst situations, primarily in the context of information processing (such as waiting time for information, inventory – redundant information, excessive processing and over production of information) where improvements could be made in order to improve efficiency and reduce variability. Further, the interaction with BIM and Lean was also evident, for instance, in achieving user needs; avoiding incomplete information, enhancing visualization and coordination with the actors. This is in concurrence with studies that have explored the benefits of adopting BIM and Lean to improve performance (Sacks et al., 2010).

FUTURE STATE VSM

In the manufacturing industry, fundamental form of waste is either due to inventory or over-production; while in this exercise, the primary form of waste stemmed from variability – both with respect to cycle times and the quality of output. For instance, the models generated by the teams showed structural clashes between the columns and beams; positioning of columns in staircases and so on. Efficiency and effectiveness are two terms that characterize performance, predictability and variability. The efficiency of a value stream is measured based on the Lead times. In this study, the mechanical and electrical modelling had a waiting time, which induced a buffer in case there was any delay from the upstream activities. However, being on the non-critical path (evident from the schedule generated in MSP), they did not affect the overall production time. Alternatively, the effectiveness of the value stream was calculated by comparing the actual cycle times with the Takt time. Clearly, the actual average cycle time exceeded the takt demand time by 34% in this study. Hence based on these insights and the value parameters identified earlier in the study, that included 'efficiency' and 'quality', the following recommendations were put forth for future state map:

- Synchronize the output with the Takt demand time to reach an ideal state in future,
- Standardize work procedures to avoid rework such as level of details and types of handrail, staircase etc.
- Restructure work where needed to improve flow and reduce variability and
- Quality control efforts such as through self-checks/checklists. For instance, during kaizen workshop, members created a checklist on constructability parameters to self-validate their model before handing it over to the subsequent modeller.

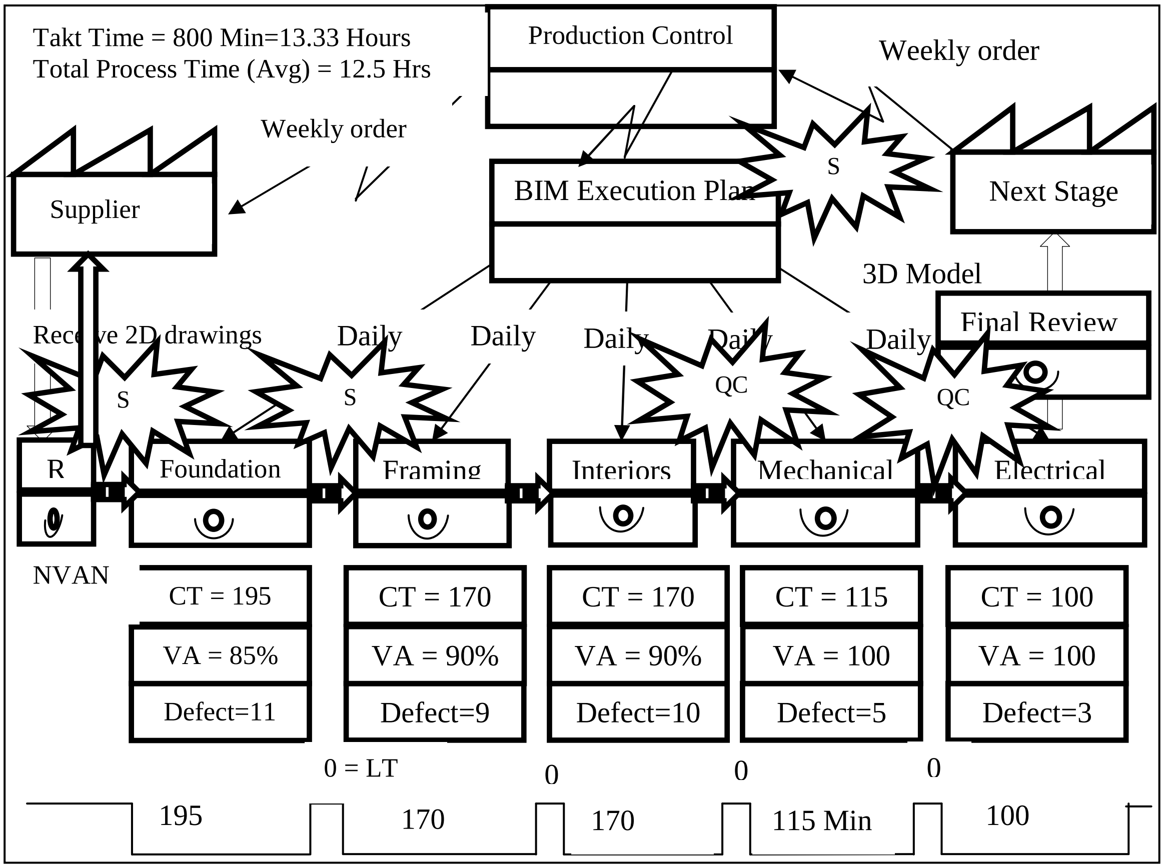

Figure 4: VSM - Future State Map

Figure 4 shows the future state map of the BIM process. The kaizen bursts in the figure shows areas for improvement in the process stations through work restructuring processes which included developing method statement on modelling sequence for stairwells, beams and plumbing ducts and developing a BIM execution plan to act as guiding reference. Such efforts reduced variability and non-value added activities such as waiting for information. Second, Quality control through self-checks were made mandatory during civil, electrical and mechanical hand-overs. Third, as observed earlier, the review stage was a necessary but non-value adding activity. Hence, coordinators were introduced at the beginning and end of the sequence to review the inputs (and seek clarification with the design team where necessary) and facilitate BIM modelling process as well as counter check the product for defects towards the end of the sequence. Though the number of resources increased, the overall cycle times was reduced (to 12.5 hours) by all these measures, which was within the Takt time. Indirect benefits included increased commitment, transparency and coordination amongst the actors apart from learning the VSM technique.

CONCLUSION

In summary, this study has attempted to demonstrate the value of VSM in BIM process in the design development phase of a construction project through an experimental study.

The scope of the study was limited to analysing the BIM process for development of 3D model from 2D drawings. The findings were two-fold: foremost, it reinforced the value of the lean tool in identifying and eliminating waste in the BIM process. Also, BIM and Lean are two distinct approaches and this study reinforces their synergies. Second, it helped the members to develop their team building skills.

In specific, mapping the information in the BIM process showed variability in production. Some of the improvement measures included developing method statements, standardizing the process and ensuring quality checks at intermittent levels to minimize rework and waste. Further, enhanced communication such as through a BIM execution plan, aided in establishing pull systems for information and enabled a more efficient flow within the process.

The study has inbuilt limitations due to experimenting in a controlled environment, and the competency level of the participants, who were post graduate students. However, lessons learnt through such action-based-learning experiences can act as a stepping stone for application in practice for professionals. These findings are therefore significant to theory and practice. Future studies could benefit by mapping a comprehensive set of BIM processes and conducting the experiment on live case-situations in projects as well as exploring in relation to upstream and downstream activities.

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LAMINATED TIMBER VERSUS ON-SITE CAST CONCRETE: A COMPARATIVE STUDY

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ABSTRACT

Laminated timber is a relatively new construction material for multi-story buildings. With this type of structural engineered wood product, timber is glue laminated to increase its constructive strength. Laminated timber represents an opportunity to lower GHG emissions, while traditional on-site cast concrete is believed to be cheaper. The study examines differences between construction in laminated timber and cast concrete, and pros and cons associated with construction in laminated timber. The study began with a literature review. Then the construction of two neighboring apartment buildings that used Last Planner during both design and construction were studied. Takt planning was used in the production planning. Twelve interviews represent the main source of data and was supplemented with a study of documents and direct observations in design meetings. Use of laminated timber requires more resources in the design phase compared with the use of cast concrete. Fire and acoustic regulations, in particular, demand new construction guidelines. However, use of laminated timber saves time and provides a cleaner working environment during construction. Under the right circumstances, laminated timber appears to outperform on-site cast concrete. This study suggests Lean measures for contractors that want to benefit from the advantages of laminated timber and improve such construction.

KEYWORDS

Cross Laminated Timber, Cast Concrete, Last Planner, Takt, Prefabrication

INTRODUCTION

The fifth assessment report (IPCC 2014) of the Intergovernmental Panel on Climate Change confirms with 95% certainty that global warming is caused by anthropogenic greenhouse gas emissions. It is estimated that 18% of the global CO_2 emissions are directly or indirectly generated by the building sector and is projected to increase by 50-

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150% by mid-century. These data highlight the need for greener materials and construction methods.

Life cycle assessments (LCAs) of the load bearing structures in mass timber and concrete buildings show that the CO_2 emissions from timber structures can be 34-84% lower than from concrete structures (Skullestad et al. 2016). A weakness in LCAs from Scandinavia is the lack of life cycle cost analyses (Petersen and Solberg 2005). Builder experience with mass timber is limited and not widely known.

Veidekke AS, one of the largest contractors in Scandinavia, has a strategy to acquire knowledge on and gain a competitive advantage by building environmentally friendly buildings. Veidekke was using both mass timber and on-site cast concrete to construct two apartment buildings at the same building site in Trondheim, Norway, in a comparable setting. The contractor used the Lean method Collaborative Planning (CP), a Last Planner adaption, during design and construction. They also used Takt Planning for the construction planning. This provided a unique opportunity to research both on Lean construction and buildings in mass timber. The objective of this study was to investigate how Lean measures like Last Planner and Takt influence the construction process when new and green materials are introduced. To answer this objective, the following three research questions were formulated:

- What are the differences between construction in cross laminated timber (CLT) and on-site cast concrete?
- What pros and cons are associated with the use of CLT?
- How can contractors improve construction with CLT?

This paper provides a short disussion of mass timber along with an introduction to the Lean methods used in the case project. Then it presents the results of the case study. These results form the basis for improvement measures for those who want to benefit from the advantages mass timber can provide.

This study was limited by the progress of the project. In the spring of 2018, the construction phase barely had begun. The scope of this paper is for that reason limited to the concept development and detailed design phase.

THEORETICAL BACKGROUND

Mass timber is a common denomination of timber elements used for loadbearing purposes, mostly in buildings (Smith et al. 2017). Mass timber elements can be assembled in several different ways, both glued and non-glued. Cross laminated timber (CLT) was found to be most cost-effective alternative considering price, durability and strength (Buck et al. 2015). Alternatives considered were laminating, nailing, stapling, screwing, stress laminating, doweling, dovetailing and wood welding. CLT elements are prefabricated with high precision in modern factory settings. Several advantages are associated with such prefabrication of CLT (Smith et al. 2017). Less material waste on the building site, element accuracy due to prefabrication, reduced on-site construction time and usage of lower quality timber in structural elements are among them. CLT consist of multi-layered panels made of construction timber (Buck et al. 2015). The layers are arranged with the fibers perpendicular to the neighboring layer and glued together. Norwegian spruce is currently the softwood species primarily used for CLT (Brandner et al. 2016). The cross-layered structure of CLT gives a better load bearing capacity in more in more than one direction.

The ideas of Lean Production were originally developed by the Japanese car industry (Womack et al. 1990), (Howell 1999). The main concept of Lean are as follows: minimizing waste, customer orientation, product quality excellence, continuous improvement, reducing costs and flow among other elements (Howell 1999). Lean Construction is the construction industry`s adaption of Lean Production (Green 2011). "*Construction is complex production of a one-of-a-kind product undertaken mainly at the delivery point by cooperation within a multi-skilled ad-hoc team*" (Bertelsen and Koskela 2004). This unique product necessitates integration of the design and production processes.

The Last Planner System (LPS) is a Lean tools that has become popular in the construction business in Norway (Kalsaas et al. 2014), (Engebø et al. 2017). Norwegian companies often adopt the LPS and create their own adaption to fit LPS into their organizations. Veidekke has an adaption called Collaborative Planning (CP). They use it in all stages of the construction and in collaboration with the sub-contractors.

LPS has two main advantages in the design phase (Koskela et al. 1997). The design phase is made transparent while the design team are influencing, and are held more accountable for, the planning of their own work and deliveries. Activity becomes measurable for the design team. The other advantage is that goals and milestones are easier to set and measure against during the process. "*The LPS has its main focus on the planning process (how to plan)*" (Bølviken et al. 2015). Several planning concepts also focus on the content of the plan, such as Takt Planning. In construction, Takt Planning is a method for structuring the work to be done during production (Frandson et al. 2014).

A pilot project in Sundsvall, Sweden, identified that the lack of knowledge regarding the use of mass timber in multi-story buildings was source of resistance from sub-contractors (Sardén 2005). The project "*was a typical, transformation focused, construction project*" (Sardén 2005). The study concluded, among other things, that future mass timber project should have a Lean Construction approach and that the project manager should focus more on customer value and flow during the construction process.

Veidekke has recently constructed a large-scale student housing project, located in Trondheim, using CLT and Takt Planning (Vatne and Drevland 2016). Even though it was the first mass timber project for most of the involved parties, the main contractor found that productivity increased. Better logistics and the repetitive work were believed to be the critical success factors, when compared to the traditional production planning.

In a case study in the US, seven mass timber projects of different sizes and scopes were compared to reference projects (Smith et al. 2017). On average, the total costs for mass timber projects were 4,2% lower than the corresponding buildings, mainly in concrete. Of those seven projects, four were considered to be pilot projects. One of the most important findings was that repetition of similar projects provided improved productivity and cost control for the contractors. Another study compared the costs of alternative load bearing structures to concrete for an art center (Mallo and Espinoza 2016). The results showed that in that specific case, the cost for a load bearing system in concrete could be reduced by 21% if most of the structure were replaced by mass timber.

On average, it was found that the reduction in overall construction time was approximately 20% in the mass timber projects (Smith et al. 2017). This reduction was primarily due to the level of prefabrication of the CLT elements and a decrease in the amount of work on site. A Norwegian study found that on-site assembly was 30-40% faster for CLT elements than the typical schedule for producing the load bearing structure in concrete and steel (Finstad 2014).

Few studies have had an opportunity to compare these two construction methods using such similar surroundings as was available for this case project. By reducing other variables, we identify what differences there are between the two approaches to fill in the knowledge gap regarding these methods.

METHODOLOGY

This study started with a literature review and continued by conducting case-specific observation, interviews, and document studies. The initial literature review was on the topic “mass timber”. The aim was to map the state of the art from a project management point of view in relation to construction in mass timber. A scoping study approach (Arksey and O'Malley 2005) was used to gradually focus the review from a general scope onto previous comparison studies between mass timber and other traditional materials.

The case is an ongoing project in Trondheim, Norway. Two apartment buildings at the same construction site were studied. One building (building A) has 5 floors. It is constructed in concrete and steel, as load bearing structure. The second building (building B) has 8 floors. It is constructed in mass timber, mainly in CLT. The footprints of buildings A and B are equal, and the floorplans are approximately the same. The two buildings were designed and are being constructed by the same main contractor, Veidekke, and with the same group of sub-contractors. A previous construction phase at the site (building C) was used as a reference for building A and B for the concept development. Building C has approximately the same gross floor area and specifications as buildings A and B.

A case study method described in (Yin 1994) was used. The strength of a case study is the variation of sources of data (Yin 1994). Documenting an ongoing case such as this building project creates unique opportunities for comparison. The ongoing project provided several opportunities for collection of different types of data in a comparable setting. In this case study, three sources of data were used. A triangulation of the data from multiple sources strengthens the validity of the results (Denzin 2012). In addition, the main author had a summer internship at the case project and is now employed as a trainee in Veidekke. The 2nd author was a special advisor at the project. This insider knowledge provided access to documents as well as an understanding of who to interview.

Three direct observations were conducted in design meetings. A role as a participating, but passive, observer was used as described in (Gold 1958).

As the primary source for qualitative data, five respondents from the main contractor and seven respondents from the sub-contractors, were interviewed. The interviews were semi-structured. The respondents from the primary contractor were as follows: two project developers, the project manager, the design manager and the construction manager. From the sub-contractors, the architect, the fire and acoustics consultants, and the electrical, plumbing and ventilation engineers were interviewed. The interviews were recorded and transcribed to minimize sources of error. The data from the interviews were then put in the context of the findings the study of project documents and direct observations. The document study was based on the available and relevant documents in the online project hotel of the main contractor. Economic overviews and production schedules among others were compared for the two buildings.

Since the project was still ongoing, some limitations were present. Some of the documents studied and economic overviews are not entirely complete. Regarding the production, the study is limited to what is planned. Different contract agreements made some economic comparisons difficult. The scope of the study is also limited to the most essential consultants and sub-contractors in addition to the main contractor.

RESULTS AND DISCUSSION

DIFFERENCES IN CONCEPT DEVELOPMENT AND DETAILED DESIGN

In this case, the buildings are constructed over a shared parking garage located in the basement. The structural engineer estimated that it took triple the time to complete the design of the concrete ground floor in building B than for building A, primarily because the CLT elements lacked the ability to distribute the vertical loads horizontally in the load bearing walls. This characteristic of CLT resulted in the need to add **large concrete beams** under the ground floor. In addition, the CLT-elements needed to be anchored to the concrete slab at the ground floor. Over one hundred steel plates for anchoring had to be modelled and drawn in separate drawings and cast into the concrete slab. For contractors who want to benefit from the advantages of CLT, an optimized basement design is feasible. However, a way to acquire knowledge on new materials is by conducting pilot projects. The large beams became an unexpected challenge for the technical infrastructure in the basement and led to extra design work.

The difference between the time and design required for building B versus A seems to be a direct effect of the use of mass timber in building B. An alternative use of the basement space may have made this difference smaller. Optimizing the basement for mass timber could potentially eliminate most of the extra challenges experienced in this project.

The two main issues influencing both design and planned production evidently were **fire** and acoustic-related **challenges**. The timber material is flammable, while concrete is not. This difference results in stricter requirements for fire engineering in Norway for CLT construction. A combination of limited knowledge and a lack of available pre-accepted solutions for CLT construction in apartment buildings, developing techniques to accommodate CLT has provided challenges and required extra time of the fire consultant during concept development and detailed design. Once standard approaches are developed using CLT, the need for extra time to develop fire-related solutions is likely to decrease.

The reduced internal mass of the building when switching from concrete to CLT has also posed **acoustic challenges**. Noise reduction requirements between apartments are the same regardless of the materials used. The lack of construction approaches for buildings using CLT was evident during the design phase. The acoustic consultant estimated an increase of up to 100% more time spent to develop details for building B than usual.

The architect and the main contractor emphasized the combined effect of the fire and acoustic challenges. Because both had limited experience with CLT in apartment buildings, their engineered solutions were cautious to make sure the requirements are met. As a result, construction details were developed that made the planning of the furnishing work by the order of the work packages more complicated in the takt plan. Hence, the takt plan was different for the two buildings. The same crew was planned to work through both buildings in a takt train. The new solutions and details necessitated a second takt plan with more work packages. It also lead to a significant increase in the assembly of fire plasterboards compared to the concrete counterpart, requiring a greater proportion of simple assembly work planned for building B compared to building A.

In traditional concrete buildings, the concrete walls often have the same dimensions on all floors. In the mass timber building, the **dimensions of the CLT elements** decrease up through the floors. This difference has led to increased work for several parties during detailed design. The apartments, which essentially should be equal, have some variations due to the CLT-elements.

The possibility for labour saving copying of work in the BIM-model decreases when the dimensions are changing. This variation has led to more time spent to adjust the BIM-model for building B. It was an effect that was hard to mitigate when the main contractor also wanted to limit the CLT-volume to reduce costs. In building A, more copying was possible, placing a greater burden on the architect for building B. In addition, the electrical engineer expressed inconvenience for placing of electrical components in the BIM-model.

The main contractor expected **improved HSE** for the mass timber building. Previous experience from a student housing project using CLT by the main contractor Veidekke indicated significantly improved noise and dust conditions.

These factors are believed to generate improved productivity and earnings for the contractor in the short term but can also be significant for the long term. Worker health is important to any contractor to maintain productivity rates long term.

In general, all the respondents expressed an **increased level of uncertainty** related to the mass timber building, mostly related to the lack of experience and pre-developed solutions. The respondents had experienced this kind of uncertainty previously when new construction methods and materials were introduced. Some of the parties had taken precautions and expected greater time consumption in the design phase but unexpected challenges occurred. Most of them were believed solved during concept development but had to be revised during the detailed design phase. In addition, the architect was assigned several unexpected tasks. This type of uncertainty seems not to be unique for mass timber projects but instead can be expected when other new materials and methods are introduced.

Involvement in the concept development in this project was more extensive than usual both a measure for risk control and because the main contractor needed to develop **new construction details** for the CLT option. The main contractor also engaged one additional in-house resource with experience on CLT during the development phase.

Both the concept development and the detailed design were carried out using the same methodical approach, CP. **Early involvement through CP** may have lowered the perception of risk concerning building B. Also, the early development of many of the main features of building B seem to have positively affected the perception of risk in the project.

All the respondents concur and were satisfied with the **implementation of the design process**. The main difference for them was an increased number of special design meetings. Held in addition to the main design meetings, these meetings were where special topics were worked through by the relevant parties. Since the process was common for both buildings, some conflicts occurred. Challenges in one building influenced the progress of the other. These delays affected both buildings, but the respondents felt it was most problematic when the concrete building influenced the mass timber building, especially because the level of uncertainty was higher concerning the CLT.

Observations also confirmed that up to 2/3 of the time in the design meetings was used for building B, possibly resulting in some level of neglect for building A. Overall. the process with CP seemed to result in a relative smoothly implementation of both phases.

The total construction time from the ground floor to move-in ready for building B were scheduled for 38 weeks and for building A, 42 weeks. The assembly of the CLT elements was scheduled at 8 weeks for building B. The construction of the concrete and steel was scheduled to take 13 weeks for building A. The detailed design period was the same for the two buildings since it was one common process and consisted of 13 design meetings over a period of 26 weeks. The furnishing phase, however, was scheduled for 19 weeks for each floor in building A and for 23 weeks in building B. Even though the furnishing phase had a longer duration, the CLT was advantageous when it came to total construction time when taken in to consideration that building A is 5 floor and B, 8 floors.

Some **cooperation issues** occurred during the detailed design phase. The structural engineer for the mass timber was not present in any of the design meetings. Several in the design team pointed this out as problematic, especially the architect, who usually cooperates closely with the structural engineer, found it difficult to facilitate the cooperation. Feedback was also late, which on several occasions resulted in having to redraw, thereby slowing down the design process for the architect and sub-contractors. In hindsight, the CP could have been stricter on committing the structural engineer.

The observations confirmed several obstacles for good flow in design meetings caused by the mentioned issue. To get a good flow through the design process the main contractor depends on reliable consultants and sub-contractors. The issue had also been experienced in other projects by the respondents.

A general challenge in projects is **builder choices**. In this case, limitations created by early decisions from the builder also created constraints, complicating the development of solutions and construction details. Such challenges also occur when using traditional concrete, but the implications are greater when new main materials are introduced.

The mass timber contractor was a turnkey contractor, who delivered and assembled the CLT elements. For the concrete counterpart, the main contractor performed the load bearing structure construction. This difference led to a **loss of own value creation** for the main contractor. If the contractors were to acquire the assembly skills, this loss could be reduced or eliminated.

COST DIFFERENCES IN CONCEPT DEVELOPMENT AND DETAILED DESIGN

The case project had 7% higher total cost during concept development than building C, mainly due to a higher architect cost. The builder was surprised it was not more significant difference. For building C, it had been necessary to redraw the floorplans to accommodate the housing market, leading to higher costs. The case project was built on sensitive clay and it is worth mentioning that there was a 50% reduction in the costs for geotechnical consultants in the case project compaired to building C. The reduced weight of building B was the main reason for the savings. For building A and B, costs for the architect, fire and acoustic consultants, and the structural engineer were different. The cost differences for the structural engineering, fire consultant and acoustic consultant in the concept development are shown in table 1. Other consultant costs were approximately the same.

Table 1- Key figures, cost data from the concept development

Costs for concept development (NOK):		
	Building A	**Building B**
Structural engineer	80’	165’
Fire consultant	42’	260’
Acoustic consultant	42’	46’

During detailed design, mainly the costs for the architect, fire and acoustic consultants, and the structural engineer were greater for building B. Other consultant costs were similar during concept development phase: when adjusted for gross floor area.

Table 2- Key figures, cost data from the detailed design

Costs for detailed design (NOK/m^2):		
	Building A	**Building B**
Architect	218	260

Structural engineer	95	101
Fire consultant	21	42
Acoustic consultant	32	55

These increased costs during concept development and detailed design were with great certainty mostly attributable to the use of mass timber. The main contractor likely will be able to reduce these if more buildings were to be constructed using CLT in the future.

CONCLUSIONS

The objective of this study was to investigate how lean measures like Last Planner and Takt influence the construction process when new and green materials are introduced. To answer this objective, three research questions were formulated:

- What are the differences between construction in cross laminated timber (CLT) and on-site cast concrete?
- What pros and cons are associated with the use of CLT?
- How can contractors improve construction with CLT?

Three categories of differences between construction in CLT and on-site cast concrete were identified by the respondents in this study, listed in Table 3.

Table 3- Experienced differences when constructing in CLT versus cast concrete

Due to mass timber:	**Due to new material, not mass timber explicitly:**	**Occurring in any type of project:**
Enlarged concrete beams in the basement	Level of uncertainty in concept development and detailed design	Cooperation issues
Development of acoustic solutions	Development of new construction details	Builder choices
Development of fire solutions	Early involvement of sub-contractors and consultants using CP	Decreased value creation for the main contractor
Dimensions of CLT-elements	Implementation of the design process	
Improved HSE during production	Shortened construction time	

Acoustic, fire and structural challenges related to the use of CLT caused extra work during concept development and detailed design. The architect and the main contractor were the most influenced parties. The costs for building B can most likely be reduced if the main contractor reuses the developed solutions in future projects.

The CLT-elements represent an advantageous construction method. Reduced construction time and the accuracy of the elements due to prefabrication are the most significant benefits. Reduced material waste at the building site, improved HSE and reduced CO_2 emissions are among the sustainability benefits for contractors. The main drawbacks with CLT in this case is the loss of work that can be carried out with in-house capacity and an increased design cost. Production costs were not included in this study.

When it comes to how contractors can improve construction with CLT, Lean tools such as Last Planner and Takt proved advantageous in the studied pilot project. With higher uncertainty arises the need for increased planning for the unforeseen. These tools provided the stability needed for tackling the uncertainty that entailed the introduction of a new and green material as CLT. Early involvement through CP may have lowered the sub-contractor's perception of risk concerning building B. To get a good flow through the design process, the main contractor depended on reliable consultants and sub-contractors. CP and Takt can be used to secure this reliability, and these tools may have influenced the outcome more than the respondents have realized so far.

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THE ROLE OF SLACK IN STANDARDIZED WORK IN CONSTRUCTION: AN EXPLORATORY STUDY

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ABSTRACT

Standardized work (SW) is a type of action-oriented procedure that sets a basis for continuous improvement in the Toyota Production System. However, the usefulness and applicability of this practice to construction is still unclear. Furthermore, while some studies have addressed the key elements of SW, the role played by the concept of slack as a fundamental element of operations design is rarely discussed in an explicit way. This is a drawback since slack resources allow for the system to cope with variability from different sources.

Considering the context of the construction industry, the aim of this study is to carry out an exploratory investigation of the role played by slack in SW. This analysis is mostly based on a matrix that checks strategies for the deployment of slack resources against sources of variability in construction. Results indicate that SW, in construction, should account for a broader range of slack resources in comparison to what is accounted for in manufacturing. In addition, we propose that slack resources and the corresponding variability sources be explicitly anticipated when designing SW for construction operations.

KEYWORDS

Slack, Standardized Work, Variability.

INTRODUCTION

Standardized work (SW) is a type of action-oriented procedure that is an essential element of lean management systems (Ohno, 1988). As such, SW is a specific type of standardization, which may or may not be jointly adopted with other standardization

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approaches described in literature (Gibb, 2001). SW aims to reduce variation in operations and establishes a basis for continuous improvement(Martin and Bell,2011).

Although SW is commonly applied in the manufacturing industry, existing literature indicates that the same does not happen in construction. There are no reported examples in which the same standardization method originally devised for manufacturing was implemented in construction projects (Mariz et al., 2012). In this respect, Liker and Meier (2007) point out that SW requires a certain basic stability of production processes, which is difficult to be achieved in construction projects. However, adapted applications of SW to construction are known for the reduction of wastes in activities such as waterproofing (Fernandes et al., 2015), masonry and ceramic floor tiles (Saggin et al., 2017).

This paper explores the role played by slack in SW when applied in construction, and it is based on the assumption that slack is relevant for SW because it can be used to absorb variability from different sources. Furthermore, in lean literature the concept of slack has been explicitly addressed only in terms of time, capacity and inventory of materials. This narrow conceptualization can contribute to the unintended removal of slack resources as part of lean implementation, once it is not always possible to distinguish slack from waste (Saurin, 2017).

Considering the context of the construction industry, the aim of this study is to carry out an exploratory investigation of the role played by slack in SW. This analysis is mostly based on a matrix that checks strategies for the deployment of slack resources against sources of variability in construction.

BACKGROUND

WHAT IS SLACK?

According to Safayeni and Purdy (1991), slack is a mechanism for reducing interdependencies and minimizing the possibility of one process affecting another – i.e. slack makes processes loosely-coupled. Slack can also be defined as a cushion of current or potential resources that enable an organization to successfully adapt to internal or external pressures (Bourgeois, 1981). Righi and Saurin (2015) suggest that slack is an asset for resilience in complex systems, as it provides resources for performance adjustment and the maintenance of the system´s core functions during both expected and unexpected situations.

Fryer (2004) suggests that a cushion of resources does not necessarily mean extra or idle resources, because it may contain existing and strictly necessary resources that can be reallocated and used in different ways. Saurin and Werle (2017) also highlight that, if not by design or opportunistic intentional use, any resource can contribute to slack in a certain context. Therefore, chance can play a role in transforming a resource into slack.

Sometimes a slack resource designed for tackling a certain source of variability can, unintentionally, offer protection against other variability sources (Saurin and Werle, 2017). Thus, it is important to identify the possible sources of variability that each slack resource is intended to cope with. Hollnagel (2012) suggests that there are three sources of variability in a system: (a) internal variability, which refers to the variability of the activity itself; (b) external variability, which refers to the variability of the work environment; (c) upstream variability, which refers to the variability of the output from upstream activities.

SLACK RESOURCES IN LEAN PRODUCTION

According to Saurin (2017), besides work-in-process and safety stocks, some practices often adopted in the Toyota Production System indicate the existence of other subtler instances of slack resources. For example, according to Shingo (1989,92),"workers must be taught to help each other, because individual differences in work times, caused by physical conditions, will be absorbed by the first worker in the process". In other words, Shingo is referring to a situation in which the use of multifunctional and cross-trained workers could be a slack resource.

The concept of "help chain" is another example of slack in lean system, as presented by Spear and Bowen (1999,101): "if our seat installer, for example, needs help, that too comes from a single, specified supplier. And if that supplier cannot provide the necessary assistance, she, in turn, has a designated helper. In some of Toyota´s plants, this pathway for assistance is three, four or five links, connecting the shop floor worker to the plant manager".

Toyota has also applied some practices that could be regarded as cognitive slack (Shulman, 1993), such as: (i) the consideration of several alternatives for solving complex problems, delaying the final decision to the last possible moment, as presented by Shook (2008); and (ii) the "set based design", strategy for product development, which considers a broader range of possible designs and delays certain decision longer than other car companies do (Sobek et al., 1999).

STANDARDIZED WORK:

DEFINITION AND BASIC ELEMENTSIN MANUFACTURING

Standardized work (SW) can be defined as the current best-known method for accomplishing the work (Martin and Bell, 2011). According to Liker and Meier (2007), the primary purpose of SW is to analyse a task for the identification of waste and to systematically eliminate it. Ohno (1988) suggests that there are basic elements necessary for SW that must always be present in one form or another. These elements are:

- Takt time: it corresponds to the rhythm at which a product must be completed to satisfy customer demand in the time we have *allotted* to do so (Dennis, 2002). It is computed by dividing *allotted* time by the quantity required per day.
- Work sequence: it refers to the specific order or sequence of operations in which an operator processes items. Thus, it is different from the order of processes along which products flow (Shingo, 1989).
- Work in Process (WIP): it is the minimum amount of items required in the process that allows for the operator to work efficiently (Ohno, 1988).
- Cycle time: it is the time that takes between one component and the next to leave the same process. In other words, cycle time is the frequency with which a part is completed (Rother and Shook, 1999).

Table presents some relationships between slack resources and the SW elements, based on the literature. As Table suggests, if there were no slack between cycle time and takt time there would be no time available in the system to recover from delays, equipment or material failures (Rother and Harris, 2002).Although not presented in this Table, the slack resources previously mentioned (i.e. “multifunctional team”, “cross-training” and “help chain”) also play a role to deal with variability and therefore they can support the application of SW.

Table 1: Relationships between slack resources and the basic elements of SW

Basic Elements	Slack resources	LP approach	Variability
Takt and Cycle Time	Time	Cycle time for a process should be calculated as 80% of Takt time to ensure that any difference in setup or performance of workers or machines can be absorbed (Rother and Harris, 2002).	Internal variability
Takt Time	Capacity	Toyota assembly lines operate in two eight -hour work shifts with a four-hour interval between them. This interval allows for Toyota to increase capacity whenever the production quotas for a shift are not met in normal working time. (Hopp and Spearman, 2004).	Internal variability
Work-in-Process	Safety stocks	The stock of a completed part that is planned for protection from disruption in the flow of the product (Martin and Bell, 2011).	Upstream variability

UNDERSTANDING THE BARRIERS TO STANDARDIZED WORK IN CONSTRUCTION

The distinctive characteristics of construction in relation to the manufacturing industry are well-known, such as one-of-a-kind production, long lead times and temporary organization (Koskela, 2000; Bertelsen, 2001; Koskela et al., 2013).In fact, construction projects are complex socio technical systems, to the extent they have features such as a large number of elements in dynamic interactions, non-linear interactions, unanticipated variability and resilience (Koskela, 2000; Bertelsen, 2003a; Bertelsen, 2003b).

As such, the basic SW elements, described above, which were originally devised for application in assembly lines and cells, need to be adapted into the construction context:

- Takt time: this concept is regarded as the pace that a trade should complete their elements of work in a certain physical area (zones) of the site (Frandson et al., 2013). This emphasis on limited physical areas is necessary, otherwise the takt time would be equal to the total time that it takes to build a single building (Martin and Bell, 2011).
- Cycle time: it corresponds to the sum of task durations for concluding a work zone by a trade. Cycle time does not cover overlaps between activities, butincludes the sum of queue times (Ballard, 2001). Although cycle time can be

equal to takt time, it is recommended that the cycle time be lower than the takt time, and a time buffer is designed to protect the system against variability sources.

- Work in progress: it is usually associated with the number of simultaneous work zones in a given site (Bashford et al., 2003; Sacks et al., 2010). In other studies, this concept appears implicitly associated to unfinished work (Fireman et al., 2013; Ibarra et al., 2016).
- Work sequence: differently from lean production in which it refers to a sequence of detailed operations, in construction it is usually associated with the order or sequence of aggregate groups of operations (Bulhões and Picchi, 2011; Fernandes et al., 2015; Saggin et al., 2017).

Furthermore, differently from repetitive manufacturing operations with short cycle times, activities in complex adaptive systems such as construction tend to have a wider gap between “work-as-done” and “work-as-imagined” (Hollnagel, 2012). For example, in complex systems the number of interdependencies between activities tends to be large and as a result some preconditions for starting work may not be met. In turn, this triggers workarounds detrimental to both safety and quality (Hollnagel, 2012).Work done under suboptimal conditions is ubiquitous in construction sites (Formoso et al., 2017), this creates a kind of waste known as *making-do* (Koskela, 2004).

SLACK AS A BASIC ELEMENT OF SW IN CONSTRUCTION

In construction, buffer and contingencies are terms more commonly used than slack. These usually refer to specific resources such as material, capacity, time, backlog of made-ready work packages, money or even work in process (Gonzalez et al., 2006; Sacks et al., 2010; Ortiz-Gonzalez et al., 2014; Russeal et al., 2012). However, the extant literature on complex socio-technical systems suggests that slack can be interpreted as a broader concept, which is not limited to any specific type of resource or deployment strategy (Saurin and Werle, 2017). In this sense, Saurin and Werle (2017) identified five strategies for the deployment of slack in complex socio-technical systems, such as construction, which are not limited to specific types of slack resources. Table 1 presents examples of how these five strategies could be applied in construction by using different slack resources.

The importance of slack to support SW in construction becomes more evident when the slack deployment strategies are explicitly checked against the high variability involving the availability and quality of the necessary preconditions for starting a construction task. According to Formoso et al. (2017), there are at least eight types of preconditions for a construction task: construction design, components and materials, workers, equipment, space, connecting works, external conditions and work infrastructure (water, electricity). The availability and quality of these preconditions is usually subjected to high variability, and thus the probability of interrupting a sequence of work is high (Koskela, 2000).

Table 1: Strategies for the deployment of slack in construction
(adapted from Saurin and Werle 2017)

Strategy	Definition	Examples of application
Redundancy	It is divided into four sub-categories: (i) standby redundancy, which is redundant resources not immediately involved in the task at hand; (ii) active redundancy, which means redundant resources that is involved in the task at hand; (iii) duplication of functions; and (iv) redundant procedures or redundant inspections across process stages.	1.Redundant equipment/tools 2.Creating formal or even informal leadership redundancy to distributed authority when necessary
Work in Progress	Refers to stocks of raw materials, partially finished products and finished products.	1.Several simultaneous work zones 2.Stock of materials
Margins of maneuver	It is characterized by autonomous or coordinated strategies that create margins through reorganization of resources.	1.Multifunctional workers 2.Layouts that allows for different trades share or change space for inventories and flow of workers when necessary 3.Capacity and time buffer
Cognitive diversity	Refers to divergence in analytical perspectives among members of an organization	1.Short-term meetings involving different team leaders to identify and solve problems of previous week 2. Cross-training
Control slack	Refers to individual degrees of freedom in organizational activity, with some range of individual action unconstrained by formal coordination or command.	1.Supervisors allow for experienced subordinates to improvise when the action adopted is consistent with the overall goals of the process

Table 2 consists of a matrix, which indicates that the variability of preconditions can be dealt with by all of these five strategies, especially by the margins of maneuver and redundancy. These are some examples of the application of margins of maneuver in construction: (i) use of safety tolerances in construction design; (ii) work in different shifts, daytime and night time, which allows for different trades to use space, equipment and temporary facilities on the same day; (iii)use of general purpose machines;(iv)scheduling of a backlog of tasks without pending constraints so that crews can perform these during adverse weather conditions or when the weekly work packages have to be interrupted due to the lack of any prerequisites.

These are some examples of redundancy: (i) incorporation of redundant inspections into construction design to minimize errors; (ii) redundant equipment, materials or work infrastructure; and (iii)stand-by workers or areas that are intentionally left idle to deal with unexpected variability.

It is worth noting that there may be a trade-off between the redundancy and control slack strategies. Redundant inspections or redundant procedures should not be in excess, because this may weaken the effectiveness of the strategy control slack, and thus, reduce the freedom and flexibility of the organization.

Table 2- Interaction matrix between strategies for deploying slack and variability of preconditions for a construction task

	Variability of preconditions for a construction task							
Strategies	Construction Design	Components and materials	Workers	Equipment/ Tools	Space	Connecting Works	External conditions	Work Infrastructure
Redundancy	X	x	X	X	X			X
Work in progress		x				X		
Margins of maneuver	X	x	X	X	X	X	X	X
Cognitive diversity	X		X					
Control slack		x		X	X	X		X

Regardless of WIP being the most well-known strategy and also one of the basic elements of traditional SW, Table 2 indicates that it needs to be applied jointly with other strategies, because it only copes with two variability sources. As an additional drawback in construction this strategy is not usually implemented in a controlled way: the number of simultaneous workstations is not properly monitored, and there is much unfinished work.

Cognitive diversity also needs to be applied jointly with other strategies, because it directly covers just variability from construction design and workers performance. These are some examples of the application of cognitive diversity: (i) use of multidisciplinary teams during development of the construction design; and (ii) application of cross training enables a worker to perform more than one job.

CONCLUSIONS

This paper presented an exploratory discussion on the role of slack in SW in construction and the relationships between slack and the basic elements of SW in lean production. A matrix for assessing whether strategies for the deployment of slack can cover different sources of variability in construction was developed. This matrix indicates that, although the strategy of using WIP may be the most known, it needs to be jointly applied with other strategies to support SW in construction. This matrix also makes it possible to identify that two slack strategies (i.e margin of maneuver and redundancy) play a key role to coping with variability arising from the preconditions of a construction task. Thus, these two strategies of slack should probably be explicitly in corporated into the list of basic elements of SW in construction.

As for future research, we propose: (i) the development of a conceptual framework to distinguish slack from waste; (ii) the development of empirical studies to test and refine the set of strategies for slack in construction sites; (iii) the development of new methods for the design of SW that explicitly account for a broader range of slack resources and the corresponding variability sources; and (iv) the assessment of strategies for slack used in long, medium and short term planning and control.

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VALUE-ADDING ACTIVITIES LEVEL IN BRAZILIAN INFRASTRUCTURE CONSTRUCTION COMPANIES - 9 CASES STUDY

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ABSTRACT

This paper presents an approach to answer the question of what is the level of value-adding activities that infrastructure projects usually operates. Considering the Lean Construction concepts, waste definitions and Value Stream Mapping, added to an Operational Excellence perspective, the paper bring the result of nine infrastructure projects conducted by a consultancy company in seven Brazilian Construction Companies. In the presented analysis, eight projects took place in Brazil and one in Trinidad and Tobago.

The methodological analysis here presented consists of two standard phases of the referred consultancy projects where on-site and data analysis, construction value stream mapping, and "*gemba*-walk" are used to understand the project and quantify the level of value-adding activities and wastes in the construction process. The Multi Moment Analysis will be used to measure wastes and value added in operations performed on-site.

The results show a low level of value-adding activities, representing, in the general analysis, 26% percent of the total available time. The results are also divided for project and type of operation, i.e. earthworks, steel assembly, pre-fab, for example. That analysis brings the possibility to understand specifics characteristics of each project product and different approaches towards planning and production control and a new managing attitude in each company. This understanding was hold in those construction companies and may be a great improvement opportunity for the infrastructure construction sector.

KEYWORDS

Value-adding activities, Gemba, Value stream map, Multi Moment Analysis

INTRODUCTION

Lean construction, from concept definition, seeks to increase productivity in construction industry (Issa, 2013). The goal is to understand the production as a sum of flow and transformations activities that deliveries value to the customer (Koskela, 1992, Koskela,

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2000). In this perspective, improving practices of construction processes, seek to understand and maximize the activities that add value on the product. For achieving increased levels of activities that add value is essential understand the production operations and how to identify inefficiencies in the process (Rother and Shook, 1998).

Given the premise of understanding the operational level of value-adding activities as a basis or kaizen implementations and productivity improvement, construction groups, focused on infrastructure in the public and private sector in Brazil are investing in improvement consulting processes and implementation of operational excellence programs. To understand the level of value-adding activities on site, the process diagnostic step is conducted integrated three main concepts: Waste identification, Value Stream Mapping and Gemba routines and observations of the shop floor. In this last, the Multi Moment Analysis (MMA) will be used to enable quantify value-adding activities and wastes. The lack of literature about the using MMA on construction is a limitation but also a factor that motivates this study.

The goal of this initial diagnostic step, which precedes the productivity improvement implementations, is to understand the processes involved in operational or support activities to provide resources and sufficient information for production. Thus, this study aims to illustrate the value-adding status in infrastructure projects in the public and private sector. It also aims to demonstrate the use of production analysis tools that allow us to understand the zero line for the implementation of productivity kaizens the analysed works.

The results presented were developed in projects in partnership between those Brazilian Construction Companies and a Consulting Company in nine infrastructure projects in the public and private sector held in Brazil and Trinidad and Tobago between 2013 and 2017. All the projects were performed by Brazilian construction companies. This analysis considered the Value Stream Mapping and wastes observation through Gemba Walk.

The following paper is divided in three phases. First will be explored the conceptual references in the literature about adding value, wastes, value chain and value stream mapping, and how to identify value throw the understanding the production process. Second, the paper will describe the methodology used to identify value-adding activities in the production process, and, in the end, will be presented the results and discussions from analysis.

BACKGROUND

This section will bring the literature review of four main concepts and tools used to understand the value-adding activities in the construction processes. Those are: (a) value adding activities and waste definitions; (b) Value Stream Mapping; (c) Gemba Walk and (d) Multi Moment Analysis.

VALUE-ADDING ACTIVITIES AND WASTES

The traditional definition for value-adding activities was made by Koskela (1992) and states: “Value-adding activity: Activity that transforms material and/or information towards that which is required by the customer; Non-value-adding activity (also called waste): Activity that takes time, resources or space but does not add value".

Non-value-adding activities is connected to production wastes. The seven wastes were identified by Taiichi Ohno in 1988. These included: overproduction; time on hand; transportation; processing itself; stock on hand; movement; and making defective products. Ohno argues that the elimination of these seven wastes will reduce the non-value activities level (Ohno 1988).

Koskela (1992), also argued that non-value-adding activities have three root causes: design, ignorance and the inherent nature of production. The previously definition is aligned with the discussion proposed by Koskela et al, (2013) where "classical list of seven wastes indeed its context specific and that for the context of construction, the crucial wastes have to be identified and defined starting from the characteristics of this type of production". Ins this scene, to analyse the possibility of wastes in a construction site, three major requirements must be considered: the list of wastes should "be conceptually compatible with construction project, empirically justified (i.e. focusing on the most significant wastes) and persuasive and motivating for action of improvement." (Koskela, et al., 2013). For this reason, the Value Stream Map is a key step for waste understanding in each project, considering the seven wastes as one possible reference.

VALUE STREAM MAPPING

Rother and Shook (1998) defined the Value Stream Mapping (VSM) as a process improvement technique that has the objective to maximize value for the final customer. This value-adding to customers consists of an analysis of identifying and eliminating waste in the entire value chain (Rother and Shook, 1998). VSM has been used and had shown good results providing significant improvements in efficiency, productivity and service quality, and to bring a reduction in production lead and production work process (Shou, et al., 2016).

In construction, VSM was previously used on the analysis of Supply Chain and flow of resources from the supplier to the construction site. (Dos Reis and Picchi 2003; Fontanini et al., 2008 and Picchi 2003). Recently, new studies considered the analysis on production on site itself (Bulhões et al. 2011; Fontanini et al. 2008; Pasqualini and Zawislak 2005). Covarrubias et al. (2016) used VSM, for improving administrative processes in construction. A recent study, developed by Shou, et al. (2016) had analysed the critical success factors on VSM for the construction perspective and identified, through a literature review, that the construction sector has recognized the functionalities of VSM, and used it as an effective lean tool to improve process performance. However, construction did not use the full capability of VSM because of the negative effect of variations in construction projects (Shou, et al., 2016).

Another benefit on VSM implementation in Lean projects isits capability toillustrate, in a systemic way, a stage or level of the productive process of construction, and, also identify possible problems and wastes. Pasqualini and Zawislak (2005) concluded that if VSM is truly applied, in the sense that it considers the productive activities, the customers and the suppliers of the process, following the value flow, the VSM can show more than wastes identification, but also the reasons the wastes exist in the value chain.

GEMBA WALK

Ohno (1988) described as a practice of Toyota Production System, the routine of going and seeing how the work happens at the shop floor. The simple act of observing production tasks as they happen could bring insights to understand production. Shook (2009), in his analysis about NUMMI factory, concluded that behaviour is a key factor for improvement. For people change their mind about their own assumption the only way is by changing their behaviours. It just happened when managers started to see and understand the problems of production and themselves (Shook, 2009).

The Japanese word Gemba means the real place, and lean practitioners use it to refer to the place where value is created in production (Kerem, et al 2013). Gemba walks is used to represent the walks managers do to see production tasks where they happen. Managers who are familiar with Lean concepts often call their team members to go to the Gemba and see work practices themselves (Samudio et al, 2011).

In construction the use of Gemba is not common. Two previously papers were published considering this approach (Samudio et al. 2011; Kerem et al. 2013) and one poster (Deschamps et al. 2015). However, this lack of information on literature, both papers brought interesting results. Samudio et al. (2011) concluded that the metrics collected by the project team indicate that the team's efforts have in fact improved their performance and the implementation of improvement. Kerem et al. (2013) brought an important insight considering that the managers discovered that none of the wastes they observed, had never been reported to management and would have remained unidentified if not for the Gemba session. After the Gemba, several managers said that even though they had heard and learned about lean in the past, they had never been able to link it to their daily work (Kerem et al. 2013).

MULTI MOMENT ANALYSIS

Plange (2015), defines a Multi Moment as a special statistical technique that enables you to gain data and information about your project and work procedures. Its main objective is to provide data and MMA enable to distinguish value-adding tasks and activities from wastes (Plange, 2015).

Even if we identify a lack of the application of MMA on construction industry, in this paper the methodology of data collecting consists in making use of this tool and applying the MMA in observing a shop floor and at regular periods, taking a photograph of the activities under execution. With every picture, the number of employees that are in production or developing activities that add value to the product are counted, employees who are in support activities such as transport, displacement, quality inspection (Non-value-adding activities – but needed), and employees at the time of photograph, are totally idle in waiting, delays, hand excess work or rework activities. The latter portion of employees are those in Non-value activities – waste. The MMA were made considering periods of at least 30 minutes of activity, and in some cases, whole shifts at which the input mobilization and demobilization output of the forward service were considered.

METHODOLOGY

The analysis and results presented in this paper were developed by a Consulting Company in partnership with another Brazilian Construction Companies in nine infrastructure projects in the public sector and private held in Brazil and Trinidad and Tobago between 2013 and 2017.Main aspects of the projects are presented:

- Intracity works characterized by preferential bus lanes (Intracity A and Intracity B) that were held in the same period in the same Brazilian city (what means the same interface with population and city traffic operation), with similar design and construction methodology, but performed by different construction companies.
- Highway A and Highway B, one covering the construction of new Highway with 52 km (Highway B) and more than 30 bridges and concrete drainage structures; and Highway A is characterized by improvements in an existing Highway. In Highway A, the longest paving path was around 3.5 km.
- Railway covering one of the largest Railway investment in Brazil in the last decade. The project holds earthworks, bridges, stations and viaducts in more than 235 km.
- Pipeline A and Pipeline B were projects for the Oil and Gas Industry. Pipeline A consisted of a 7-pipe lane between two Oil Mills with 48km long. Pipeline B is a Central Pipeline in one of those Oil Mills. Those two projects are characterized by contract modality of Engineering-Procurement-Constriction (EPC).
- Building Project are those that are involved with edification constructions. Building A was an affordable housing project and Building B was a big educational investment in constructing more than 40 public schools in one of the Brazilian main cities.

The data collection took place during the Consultancy support period and comprises two phases of the Workshops: (a) Analysis/Diagnosis and (b) Kaizen Workshop.

- Analysis/Diagnosis: In this phase is mapped the VSM for the main activity and the Gemba and waste analysis is conduced: the 7 wastes defined by Ohno (1988) are used as references. In order to identify wastes and their impacts, the following tools are used: (a) Gemba-Walk, which consists of observing and finding evidence of the aforementioned wastes; (b) Multi Moment Analysis (MMA), a count of people who add value or for some of the types of the seven wastes, an analysis of several consecutive intervals of time; (c) Chrono-analysis, which consists of an unbroken period of filming over a long period (minimum of 4 hours) to observe the level of value-adding in complete cycles of activities. Because of the low level of Chrono-analysis, the data collected with this tool will not be considered in the results of this paper.
- Kaizen Workshop: 7-phase Workshop, where in the third step the project team go deeper in the VSM analyses and after the process has been mapped and the value stream has been clarified, the Workshop team engages on field-work in order to

identify and quantify failures and wastes. The team is split up to cover some formats of analysis that include: Identifying the seven wastes; a spaghetti diagram; a MMA for periods of at least 30 minutes of observation.

As mentioned in the previously section, the wastes analysis must be conceptually compatible with the construction project (Koskela et al., 2013). For that, during the VSM the workshop team was conducted to describe the most predicted and expected waste. To quantify wastes and the level of value-adding activities the MMAis the most used tool.

RESULTS

In all the nine construction projects focused in this paper were had the Diagnosis phase; in seven of those projects were developed the Kaizen Workshop too. In these cases, the data collected in both workshops were analysed.

In both phases of the consultancy project (Diagnosis and Kaizen Workshop) the value stream was identified as the kick point of observation in Gemba. Most of them were activities that in the projects critical path. Nevertheless, in some cases the observed activities considered construction phase that the company did not domain the constructive process. For example, in one of the pipeline projects, the contractor company was not expert on concreted steel-pipe assembly in flooded plots, what requires a different type of machinery. In this project, that was one of the bottlenecks.

Going to Gemba, the results were analysed in three criteria's: (a) type of construction operation under execution during the observation; (b) level of value-adding activity in each project; and (c) level of value-adding activity in each type of operation observed.

The consultants developed over 1090 observations in a total period of 72observation hours and more than 890 man hour considering the total of frontline workers on-site in each observation. Considering the critical path identified in the value stream mapping the main operations observed are shown in the Figure 1. Steel assembly, frames and concrete represent the highest amount of observation time (representing 67% of the total time) it happened because, in seven of the nine projects, operations around steel-concrete structure were pointed as critical activities in the Value Stream Mapping even in Highway and Railway projects. On those projects (Highway and Railway, for example), bridges and viaducts were considered as critical activities for delivery time and costs, and, also, where were used the highest workforce level. In the second stage, with 21% of the observation time, is there earthworks, drainage, paving and excavation; operations clearly connected with heavy infrastructure constructions sites.

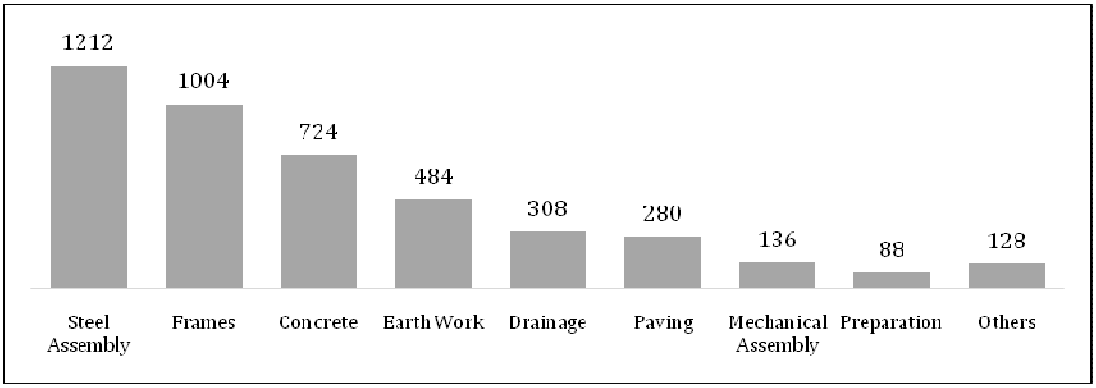

Figure 1: Time of analysis of each main activity on construction sites (time is represented in minutes)

The level of value-adding activities is shown in Figure 2. From top to bottom, it is shown, in top of the columns, the level of non-value activities and are not necessary for the construction process (wastes) like idleness, waiting, delays, defects and rework. In the middle, of Figure 2, it is represented in the middle of the columns, the non-value-adding activities but are necessary for the construction process like movements and motions. Thus, this slice of the production activities must be controlled and minimized. In the bottom are the value-adding activities and are the activities that really transform raw materials in final products and delivery value for the customer (final customer or intermediate customer). The results obtained in Gemba observation with the Multi Moment methodology, show the low level of value-adding activities in infrastructure construction project. The total observation time shows that only 26% of the workforce is operation on transformation. Only 17% of the time is spent in necessary non-value-adding activities. It is possible to see a very expressive level of non-value adding activities that are incorporated to those construction projects and in those Brazilian companies.

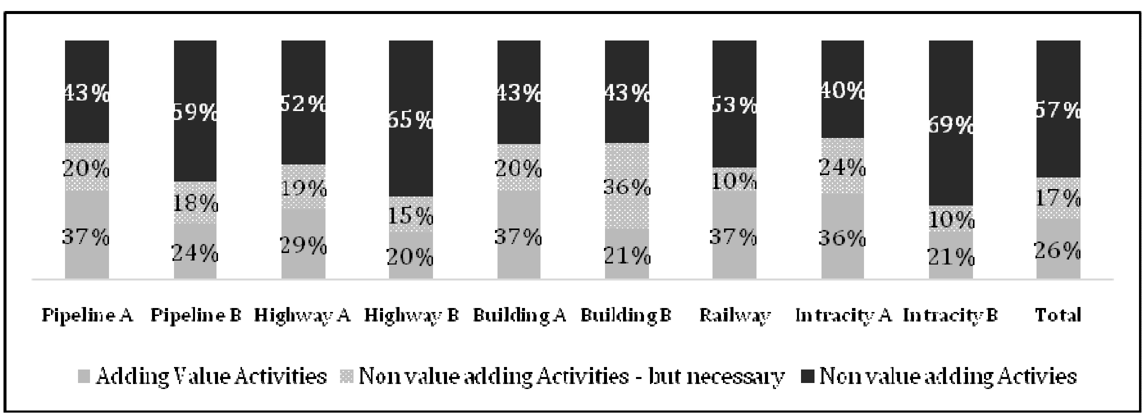

Figure 2: Value-adding activities level considering the projects observed

Going deeper in the results analysis, the highest levels of non-value activities is observed in the Project Intracity B and Highway B (69% and 65% of non-value-adding activities), and that can be justified by the large dimensions and high volume of displacement and transportation, but the Highway A and Intracity A had a higher level of value-adding activities (29% and 36% respectively) and have the same main characteristics. Is also interesting compare the results between Building A and Building B. In those projects the value-adding activities value varies in 76%, from 37% in Building A to 21% in Building B. This focused analysis, comparing different projects but with similar product characteristics, bring the perspective of planning and preparation for the discussion. Poor work preparation and lack of a strong planning and control methodology is frequent in the nine observed projects.

Comparing the Intracity A and Intracity B. They were both developed in the same city, in the same period with same kind of workers, materials and weather. The technology and design were quite similar and we see a high difference of value-adding (Intracity A is 71% more productive than Intracity B). They had one great difference: were different construction companies, and different methodologies of contract managing, planning and controlling production and target deviation.

Finally, Figure 3 illustrates the analysis of the value stream critical operations. Thus, there is important to point that operations of paving and earth work had the lower level of value-adding activities, and it is so because of the high distances and necessity of movement, displacement and consequently of waiting (meanwhile a frontline worker transport some material or equipment, another frontline worker is waiting for the material or equipment). After, in the left side of Figure 3, it is represented the Steel Assembly as the third non-value-adding activities operation. Very frequently, Steel Assembly and Frames are operations of a high number of frontline workers involved. As higher the number of worker in an activity, higher is the waste level since the lack of production control is found. On the other hand, concrete operations are the highest level of value-adding activities since it is normally an activity that must be quick (considering the time the concrete can be managed), organized and requires a pre determinate number of frontline workers. On other hands, it is an activity that must have some planning and some level of preparation activities.

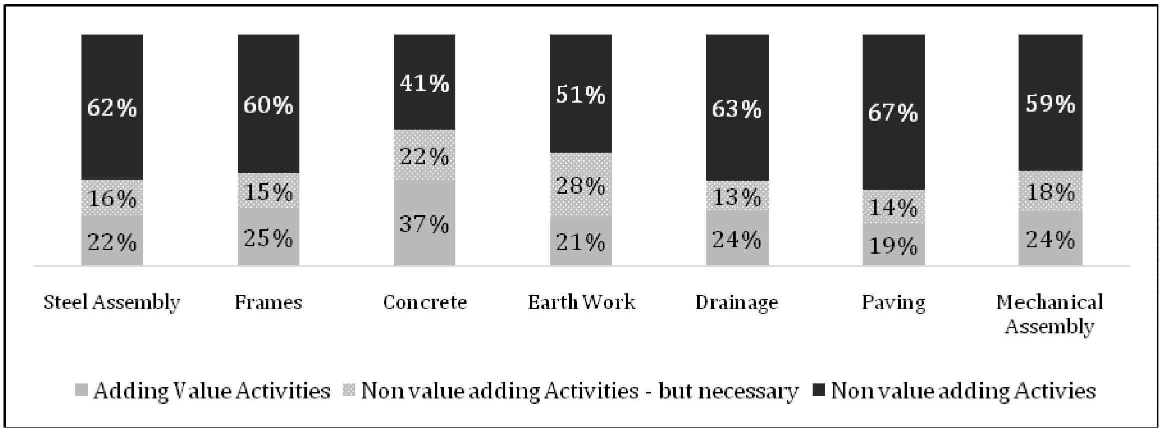

Figure 3: Value-adding activities level considering operations observed

DISCUSSIONS AND CONCLUSIONS

The papers objectives were achieved in analysing and quantifying the value-adding activities status in infrastructure projects in the public and private sector. The project also made use of production analysis tools that allowed the construction companies to understand their current status and the necessity of production improvement since the project understanding with the VSM, to the production wastes identification that occurred with the Gemba. The sample analysed enable to conclude that the MMA is an efficient tool to bring the understanding of value-adding activities in construction projects

The results show that 57% the construction activities observed did not add value (69% and 65% on Intracity B and Highway B respectively). Being able to understand this level of waste, promote critical change actions is a fundamental stage in the performance improvement process, cost savings and a leaner construction management. The perception, identification and presentation of the level of wastes and non-value-adding activities to the Construction Companies managers brought a new managing attitude toward planning, control and understand their on-site activities, what is aligned with the conclusion from Shook (2009) and Kerem et al. (2013).

By implementing the described methodology even companies with high technical level and management team with extensive experience in infrastructure works, are unaware of a high level of non-value-adding activities. It is also clear to conclude that as more organized, prepared, planned, and controlled the activity is, better level of value-adding may be found (considering concrete works as a good example of preparation).

As suggestion for future work it is interesting to expand the number of projects analyzed, in different regions, in different branches of the construction, and with different kind of technologies in order to create a database that allows benchmarking, best practices and joint improvement of the sector.

The good news for the Brazilian scenario is that the perception for inefficiencies and the need for change exists and is perceived in the sector. Now it is time to seek for new alternatives to organize and improve production aiming to transform the construction in an even more competitive and efficient industry.

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LARGE SCALE PROJECT USING TAKT PLANNING AND TAKT CONTROL-CREATING AND SUSTAINING MULTITASKING FLOW

Janosch Dlouhy[1], Miguel Ricalde[2], Bernardo Cossio[3], Carlos Januncio[4]

ABSTRACT

Takt planning and Takt control (TPTC) is a production system approach that is most commonly used in individual construction projects. The approach has not yet been implemented systematically in a large-scale project, like a Greenfield automotive plant (complete new plant from scratch) with all facilities. Furthermore, its use has not been documented in construction in Mexico. Most projects describing TPTC in research are single contractor projects, implemented by a single construction company. This paper describes a real project with over 15 different facilities using Takt planning and Takt control (TPTC), in a large scale green field automotive plant with 5 main general contractors collaborating together with the client. It shows the demands and the effects of large scale projects using the method of TPTC within a Lean philosophy and describes the system that was designed and implemented. As the main contribution from this paper, a system and its results for creating a Lean culture, collaboration, transparency, planning and overall project control within a multitasking flow is described and validated.

KEYWORDS

Lean construction, Takt planning, Takt control, Collaboration, large-scale projects.

INTRODUCTION

The approach of Takt is defined in different IGLC paper before (Horman et al., 2003) and (Frandson et al., 2013). All case studies known by the authors are describing single projects using Takt.

The new construction of a complete, green field plant requires a huge effort in project management and administration. Facilitating information flow to all practitioners, controlling construction processes, planning and sustaining site logistics, while focusing on the client's values(and changes to their demands),as well as coordinating all buildings from different construction companies, while ensuring delivery in time by for connection

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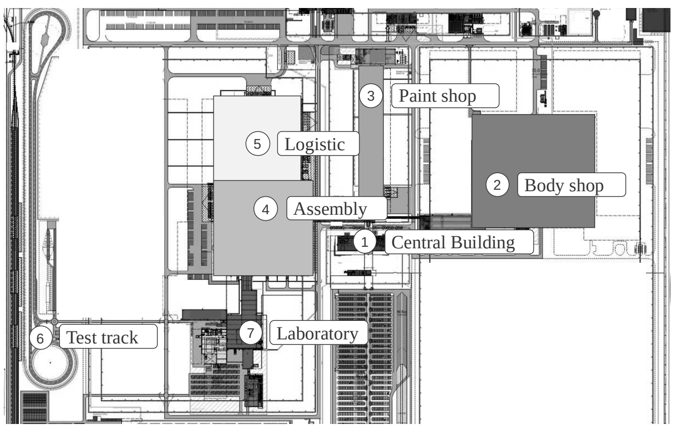
to infrastructure are only some of the many requirements for a project's management system. As a response to these demands and requests from the client, a Takt planning and Takt controlling approach from Germany was adapted for use in a real large-scale project in Mexico (Binninger et al., 2017a), thereby enabling complete transparency and collaboration, with the possibility of detailing everything, everywhere. This paper shows the implementation, operation and validation of that real-world case study.

PROJECT DESCRIPTION

The plant was built in a green field, where all services and infrastructure had to be built entirely new. The project required several bid-packages (groups of buildings) to be tendered. An overview of the project is given in figure 1, with the main buildings and the key highlights on the right.



- 2.500.000▪ ^{2} total area
- 300.000 ▪ ^{2} building area
- 5 main general contractors
- Over 3000 workers peak
- Over 10 different partial projects
- Over 20 client departments involved

Figure 1: Overview Car Manufacture Plant Mexico

IMPLEMENTATION

SYSTEMATIC APPROACH

The client's organization already possessed TPTC experience in more than 20 single projects in different cultures, before the start of the green field plant in Mexico. As a key enabler to meet the client's expectations (in terms of the quality of the product), as well as the process in construction (which was high for Mexican standard) and to integrate the client (by managing the multi-project's transparency of flow), the 3 Level Model (Dlouhy et al., 2016) was used. The Takt planning approach sought to help align the expectations with the execution of construction, synchronize and harmonize all different construction projects. The aim was to enable the entire project management of all stakeholders and external participants to pull requested information, as shown in Figure 2.

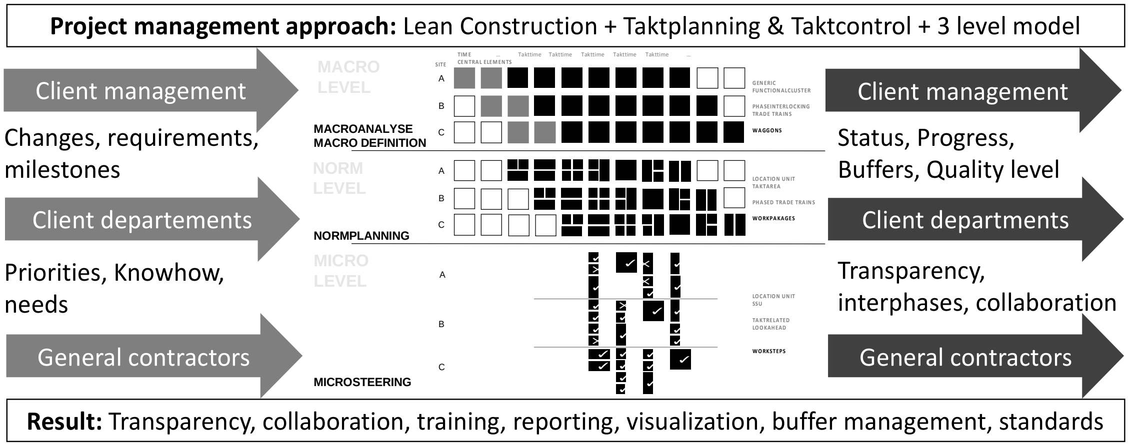


Figure 2: Organizing a value related large-scale project management

CLIENT INTERVIEW

Understanding the client’s requirements and value perception was fundamental to define the priorities for construction. This knowledge is used to align the project’s phases, to identify time buffers and optimize the construction process (Dlouhy et al., 2016, p. 18f.). This was accomplished by including the production line planners in the workshops. At this time both project team and client could identify other needs that had not been previously identified. Decisions could be made in terms of what kind of resources the project requires, where they should be and by when they should be accomplished.

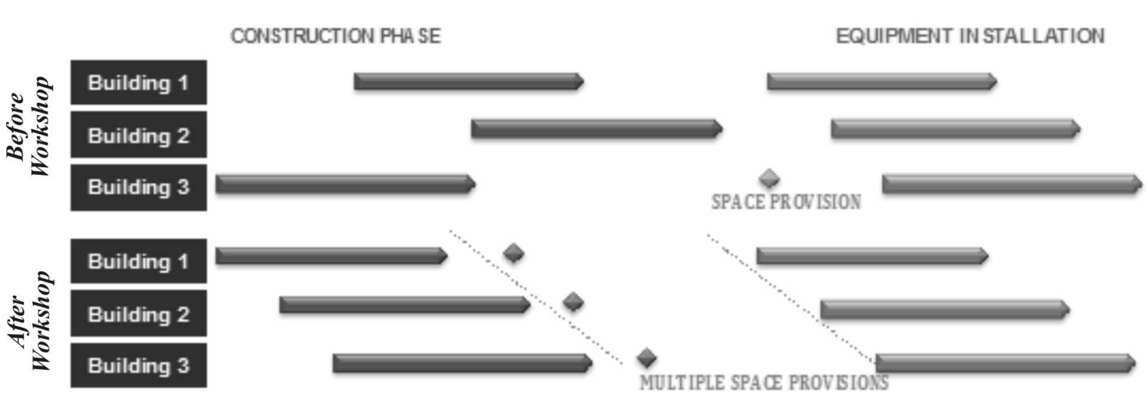


Figure 3: Re-phasing the project based on realigned priorities

IMPLEMENTATION STRATEGY

The implementation of a multi-project TPTC was planned from the beginning of the project and based on previous smaller TPTC deployments like the example of a fire station (Binninger et al., 2017a, p. 609ff.) of a smaller plant in Brazil (Dlouhy et al., 2016, p. 18ff.).It had been determined that a large-scale project would require establishing a common set of tools, understanding, and language between the various stakeholders involved (clients, project managers, general contractors and subcontractors) in order to facilitate a collaborative environment across all levels of the organizations.

During the bid process, each participating general contractor was consulted regarding their experience with the TPTC method and Lean Construction. 95% stated having had little or no experience, thus confirming the need to establish a formal strategy. The client's previous experiences in similar scenarios set the guideline to establish Lean as a contractual requirement. Furthermore, clear advice was given to the selected GCs to hire local Lean Construction consultants to accelerate the learning curve and sustain the implementation of Lean within their companies.

A framework was created to introduce Lean and TPTC to each participant, clarifying in each step the requirements and workflow needed in a TPTC and Lean environment (see table 1).

Table. 1: Client's framework for Lean as contractual requirement.

Phase	Participants	Action
Set up project	Client members	Training and developing implementing strategy
Hiring construction management	Client/ project management	Establishing Lean construction in the pm contracts, establishing a Lean Team
Pre – Bid Meeting	Client/ GC Directors	Introduction to Lean Thinking
Clarification Meeting	Client/ GC Directors	Answer/ questions with clarification
Contract	Client/ GC	Lean as a requirement in the contract, with description of the method TPTC
Kickoff Meeting	Client/ GC Team	Request correct information for workshops and implementation

QUALIFICATION

The professional client has been using a training system with different stages and levels, to implement Lean in the client organization and in their projects (Dlouhy and Wagner, 2018, p. 112 ff.) using a Takt simulation (cf. Binninger et al., 2017b). In this large-scale project, the training was extended to the systematic needs of a multi-contractor and multi-building project.

The responsible project managers were trained inside the client organization before the start of the construction phase. First elements of Lean were implemented during the design phase.

OPERATING SYSTEM

The operating system of the TPTC and Lean methodologies in this project was based on 3 main subsystems: creating and sustaining a Lean culture, continuous planning, and multilevel communication.

CREATING AND SUSTAINING A LEAN CULTURE

Following the implementation strategy mentioned earlier, a diverse Lean training program was developed to focus on individual target groups (See figure 4). Levels 1 and 2 consisted of intensive workshops with durations of 2-3 days to immerse GC´s owners, directors and project managers in TPTC and Lean thinking, gaining as a result their buy-in to the philosophy. Goals for levels 3 and 4 were to sustain the level of knowledge and adherence to the set standards, as well as to improve the implemented TPTC and other Lean tools. Since these levels (3 and 4) were targeting field engineers and construction workers, shorter interval training sessions were deemed more suitable to avoid disrupting the workflow.

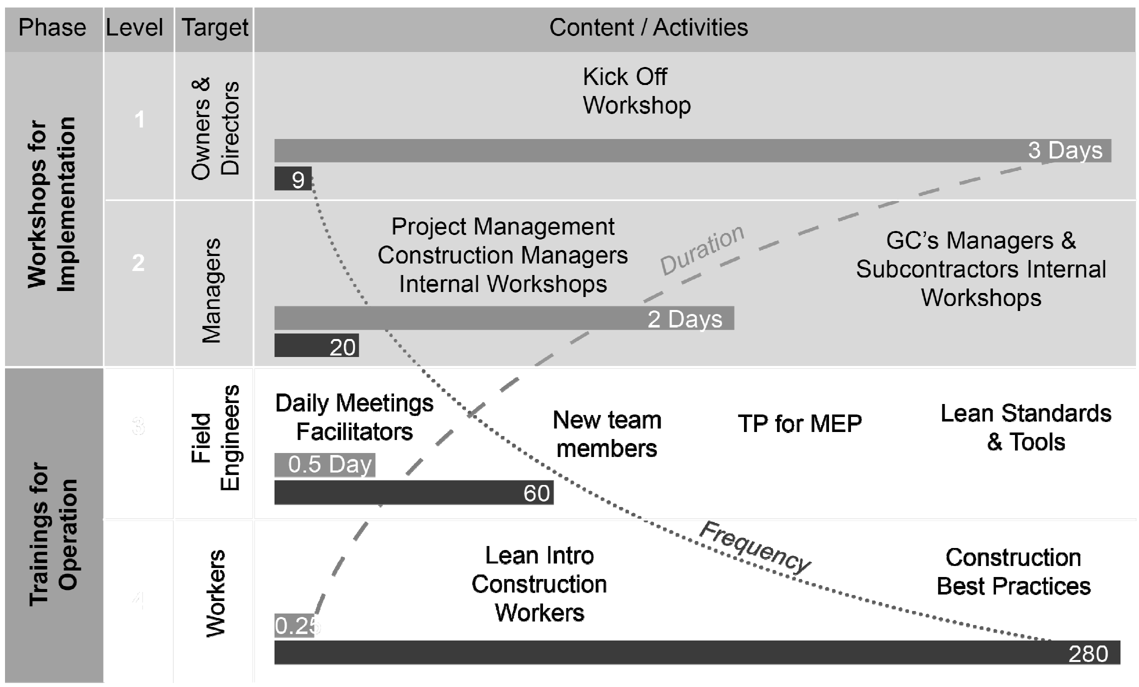


Figure 4: Levels of Training to establish a Lean project culture

CONTINUOUS PLANNING

The aim of planning a large-scale project with diverse contractors and buildings at different stages is to optimize the workflow; not only the individual demands, but also to the overall demands of the project. This includes being able to reduce delays and balance workloads to maintain and promote the entire project progress. The planning workflow consisted of a 4-tier structure behaving transparently in a bottom-up and top-down information flow, involving weekly revisions on the Norm Level and daily adaptation on the Micro Level, informing each other of improvement opportunities and requirements (See figure 5).

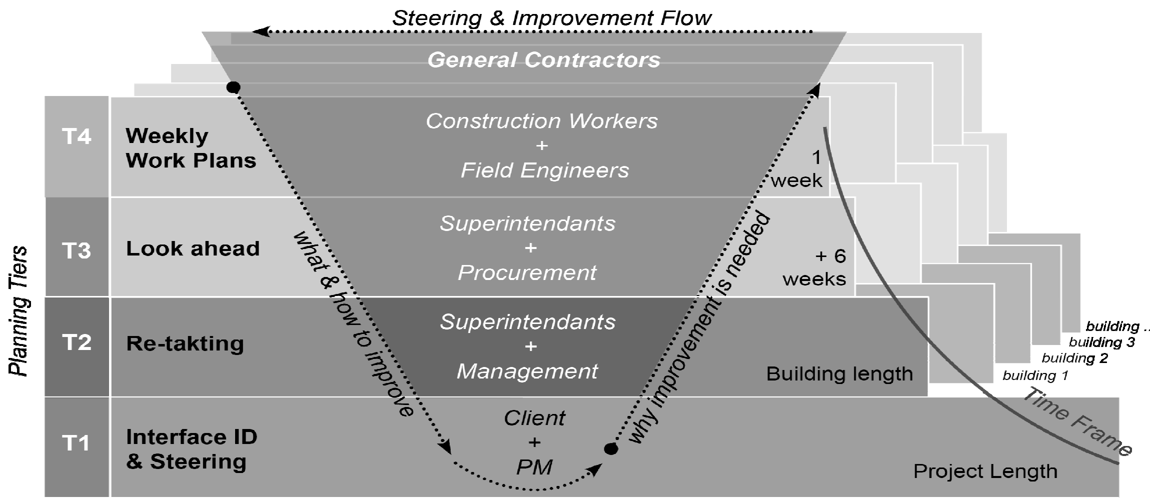


Figure 5: Planning Tier Structure

From a Macro perspective (T1), milestones from different buildings were aligned on a monthly basis. This included main infrastructure and utilities, as well as operational requirements. High reliability Takt schedules, of each building and their required utilities, have proven to be essential to support effective decision making in an ever-changing environment. Each planning tier contributed to sustain the TPTC method.

TRANSPARENT MULTI-LEVEL COMMUNICATION

Similar to the planning structure, the tools used for multi-level communication were broken down by levels and focused on target groups. Such tools were standardized to maintain transparency between all stakeholders, and focus steering efforts on collective solutions based on trustworthy data. (See figure 6).

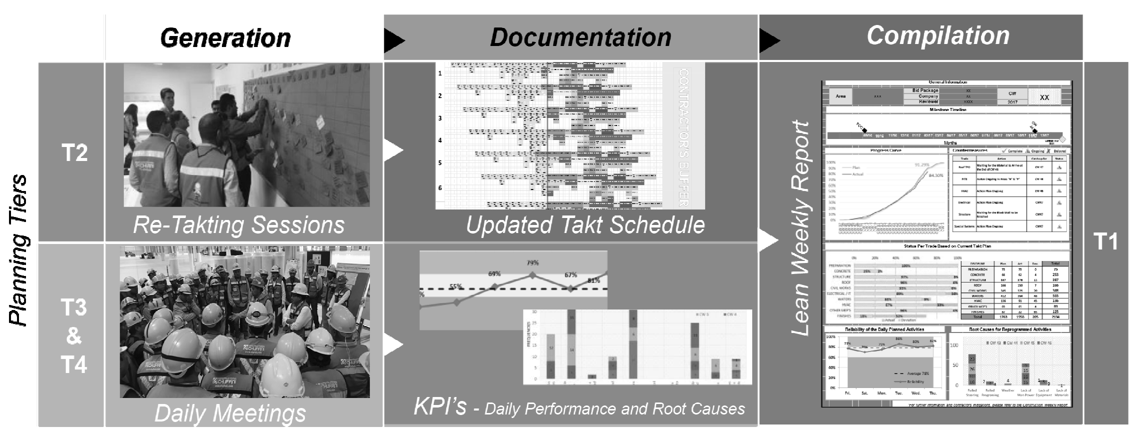


Figure 6: Standard structure and visualization of the construction process.

By standardizing the Takt Schedules (figure 6, upper middle side), the execution of daily meetings and the content for the control boards (figure6, down left side), the building status and progress could be analyzed through the same Key Performance Indicators

(KPIs) (figure 6, down middle side). Working with the same structure and language to communicate the status of each building allowed a unique Lean Weekly Report (figure 6, right side) to be processed collaboratively by the contractor and client, thus simplifying the visualization of critical interface challenges.

FINDINGS

PROJECT CONTROL

A weekly data collection system was implemented, where every Friday contractors' lean responsible updated and uploaded their takt schedules to a document control platform. The information was then reviewed, analysed and validated by the construction management team, creating a database stored in the client's server. At one point there were over 20 different Takt schedules for both, buildings and infrastructure, allowing a comparative analysis between projects behaviour.

This paper focuses the results on the 4 main production buildings: Body Shop, Assembly, Logistics and Laboratory, compiling over 100.000 data points and generating over 1000 Lean Weekly Reports. The data herein shows the project control at 2 different levels: on the *Micro* the daily performance measured daily and averaged for any given week, and on the *Norm* progress curves (planned based on Takts complete). Data regarding Root cause frequencies for reprogrammed activities was also gathered but are excluded from this study.

CONTROLLING THROUGH PERFORMANCE AT THE MICRO LEVEL

Weekly goals were deployed to the micro level as daily quantifiable activities and the performance of the daily plan was recorded. This data was then averaged per week per building. The contractors targeted to achieve a minimum of 80% reliability every day. Figure 7 shows just under a year of data, gathered for the production buildings. The resulting work averaged 78% performance, while the target of 80% was achieved 90 times (or 43%).

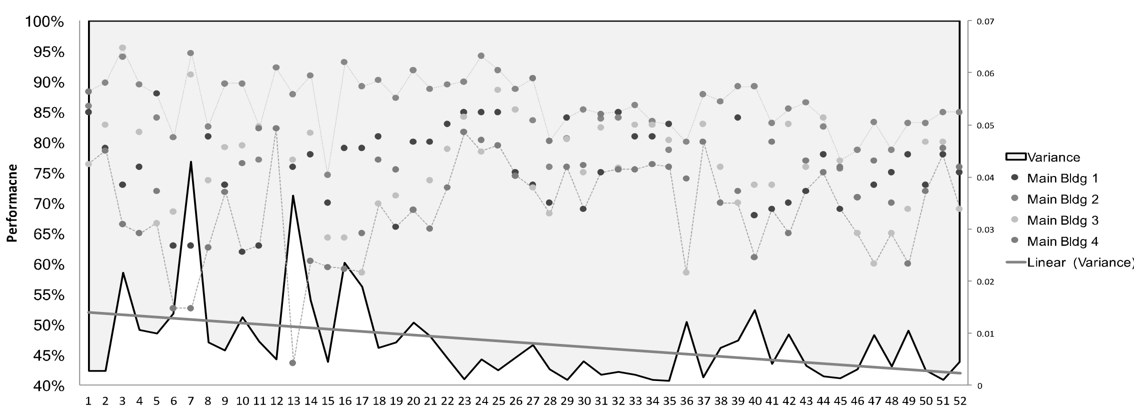


Figure 7: Performance Main Buildings

As seen in Figure 7, the variance of the performance between each Main Building was significantly reduced over time, accomplishing an overall uniform performance. Less variance in the performance, endoweda higher reliability to daily planned activities, which in turn increased certainty on Takt Schedule sand on Space Provision dates. The reduction of the variance and the increase of reliability on Takt Schedules decreased the complexity of working in a multitasking flow environment as experienced in large-scale projects.

CONTROLLING THROUGH TAKT PLANNING AT THE NORM LEVEL

From a client's perspective, the result of this project was measured based on achieving 2 main objectives; 1) Gain early access to the main production buildings to allow more time for the installation of assembly line equipment thus overlapping the latter and the remaining construction completion activities, and 2) Achieving the contractual construction finish (space provision).

Through the analysis shown herein, it is possible to observe how building in a Lean environment while using the TPTC method successfully responded to a multitasking flow in a large-scale project, achieving the client's main objectives. The following progress curves (see figure8) show the first and real Takt schedules for the main buildings, including the Space Provision date and the accomplished Early Entries. Note that on average, a construction buffer of 14 weeks was identified for each building through the TPTC method.

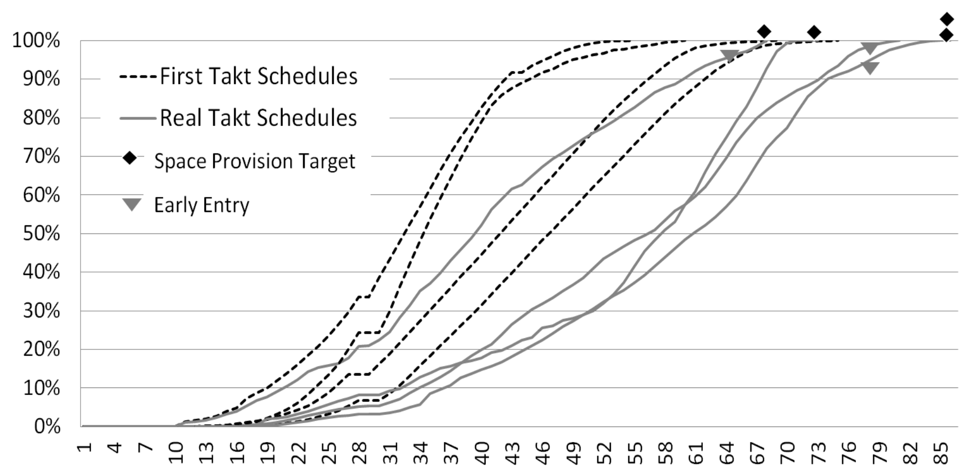


Figure 8: First and Last Takt Sch. With Space Provision and Early Entry Milestones

Maintaining an ideal production plan in construction involves a supply chain that can adapt to the required construction rhythm. Weekly or biweekly reTakting sessions were key to adapt the construction sequence and rhythm, to maintain each project's commitments as response to disruptive elements such as: 1) clients' design improvements during construction 2) the GCs' misalignment of their procurement and design teams and 3) GC's inexperience with the TPTC method. Towards the end of the construction sequence, the buffers were considerably reduced although always fulfilling the Space

Provision commitments. Figure 9, for example, shows the history of one buildings' Takt schedule continual adaptation of flow to maintain a stable production rhythm.

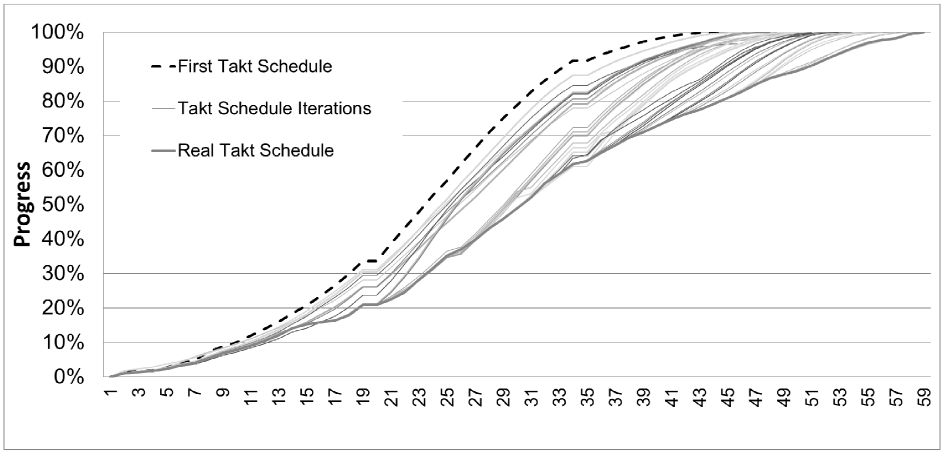


Figure 9: Continual adaptation of the Takt Schedule to maintain flow

CONCLUSIONS AND DISCUSSION

The system described in this paper implemented in a large scale project, enabled a dynamic and transparent response to changes in priorities, quicker decision making based on performance metrics, and total reporting control in all stages of the construction phase. Furthermore, this system can be used as a platform for TPTC implementation in future projects of similar complexity.

The TPTC method was successfully implemented in Mexico without any previous experience on TPTC by the building teams. This showcases the possibility to implement it in other locations using similar operating systems. Three of the main buildings, studied in this paper, achieved the goal of early entry and the agreed space provision for the fourth.

The overall project transparency, with all single flows created by the large-scale Takt-approach in different construction sites, enabled multitasking adjustments in and at the same time. Quality issues and process instabilities could be detected at a very early stage. For every Takt time, information across the single flows were collected and used for the next Takt times over all projects and general contractors. At the micro-level planning, steering and optimizing flow of trades was possible. At norm-level the flow of the single buildings in Takts was visually made clear and understandable. At the macro-level, for the overall project flow of the whole plant, the customers' needs could be prioritized, maintaining flexibility relying on data and buffer transparency.

To improve future results for large-scale projects, it is necessary to include increased involvement from other project departments (such as design), change management, safety, quality and procurement, as well as integrating a software solution for hosting, processing and analyzing the huge amount of data points generated. Although there was a cultural barrier regarding Lean practices, it was mostly overcome by training, resulting in a common use of Lean language and buy-in from both the client and the general contractors.

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MDM-BASED BUFFER ESTIMATION IN CONSTRUCTION PROJECTS

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ABSTRACT

Schedule delay and cost overrun are the two major challenges for the successful project delivery in construction. It has been reported that significant delays in construction projects are caused by rework and there are several reasons for rework. A framework has been proposed to assess the delay due to two primary reasons for rework, (i.e. design changes and non-conformances), using Multiple Domain Matrix (MDM), a matrix-based technique. This methodology would help the project planners to create an as-adjusted schedule that is more appropriate compared to as-planned or as-built schedules. Further, it is possible to arrive at a meaningful estimate of activity buffer time in order to account for delays due to rework. Eventually, this would lead to successfully implement one of the key principles of lean, namely, elimination of time-related "waste" that is due to defect and/or delay.

KEYWORDS

Buffer, delay assessment, job-sequencing, multiple domain matrix, waste.

INTRODUCTION

Indian construction industry is growing in a rapid pace and the recent initiatives are accelerating the process of growth. In India, construction industry is contributing 8% of the country's gross domestic product (GDP) and the current growth rate of this sector is 8.1%(Make in India 2018).Recent policies and investments are expected to bring a revolutionary change in the construction sector in the near future. Investments in urban infrastructure, 100% Foreign Direct Investment (FDI), increased investment in smart cities and Atal Mission for Rejuvenation and Urban Transformation (AMRUT) city projects, Swachh Bharat Mission (SBM) are some of those initiatives(Make in India 2018).Although construction sector is growing rapidly, the challenges in successful project delivery still exist. The latest monthly flash report of Ministry of Statistics and Programme Implementation (MOSPI) shows an alarming condition of Infrastructure

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projects in India. Out of 1,231 ongoing infrastructure projects costing ₹1500 million and above, about 27% of the projects are either facing cost overrun or delayed(MOSPI 2017). It is mainly due to rework at construction sites, changes in design, poor site management &supervision, poor workmanship and various other uncertain events. There is a need for the assessment of such delays due to rework in construction projects in order to estimate suitable buffers while planning for an upcoming project.

Identification and elimination of seven wastes (Ohno 1988) is one of the key aspects of lean production. The objective of the current study is to propose an alternate framework, which is built on lean concept for delay assessment in construction projects that can be used to model rework. Rework is considered to be one of the main reasons for construction delay. Two main causes for rework in construction projects are ‘design changes’ and ‘non-conformances’. The proposed framework is based on Multiple Domain Matrix (MDM), a matrix based-tool that has been found to be suitable for delay analysis. This approach to model rework and assess delay would be helpful in the meaningful estimate of activity time buffers. Two construction case projects have been analysed using the proposed framework.

LITERATURE REVIEW

This section provides an account of existing literature on delays & rework in construction, design change, non-conformance, waste, buffer and production planning & control systems.

The construction delays are broadly classified in four major groups: compensable delay(delay caused by the owner), non-excusable delay (delay caused by the contractor), excusable delay (delay caused by any third party or act of god) and delays that can occur concurrently (Kraiem and Diekmann 1989). One common reason for any of the above delays is ‘rework’. These reworks are non-value adding events and cause time waste in construction process. So, identification and elimination of causes leading to rework is crucial for successful project delivery.

Design change is one of the causes of rework, which leads to delay. Design change can happen in any stage of the project. The impact of design change is very high during the execution phase. According to Behzadand Sheryl(2012), design changes may be in the form of addition, deletion or modification to the scope of the project. Change attributes have been classified according to geometry (shape, dimension), position (co-ordinates, orientation) and specification (materials). Qi Hao (2008) reported that 30% of the clients are dissatisfied with the performance of the contractor as the contractors have failed in maintaining the quoted price, committed time, resolving defects and giving the good quality work. The root cause of the dissatisfaction was found to be the‘ change orders’ in the project.

Deviation from the quality requirements or the contractual terms is another common reason for rework and it is known as non-conformance. The Non-conformance reports (NCR) are issued by the clients or client representatives to the contractors for their substandard quality of work. Generally, the contractors are responsible for rectifying the work (rework) and getting the work certified from the client. These rectification works can delay the main activity and can halt the successive activities until the completion of the whole process. González*et al.* (2014) have reported severe negative impact of non-compliances on the project time performance. Also, their research highlights the importance of identifying the reason for non compliance and managing them for better project management. Oyewobi *et al.* (2011) have reported that rework has a positive relationship with time overrun and cost overrun and have suggested to have quality assurance to reduce the non-conformance and in turn reduce the rework in a project.

Aziz and Hafez (2013) have proposed a pathway on how the lean thinking in construction can improve the performance. Along with its other principles lean talks about the reduction of waste (i.e. non-value adding activities). Rework can be classified as non-value adding activity in a construction project.It is evident that 30-35% of waste in construction is contributed by rework(Love *et al.* 2003).Ohno(1988) classified the waste in organisations as transportation, inventory, motion, waiting, over-production, over-processing, and defects. Viana*et al.* (2012) identified three different categories of waste in construction. They are (a) Construction material waste (physical waste),(b) Non value-adding activities (process waste) and(c) Specific sorts of waste (such as accidents and rework). According to Koskela*et al.* (2013), making do waste is the lead waste in construction. Sarhan*et al.*(2014) used neo institutional theory to study the root cause for waste in construction organisations and proposed "institutional wastes" that is structural in nature. It is also recommended to shift attention from focussing merely on human behaviour and mistakes, to thinking systemically and structurally.

Buffers (in the form of material, work-in-progress, deliberate & unintentional delays, and labour & equipment) have been commonly used to safeguard production by absorbing the impact of uncertainties and variability that would normally disrupt production(Sakamoto *et al.* 2002). Also, it has been reinforced that providing some buffer would lead to superior performance in construction, as reported by various lean researchers. Ko (2006) proposed a Buffer Evaluation Model (BEM) using fuzzy logic to protect fabricators against the impact of demand variability. Application of lead-time buffer improves work flow and greater project profit(Srisuwanrat and Ioannou 2007). An investigation on the causes of time buffer revealed that project complexity, complexity of the trade task and quality of documents are the top three most frequent and severe causes (Russell *et al.* 2012).

Last Planner is a popular method for construction production control and improvement(Ballard and Howell 1998). The fourth principle among the basic five principles in this method recommends maintaining a buffer of tasks (Koskela 1999). Rational Commitment Model (RCM), complements Last Planner System in terms of forecasting capabilities to improve the reliability of planning commitments (Gonzalez *et al.* 2009). Multiple Domain Matrix (MDM) is a combination of Dependency Structure Matrix (DSM) and Domain Mapping Matrix (DMM),which can be used to map the relationship and dependencies among several entities(Mujumdar *et al.* 2014). DSM has been found to be very useful tool for project planning as it can plan the coupled activities which have both way dependencies whereas PERT and CPM tools can only model the sequential and parallel activities(Yassine 2004).The applicability of DSM has also eviden in modelling rework probabilities and scheduling of overlapping activities (Maheswari and Varghese 2005; Yassine *et al.* 2001).

There exists a need to investigate the factors leading to rework and its impact on delay that ultimately contribute to waste in construction. MDM has been found to be a promising tool to model the dependency among the activities. It has been attempted to model rework using MDM and subsequently estimate the time buffer.

PROBLEM STATEMENT

The following graphical representations (Figure 1 (a)& 1(b)) demonstrate the problem statement.Figure1(a) shows how the 'change' in design can lead to rework and in turn delay. For example, suppose a change has been proposed to an activity during the execution phase while the activity has already been started. In that situation, the work has to be stopped immediately to incorporate the required change. It will lead to rework or replacement of the whole work. The particular activity is delayed as well as the dependent activities will also be delayed. Also, the process of decision-making, agreement and finalization of the change will lead to halting of the construction activity. Similarly, Figure1(b) shows how NCRs can play a vital role in time management of a project. It reveals the impact of NCR on time, from the instance deviations in quality are measured to the closure of an NCR. One of the major concerns regarding these events is that it can be repeated any time during the project. The effect of these can be accumulated in series or in parallel. So it is very much important for a project manager to be aware of such events and take precautionary action. It would be beneficial if it is possible to assess these delays that shall lead to creation of as-adjusted schedule that is more appropriate compared to as-planned or as-built schedules. This shall also eliminate the redundant buffer time added to activity durations as a common practice in order to account for delays.

OBJECTIVES, SCOPE & METHODOLOGY

The objective of the study is to propose a lean framework for delay assessment in construction projects due to design change and non-conformance. The scope of the study is limited to time overruns only. MDM is proposed to identify and assess the relationships among the delay, design change and the non-conformance. To illustrate the design changes and the non-conformances, a transmission line project and a mall construction project have been chosen respectively. Semi-structured interviews have been conducted with the project team members to support the information gathered from the project documentation.

PROPOSED SOLUTION FRAMEWORK FOR DELAY ASSESSMENT

As represented in Figure 2, an intermediate step is proposed to assess the buffer duration to make up for the delays due to rework. The current framework suggests appropriate buffer to account for the measured rework. This lean approach can ensure the timely delivery of the project.

In order to implement this framework, it is recommended to follow the below steps.

1. Analyse similar type of construction project(s) and identify all the possible reasons for the rework.
2. Formulate project specific change classification criteria and group them based on that criteria.
3. Identify the impact of each change and quantify them in terms of time delay or cost overrun.

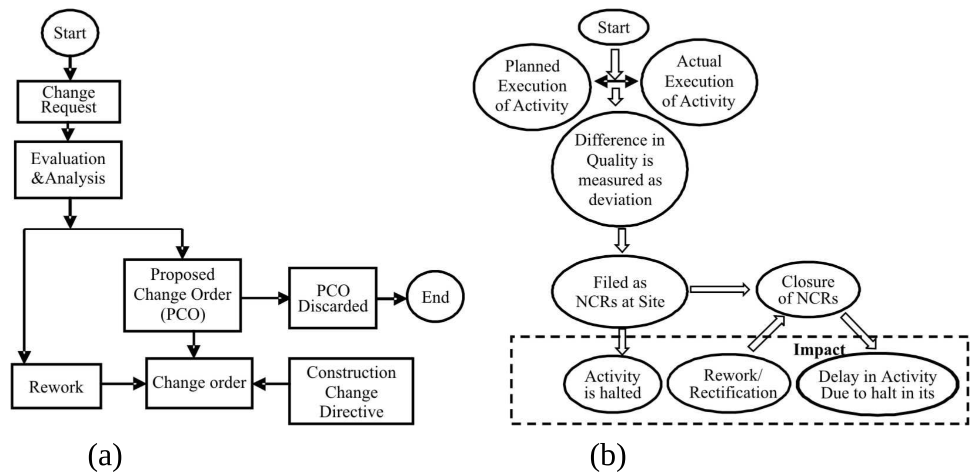


Figure 1: (a) Flow diagram for Design Changes and Delay (based on (González *et al.* 2014))
(b) Flow diagram for NCRs and Delay(based on (Kumar 2015))

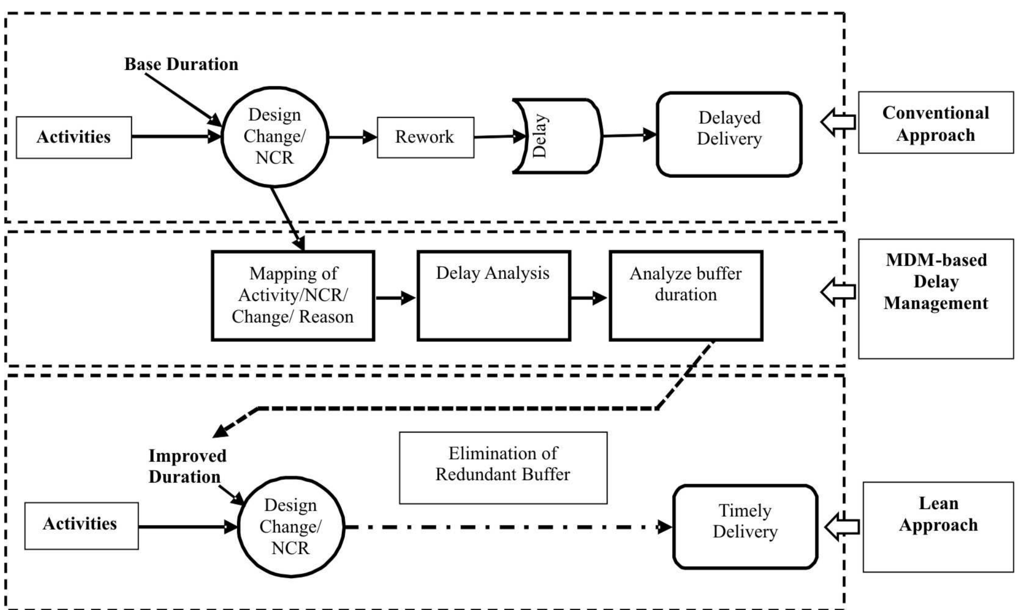


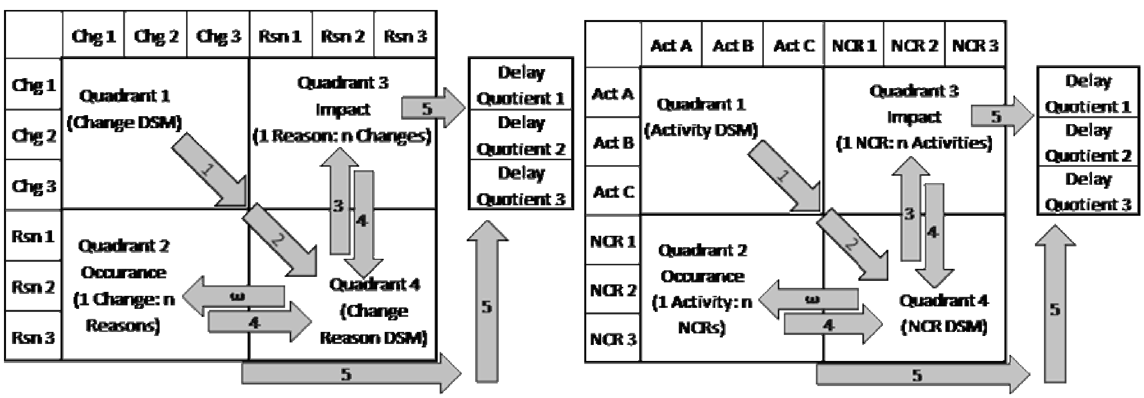
Figure 2: Proposed framework for delay management

4. Correlate the changes and reason for changes based on their likelihood or probability. The likelihood and impact can be found out from the expert opinion or by analysing a number of similar projects.
5. Construct a multiple domain matrix (MDM) model for analysing the future impact as explained in the next section.
6. Apply the same model in any existing project for assessing and forecasting the probable impact expected from the change or rework.

FORMATION OF MDM

It is possible to form MDM to represent the relationship among the characteristics of the factors causing delay. For example, an MDM can be formed to represent the relationship among the anticipated changes, reasons for the changes and the impact of the change in the case of delay due to design change (Singhal 2017). Similarly, in the case of NCR, MDM is formed to represent the relationship among activities, NCRs and the impact(Maheswari *et al.* 2016). The work flow in the formation of MDM for this purpose of delay assessment is represented in Figure 3.

In the case of design change MDM (Figure 3(a)), the 1st quadrant of the matrix represents the Change DSM that shows the relationship among the changes. The fourth quadrant, Change Reason DSM represents the relationship among the reasons for the changes occurred in the project. The second quadrant represents the relationship among various changes and the reasons.



(a) Case A: Design Change (b) Case B: Non-conformance

Figure 3: Workflow for MDM formation

The 3rd quadrant shows the impact of reasons on various changes happened in the project. The upper diagonal of the matrix represents the duration impact factor with respect to changes and the lower diagonal represents the duration impact factor with respect to reason for change (Singhal 2017). This leads to the estimation of delay quotients that is nothing but the estimate of time buffer. Similarly, MDM for the other factors causing delay such as NCR can be formed for further analysisas represented in Figure 3(b).

CASE STUDY APPLICATION & RESULTS

CASE A: DESIGN CHANGE (TRANSMISSION LINE PROJECT)

A transmission line project has been taken as the case study to investigate the impact of design change on routing of transmission line due to deviations in route. In this project, frequent deviation in the planned route has been encountered. The data collection was done to find out the different reasons for deviations in the transmission line route and they are listed in Table 1. The deviations implemented in route caused delay and cost overrun. An analysis of the project delay was done for 60 km of the stretch. It hasbeen found after analysis that angle of deviations were ranging from 0.5^0to5^0 due to reasons mentioned in Table 1. The buffer time has been estimated using the delay quotients arrived from the MDM as shown in Figure 4.

Table 1: Reasons for deviation in the proposed transmission line

Reasons for Deviations	**Abbreviations**
To Avoid new construction on the route	ANC
To avoid existing trees and Garden on the route	AT
To Avoid fouling with high Tension Line	AHT
To avoid village coming on the proposed route	AV
Land Acquisition Problem	LAP
Decreasing Route Length in some locations	DRL

	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	ANC	AT	AHT	AV	LAP	DRL
0.5	0.017										0.033	0.026	0.005	0.003		
1		0.031									0.032	0.020				
1.5			0.035								0.000	0.013		0.005		
2				0.011									0.007	0.012		0.004
2.5					0.007						0.009		0.009	0.010		
3						0.000							0.003	0.006	0.008	0.008
3.5							0.004				0.011		0.002	0.005	0.003	0.008
4								0.003					0.005	0.004		
4.5									-0.003						0.007	0.008
5										0.001					0.012	0.023
ANC	1.180	5.100	0.530		1.240		2.830				0.245					
AT	4.500	3.700	7.700									0.029				
AHT	2.500			4.900	1.000	0.320	0.630	0.730					0.062			
AV	0.660		1.150	1.800	2.200	0.970	0.900	0.670						0.062		
LAP						1.580	0.800		0.870	0.870					0.045	
DRL				-0.680		-2.270	-1.800		-0.890	-0.830						-0.061

Figure 4: MDM for Case A

CASE B: NON-CONFORMANCE (MALL CONSTRUCTION PROJECT)

Construction of a Mall has been taken as the case study to investigate the impact of non-conformance on project schedule. A pilot study was conducted for a period of three months in analysing the past NCR records of the project. The study was conducted to understand the occurrence, frequency, duration of the NCRs originating from various activities. It was found out that NCRs were repetitive in nature. A total of 350 closed NCRs from the project were analysed. Quality-related NCRs arising out of core civil construction activities such as reinforcement works, shuttering and concreting were considered for this study. The resultant MDM as represented in Figure5has been utilised to calculate the extended activity durations (with the help of delay quotients)and the updated activity durations have been estimated as shown in Table 2.

	Act A	Act B	Act C	NCR1	NCR2	NCR3	NCR4	NCR5	NCR6	NCR7	NCR8	NCR9	
Act A	70.00			0.628	0.186								0.341
Act B	0.300	60.00	0.800			0.476	0.374						0.348
Act C		0.500	70.00					0.021	0.515	0.024	0.001	0.091	0.260
NCR1	0.444			49.80									
NCR2	0.333				19.70								
NCR3		0.475				61.10							
NCR4		0.325					70.10						
NCR5			0.034					17.00					
NCR6			0.483						30.50				
NCR7			0.034							20.00			
NCR8			0.034								1.00		
NCR9			0.103									25.00	

Legend:

Act A: Reinforcement
Act B: Shuttering
Act C: Concreting
NCR1: Bars not as per specification
NCR2: Rusted Bars
NCR3: Alignment
NCR4: Shuttering pieces inside
NCR5: Inspection
NCR6: Honeycombing
NCR7: Cracks in concrete
NCR8: Improper curing
NCR9: Concrete Testing

Figure 5: MDM for Case B

Table 2: Calculation of extended activity durations

Activities	**Duration**	**Delay quotient**	**Delay in activity**	**Extended duration**
Reinforcement	70 days	0.341	23.87 days	93.87 (≈94 days)
Shuttering	60 days	0.348	20.88 days	80.88 (≈81 days)
Concreting	70 days	0.260	18.2 days	88.2 (≈88 days)

From the above cases, the delay/time waste resulting from the rework has been calculated using the proposed framework. These models have been found to be effective in capturing the delay. In both the cases, the complexities are avoided by considering some basic assumptions such as NCRs are initiated before the scheduled completion of an activity. But for large and complex projects there is much scope for further studies.

SUMMARY &CONCLUSIONS

The delay due to rework is a common issue in construction projects. The MDM models formed using the proposed framework for delay assessment have captured the relationship between change and its reasons as well as the dependencies among the activities and NCRs effectively. Further, the resultant MDM models have been used to estimate the delay in an objective way for a meaningful time buffer estimation. This method has been found to be very useful in the application of lean principles of eliminating/minimising the time waste by managing construction delay. The reduction of time delay by way of managing the rework probability can be a future scope for intensive research. The training of the model with more number of cases can provide precise forecast. However, the results from the proposed framework can help the project managers in assessing the possible time delay in the project arising from rework and take necessary corrective actions to manage them in future projects.

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TOWARDS IDENTIFYING MAKING-DO AS LEAD WASTE IN REFURBISHMENT PROJECTS

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ABSTRACT

Refurbishment projects have shown declining productivity in the last decades. At the same time, refurbishment activity is increasing rapidly worldwide to achieve a more sustainable built environment. Thus, understanding reasons for the low productivity is a key aspect to reach environmental as well as economical sustainability. The aim of this research has been to identify Making-Do in refurbishment projects and the reasons behind it. A case study research approach has been used to collect data by actively participating in weekly Last Planner System meetings, observing work in progress on-site on three projects and conducting work sampling studies on six trades. The research showed that Making-Do is highly likely to be both the prevailing and lead waste form in all of the three cases, and that insufficient management of production was the main cause. This was found by firstly identifying an overlap between known impacts of Making-Do from literature and the most occurring negative impacts observed in the cases. Secondly, finding that talking generally contained the biggest potential for being reduced and that this potential had an apparent correlation with Making-Do. This research is an important step towards understanding Making-Do in refurbishment projects and how to detect and reduce lead waste in refurbishment, and to improve construction productivity.

KEYWORDS

Lean Construction, Refurbishment, Work Sampling, Waste, Making-Do

INTRODUCTION

The Danish government has a goal of being CO_2 neutral by 2050 by launching 21 initiatives, with one aimed at reducing the energy consumption of existing buildings by 35%(Danish-Government 2014). Reducing the energy consumption of existing buildings will provide a significant contribution seen in the light of Ravetz's (2008) work, estimating that 75% of all existing buildings will still be in use by 2050. To signify the

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importance of refurbishing existing buildings, numbers from The Danish Government(2014) show that 40% of all energy consumed relates to heating and running equipment in existing buildings. Numbers from the Danish construction sector show that refurbishment now has a 42% bigger market share than new build (refurbishment 35,8% and new build 25,2%). Despite the importance of refurbishment, statistics show that productivity in refurbishment has been declining for the past two decades with new build going slightly up(Tænketank-om-Bygningsrenovering 2012).

Declining productivity in a large and growing domestic market will have negative economic consequences, sounder standing the reasons for low productivity is urgent. Furthermore, a report by LCICG(2012) shows that investing in optimising the building process through innovations contains the largest potential for saving carbon emissions in refurbishment and new build projects when working with a 2050timeline.

REFURBISHMENT

Refurbishment has a higher complexity and uncertainty than new build due to several circumstances: existing site and building conditions with low accessibility before actual start of construction, tenants either living in the buildings or being temporarily relocated during refurbishment work, less space and more uncertain work conditions. This combined with the fact that some refurbishment work is significantly different from new build(Egbu et al. 1998) create a project environment that is difficult to manage. Furthermore, anill-managed building process also creates problematic consequences in the value perspective of a refurbishment project because the tenants (end-users) have to accept dust and noise from construction(Holm and Bröchner 2000).

To solve the problem of managing refurbishment projects, Kemmer and Koskela (2012) propose lean theory. In(2013) Kemmer et al. presented several cases of refurbishment projects with superior performance, managed by lean principles. Despite proven results, lean use is still often limited(Kemmer et al. 2013).This tendency is also visible in this research, and the negative consequences are showcased in the results and discussion.

WASTE

To optimise production, waste must be removed and for this Oh no (1988)defined the seven intuitive, recognisable waste types. These waste types can be recognised and understood by Going Gemba (going to the site and doing visual observations) and then take action to remove them.

Since manufacturing and construction constitute two different production systems(Ballard and Howell 1998), the inherent waste is also different, thus Ohno's seven waste categories do not have the same intuitive nature when applied in construction(Bølviken and Koskela 2016). Koskela (2004) adds to this by defining the eighth construction specific waste, Making-Do: "*Making-Do as a waste refers to the situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased*".

The primary aim of this research has been to identify Making-Do, its significance and impaction refurbishment projects. This work is a step in the right direction of understanding the reasons for low productivity in refurbishment projects and adds to closing a knowledge gap in the current state of the art on prevailing waste forms and reasons for low productivity in refurbishment projects. The research will, in the following, be presented in sections with content and sequence as follows: method, results, discussion, conclusion and references.

METHOD

Three social housing refurbishment projects were followed for12, 8 and 8 weeks respectively. A multiple case study approach with the use of multiple methods was used to obtain higher reliability and validity in the collected data(Yin 2009). The use of multiple methods was applied to achieve a qualitative contextual understanding combined with an in-depth knowledge of the construction work observed. The methods applied were 1) interview and observation sand 2) work sampling (WS). First, the three selected cases are presented. Second, the contextual qualitative interviews and observations are described. Third, the quantitative WS method is outlined including work description, chosen categories of activities for data collection and uncertainties for the method.

CASES

All cases were planned to go through a comprehensive refurbishment including total renovation of the building envelope and the interior, including installations. All projects used limited parts of Location Based Planning (LBS) and Last Planner System (LPS) to manage their production. LPS weekly meetings with foremen were held to register weekly planned activities. Percent Planned Complete (PPC) was only calculated in weeks where the research team participated in the meetings. Look-ahead planning and restraint analysis were not explicitly used. Case details are displayed in Table1 below.

Table 1: Data collection from three cases

	Case 1	**Case 2**	**Case 3**
Contract type	Turnkey contractor	General contractor	General contractor
Contract value	USD 53 millions	USD 31 millions	USD 55 millions
Contract period	2015 - 2018	2017 - 2021	2016 -2019
Apartments	297	291	601
m2	23.700	22.800	46.500
Stories	Basement to 2	Basement to 2	Basemen to 3
Originally built	1960s	1950s	1950s
Project followed	12 weeks	8 weeks	8 weeks
PPC measured for	8 weeks	5 weeks	5 weeks
PPC percentage	54%	46%	60%
WS-study	6 trades	0	0

Interviews

Unstructured and semi-structured interviews were conducted on all cases (Ritchie et al. 2005). Five to six craftsmen from different trades were interviewed semi-structured. In addition, one unstructured interview with the PM responsible for processes and planning and one unstructured interview with the PM responsible for the interviewed craftsmen were conducted. The people interviewed in case 1 were all working with the studied trades.

WORK-SAMPLING METHOD

A general description of work for the six observed trades is presented below. This is followed by a section describing the WS method used in this research.

Work Description

The work of the six trades can be regarded as traditional refurbishment work. The construction site was unlocked and unguarded outside working hours, so all contractors had to move tools back and forth between the construction site and cars/containers to prevent theft (distance 40-50m). The following crafts were studied: Decking (two carpenters), Flooring (four specialists) Kitchen (two specialists)Plumbing (two plumbers)Painting (two painters) Façade (four specialists).

Categories for work-sampling data collection

The work-sampling study approach was used to collect and categorise work for the six different crafts. The method is quantitative and based on direct visual observations(Terp et al. 1987). The method is mainly used for understanding how workers' time is being used. Josephson and Björkman (2013) emphasise that this method is not capable of directly measuring productivity, which must be kept in mind when interpreting the results.

In the collection of data, the lean tradition has previously used only two categories: value-adding/productive and non-value-adding/waste. Later, this has been expanded into three categories: direct work, indirect work and waste(Womack and Jones 1996). These three categories were adopted in this research as overall categories to better understand the details of the observations in Indirect Work and Waste. Indirect Work and Waste were divided into three sub-categories with indirect work being: Talking, Preparation and Transport, and Waste being: Walking, Gone and Waiting. All categories are tabulated and described in Table 2. All categories were discussed with the workers observed to secure that the categories were sufficient and adequate to describe their work.

Table 2: Definition and description of observation categories

Category	Description
Production	Activities that physically add value to the product, processing of materials or assembling of a kitchen element.
Talking	The time used to discuss drawings or work at hand, conversations with persons outside the crew such as tenants or managers. There is no distinction between professional and private talk.
Preparation	Non-value adding handling of materials and elements, adjustment and cleaning of machines and tools, looking for tools or materials and measuring and marking.
Transport	Driving in a truck to move materials, carrying materials or tools from one place to another.

Walking	Walking without carrying any tools or materials from one place to another.
Gone	Time absent from the construction site such as visits to the toilet and smoking.
Waiting	Time spent waiting for co-workers, information and materials.

Uncertainties in work-sampling

Observations were done in random intervals of between 1 and 7 min. (on average 15 per hour), each time noting the current activity of the workers into one of the seven categories. This approach was used to avoid the risk of synchronising observations with given work intervals. Categorising each observation should be done immediately and without any subjectivity. Unfortunately, reality dictates otherwise because all workers cannot be categorised at the same time(Terp et al. 1987). Furthermore, some observations can be difficult to categorise, but since no observations can go in-between categories, these must be placed in one of the seven categories, representing an inherent uncertainty. To accommodate these uncertainties, both statistical analysis and stabilisation graphs have been done as described by Terp et al.(1987), but only the statistical analysis is presented in the results. Data was collected manually with pen and paper, so observations could be done simultaneously.

RESULTS

The results from this case study consist of interviews and observations including PPC measurements and a WS-study of six different trades.

INTERVIEWS AND OBSERVATIONS

Interviews and observations drew a consistent picture of the three projects showing that there is only little trust in oral agreements made regarding weekly work plans. The lack of trust was observed to be a direct consequence of insufficient production management.

Interviews with workers revealed that unhealthy and out of sequence activities were very often started. And, that healthy activities regularly deteriorated due to unknown existing conditions and previous activities not being finished as planned or being outside of scope. All craftsmen agreed that increased reliability of production plans would increase effectiveness. When craftsmen from the WS-study were introduced to the results, they all identified several categories containing opportunities for optimisation, but talking most often stood out as having the largest potential. They also noted that bad planning often resulted in:1) talking, 2) transportation of tools and materials and 3) leaving unfinished work because other trades had more important work to do.

The five most common negative occurrences from on-site observations are listed here, exemplifying the above:1) large amounts of talking on-site because planning and problem solving now had to be done within planned production time, 2)frustrations, 3)breach of HSE regulations, 4)overloaded and empty locations and 5)activities started out of sequence.

When PMs from the turnkey/general contractor were asked about the biggest planning challenges, a combination of two things stood out: firstly, insufficient and inadequate design material and secondly, little or no access to the apartments until a few days before the actual start of construction, making control of design and planning very difficult.

PPC measurements were also done for 8 weeks on case 1 and 2x5 weeks on cases 2 and 3,respectively, giving an overall average of 53% with case 1 at 54% [min: 32% ; max: 70%], case 2 at 46% [33% ; 60%] and case 3 at 60% [42% ; 74%].

WORK SAMPLING

Figure 1 presents an overview of the relative frequencies in the three overall categories: Direct Work, Indirect Work (Talking, Preparation and Transport) and Waste (Walking, Gone and Waiting) for the six trades, Decking, Flooring, Kitchen, Plumbing, Painter and Façade, followed by a weighted case average. The results are based on 6,324observations. The relative frequencies for the seven categories within each of the six trades are tabulated in Table 3.

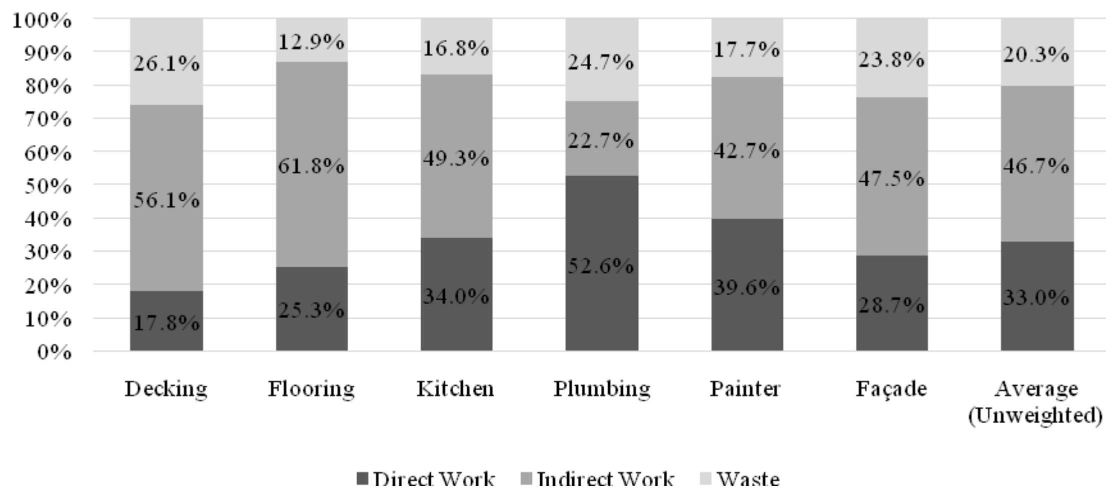

Figure 1: Relative frequencies divided into three categories

To accommodate uncertainties in the WS-study, both statistical analysis and stabilisation graphs have been used (graphs are not displayed in this paper).

Results from the WS-study and the following statistical analysis are displayed in Table 3 for all six trades and have been done according to Terp et al.(1987). The tables present $\bar{p}$ (relative frequency), n (number of observations) and $\pm 2 \cdot \delta$ (δ ,one standard deviation) for the main categories: Direct Work, Indirect Work and Waste. $\bar{p}$ for the three main categories lies within the span of $\pm 2 \cdot \delta$ with a 95,5% certainty where

$$2 \cdot \delta = \pm 2\sqrt{\frac{\bar{p}(100-\bar{p})}{n}}$$

The last rows in the tables below show $\bar{p}$ for each of the seven subcategories. Statistical analysis on these were left out since N is low for some subcategories, thus statistical validity becomes low. Moreover, when comparing with other research, subcategories often vary, leaving the three main categories as most relevant for comparison as pointed out by Josephson and Björkman (2013).

Table 3: WS-study data from six trades

Decking, N=847								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	17,8	56,1			26,1		
n		151	475			221		
$\pm 2 \cdot \delta$	(%)	2,6	3,4			3,0		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	17,8	11,9	35,5	8,6	8,5	15,8	1,8
Flooring, N=991								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	25,3	61,8			12,9		
n		251	612			128		
$\pm 2 \cdot \delta$	(%)	2,8	3,1			2,1		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	25,3	16,5	27,2	18,0	6,0	3,0	3,9
Kitchen, N=536								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	34,0	49,3			16,8		
n		182	264			90		
$\pm 2 \cdot \delta$	(%)	4,1	4,3			3,2		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	34,0	12,1	27,8	9,3	8,8	6,5	1,5
Plumbing, N=740								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	52,6	22,7			24,7		
n		389	168			183		
$\pm 2 \cdot \delta$	(%)	3,7	3,1			3,2		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	52,6	9,9	10,1	2,7	4,6	18,9	1,2
Painter, N=813								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	39,6	42,7			17,7		
n		322	347			144		
$\pm 2 \cdot \delta$	(%)	3,4	3,5			2,7		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	39,6	21,8	14,8	6,2	7,4	9,7	0,6
Facade, N=2270								
Work types		Direct	Indirect			Waste		
$\bar{p}$	(%)	28,7	47,5			23,8		
n		687	1139			571		
$\pm 2 \cdot \delta$	(%)	1,8	2,0			1,7		
Category		Prod.	Talk.	Prep.	Trans.	Walk.	Gone	Wait.
$\bar{p}$	(%)	28,7	6,4	21,9	19,3	9,9	7,2	6,7

DISCUSSION

Reducing the embedded energy in the execution phase of refurbishment projects can be achieved by initiatives such as extra insulation of site offices and facilities, construction site heat reduction at night, etc. But to significantly reduce the embedded energy, we must optimise productivity, reduce execution time and hereby remove the energy use. To optimise productivity, we must know the current state, potentials and reducible wastes.

The results section presents the current state for three similar refurbishment projects with the following five negative impacts frequently occurring in all cases:1) lots of talking, 2) frustrations, 3) breach of HSE regulations, 4) overloaded and empty locations,5) activities started out of sequence. In addition, a 53% PPC average on cases 1,2 and 3was measured. Further, a WS-study was conducted on case 1 giving a deep insight into the structural composition of the time used to execute work on-site with a case average (un weighted) at: Direct Work 33,0%, Indirect Work 46,7% and Waste 20,3%.The consistent picture in all three cases also means that the WS-study from case 1 can indicate how work time is structured in cases 2 and 3.

To understand if an optimisation potential is present in the three cases, a look at ten other PPC studies makes a good starting point. The average PPC achieved across different construction types with lean use was on average above 70% in the range of [67% ; 100%] (AlSehaimi et al. 2009; Ballard 2000; Lindhard and Wandahl 2014) and reveals a potential for optimising plan reliability with at least 32% (from 53% to 70%),which is significant and worth pursuing. Unfortunately, PPC measurements are only addressing planning reliability and not productivity (direct work) and waste removal.

The productivity (direct work) measured [18%; 53%] are examined to understand productivity potentials. Analysing twenty WS-studies and own results shows high variance, even within the same case and trades (e.g. plumbing), making baseline comparison difficult. WS-studies included in analysis: 1) Gouett et al. (2011) six cases of either power, petroleum or petrochemical construction projects, direct work measurement [27% ; 42%], 2) Josephson and Björkman's (2013) eight different cases of plumbing work, direct work measurements [9,3% ; 18,5%], 3) Shahtaheri et al. (2014)six construction projects of either natural gas or water treatments plants, directwork measurements [29% ; 37%].

Context and field of work are highly influential, making it difficult to create valid productivity (direct work) baseline rates (Shahtaheri et al. 2014). Nevertheless, using WS-results in a continuous optimisation process has shown significant results (Gouett et al. 2011) because it creates an informed starting point for both craftsmen and management to address optimisation opportunities (Josephson and Björkman 2013).

The WS-study results were also used in this research to start an informed talk about optimisation opportunities. This approach was highly rewarding and revealed several possibilities across the seven observation categories. It also revealed talking as the category with the overall highest potential for being reduced if plan reliability increases across trades. From the researcher's point of view, talking is a logical consequence of bad planning and missing input. A normal reaction to task uncertainties is talking among craftsmen followed by management involvement. This talking, caused by missing input, often leads to change of plans, moving tools and materials, leaving unfinished work, etc. This domino effect of wasted time is what Koskela et al. (2013) describe as a chain of wastes where one waste causes a chain of other wastes such as walking, waiting, talking, preparation, transportation, etc. One can of course not claim that talking is a waste form, but rather a clear symptom of the lead waste identified by Koskela (2004) as Making-Do.

Following the connection between excessive talking and Making-Do, a comparison is made between the five most common negative impacts mentioned earlier in the three cases and known impacts of making-Do identified by Firemann et al. (2013) and For moso et al. (2011): 1)reduced productivity, 2) lack of motivation, 3) poor safety, 4) unfinished work, 5) rework, etc. This comparison reveals significant overlaps.

A correlation between the optimisation potential in the category of talking and Making-Do becomes clear when a short summing up is made. Firstly, craftsmen identify talking as having the biggest optimisation potential. Secondly, the occurrence of a Making-Do events initially leads to talking and then to other wastes. Thirdly, Making-Do events are heavily present in all three cases.

This apparent correlation and the fact that all cases are highly identical reveal that Making-Do is highly likely to be the prevailing cause of the declining productivity in refurbishment projects. An explanation for the continuous descent can probably be found in the combination of evolving quality and technical demands combined with an almost absent use of new managerial methods such as Lean Construction.

That the combination of interviews and observations has been so important in understanding the full potentials registered between the lines of the WS-study, for locating optimisation opportunities and lead wastes is due to the fact that waste in construction is a "*a parade of singular, evanescent events*" (Bølviken and Koskela 2016) not easily identified, even as a fulltime observer in a WS-study.

Experience from this research has convinced the authors that any optimisation attempt starts with a quantified baseline (WS-study and PPC) followed by a future state identified through PPC comparisons and craftsmen and management feedback. This will create a change process in the specific project with ownership from the people doing the job.

CONCLUSION

The lead waste Making-Do was found to be significant in the three refurbishment projects investigated, and it was found that Making-Do is highly likely to be the prevailing reason for the low productivity in refurbishment projects. Further, an apparent correlation between excessive talking and Making-Doshowed that talking is a valid Making-Do indicator.

Feedback from craftsmen on the WS-study results was a crucial source in waste identification, implying that WS-studies is an effective method for optimisation work.

This research is an important step towards understanding Making-Do in refurbishment projects and to find out how to detect and reduce lead waste to improve productivity.

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MASTERING COMPLEXITY IN TAKT PLANNING AND TAKT CONTROL - USING THE THREE LEVEL MODEL TO INCREASE EFFICIENCY AND PERFORMANCE IN CONSTRUCTION PROJECTS

Janosch Dlouhy[1], Marco Binninger[2], Svenja Oprach[3] and Shervin Haghsheno[4]

ABSTRACT

When scheduling a construction project, resource consumption, efficiency of the trades, external influences and the possible changes within the construction process must be taken into account. Hence, the complexity of the construction schedule and an exact planning is difficult. So often the time buffers are balancing the unexpected events. That’s the reason the full potentials of the construction project are often missed. The approach of Takt Planning and Takt Control (TPTC) offers a possibility to dimension buffers and schedule them transparently. This approach is often seen as a rigid and complicated procedure. The planning has to be adapted with a huge effort to changes in the construction process and therefore often does not show the real image of the construction site. The three-level model tries to structure the method for all participants. This paper aims to improve the simplicity of dimensioning value, time and activities in Takt Planning. Performance indicators can provide information about the dimensioning and its adaptation to the construction process. Thus, TPTC can be seen as a flexible method for controlling the complexity of construction planning and excellerate efficiency of the hole project.

KEYWORDS

Lean construction, Takt, three-level model, complexity

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INTRODUCTION

In many construction projects, Takt Planning in a classic application, is often seen as a complicated and rigid scheduling process. Conventional the Takt of the individual trades is based on mass determination of a construction project. By the use of the Line of Balance (LOB) the different paces become evident, as shown in the figure 1 Subsequently a harmonization of pace is done with a complex buffer dimensioning (cf. Moura et al., 2014).

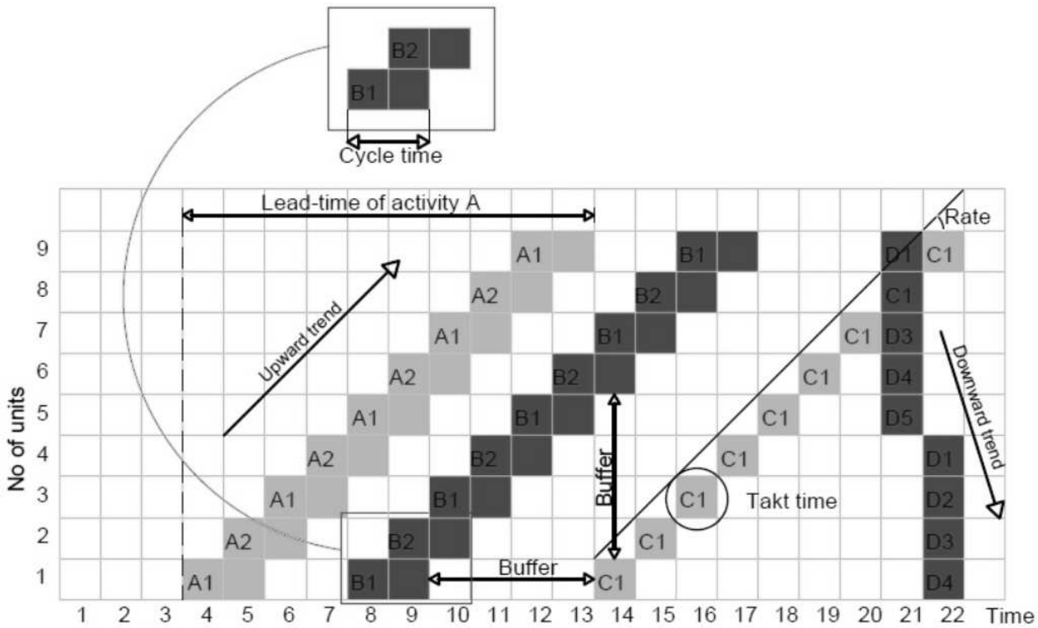

Figure 1: Buffer Dimensioning (Moura et al., 2014, p. 712)

A quick and transparent reaction in order to change the schedule is prevented due to the detailed planning and post calculation. Therefore, a standardization of the product and an always similar process with as little disruptive factors, is often the main condition for Takt. In doing so, rigid requirements are given to the contributors of the construction project, in order to comply with the Takt Plan. These requirements create little acceptance with the contributors and already with minimum disruption in the procedure, for example caused by lacking material, disease or default in the rendering of services, the takt plan fail to comply with the reality on the construction site. Therewith, a high lack of precision during the implementation of the project is created, because the target-actual comparison can no longer be methodical identified.

Takting, as a principle, is applied since many years (cf. Nezval, 1960)(cf. Horman et al., 2003), but not transmitted and used up as an extensive construction method. In order to represent a realistic image of the construction site in the Takt Plan, a systematology of generalities for the simplification of the scheduling and the possibility to react to modifications during the construction workflow is needed. In this paper generalities are introduced, which should reduce the complexity of takting.

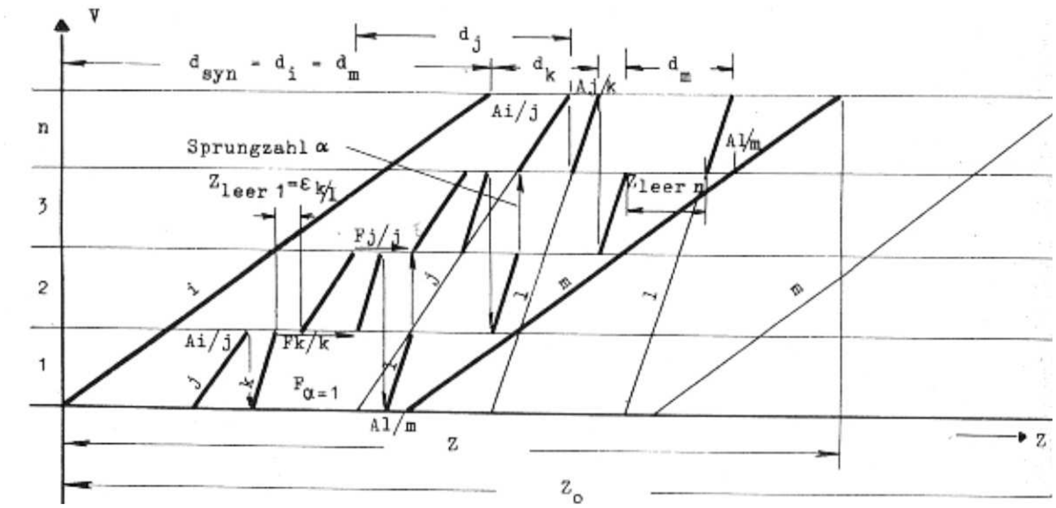

Figure 1: Example of Takt optimization by mathematical angles(Schub, 1970, p. 45)

THEORETICAL FOUNDATIONS

The term „Takt“ derives from the Latin word „tactus“, which means „touch, feeling or Beat“ (Dudenredaktion, 2014). In the 16th century Takt was defined as „a rhythm triggered by a touch.“ (Dudenredaktion, 2014)(Haghsheno et al., 2016, p. 53). Therefore, a Takt can be understood as an initiator, which causes an action in regular intervals.

Takt is not an one-dimensional unit, but it is an interaction of different dimensions. By considering the components of Takt principles in figure 2, the following three dimensions of Takt become visible:

1. **Takt time** is the time dimension. For every Takt in a system is it the same or scalable. It creates a generally valid rhythm.
2. **Takt process** or Takt content represent the ongoing, which takes place in the Takt. This dimension is often combined with Takt time. (cf. Verband für Arbeitsstudien, 1985, p. 282).
3. **Takt location** describes the place, where the Takt process happens. It is not necessarily a physical place.

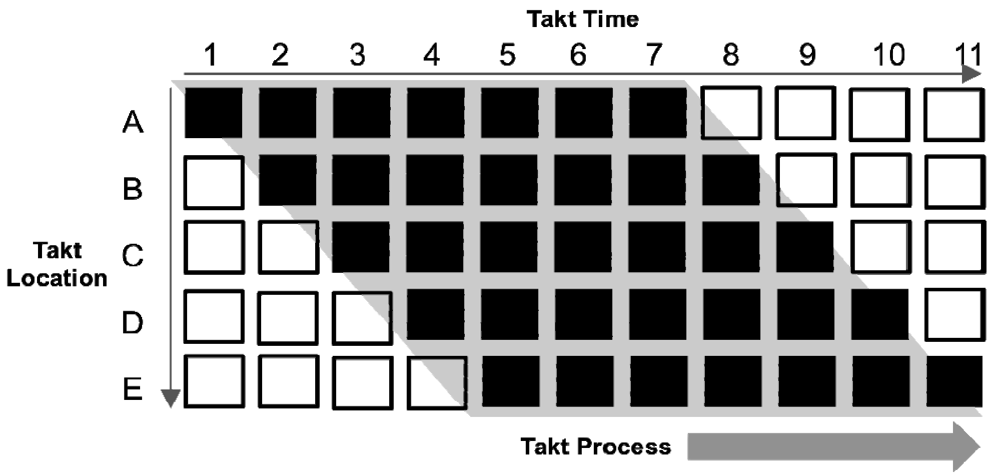

Figure 2: Example of a simple Takt schedule

Takt Planning can be defined as: in construction work is moving through the product, the takt (if there is to be a takt) has to be established by the plan. This is done by dividing the object (e. g. the building or road) into zones and deciding a construction direction in which work is to move"(Bølviken et al., 2015, p. 95)The trades are moving in the construction direction through the zones in a constant speed, the Takt Time.

Whereas the Takt Control relates to the control and adaptation of the Takt Plan during the construction. „Takt Control is responsible for maintaining the necessary stability. Systematic and short-cycled construction control is a significant success factor in the process of construction projects..“ (Haghsheno et al., 2016, p. 8) The planed process is approached more and more to an realistic image of the construction site. Disorders get eliminated and the process gets more stable. Accordingly, the principle of Takt has the task of standardizing and systematization of the procedures, in a way that the process is stable without any further reorganization or modification. The first step thereby is not the optimization of the system, but it is the stabilization. Based on a stable and foreseeable procedure the optimization is supported.

Due to the differentiation of the Takt into three dimensions, the complexity of an optimization becomes more difficult. Currently, for simplicity, often at least one of the dimensions; time, location or process, is held. If it is possible to influence, in a flexible way, the interaction between the three dimensions in a simple system and to analyze their effects, the Takt Planning could be essentially simplified.

TECHNICAL TAKT PLANNING AND TAKT CONTROL IN CONSTRUCTION by the Karlsruher Institute of Technology (2015)

The approach, developed at the Karlsruher Institute of Technology, represents a further development of parts of Kiser's approach. The basics has been published at the IGLC Conference 2016 (cf. Haghsheno et al., 2016).The method of Technical Takt Planning and Takt Control was described in-depth and defined in the following year at the IGLC Conference 2017 (cf. Binninger et al., 2017a). The method is furthermore specified in additional publications (cf. Binninger et al., 2017b); (cf. Binninger et al., 2016). The ambition is it to illustrate existing practical implementations in a methodical approach in Germany and to continue the developments systematically. In the publication of Binninger et al.(2017a) the following 12 steps of the Takt schedule are described.

1) Define functional areas (2) Define priorities 3) Pick one functional area 4) Define SSU(s) for one functional area 5) Define work packages for every SSU (standard space unit – the smallest area you can work with the defined work packages) 6) Do the calculation oft he amount of work for every step 7) Allocate detailed work steps to work packages 8) Determine Takt time and Takt area 9) Takt levelling 10) Combine the work packages best for determined Takt time and Takt area 11) Do steps 3 to 6 for all functional areas 12) Prepare the takt schedule and determine milestones in order to costumer priority.

Regarding the work content there are different detail levels to be distinguished: On the working level there are work steps, in the Takt plan work packages are defined and on a customer view there are phases. To master the complexity of the work content in step 7 and step 10, there is a double assignment, which is defined as double packaging and double sequencing.

The double packaging and double sequencing represents at the current status of research the first type of such a solution. The multiple packaging allows an itemization of the work steps whilst simultaneous overlapping level of detail. As shown in figure 3, the smallest work steps are single-origin allocated at first to the trades, whereby useful work packages are created. In step 2 those work packages are combined in a necessarily order, where a process sequence is build. Thereby sequenced work packages (trade sequence) are created out of the work steps.

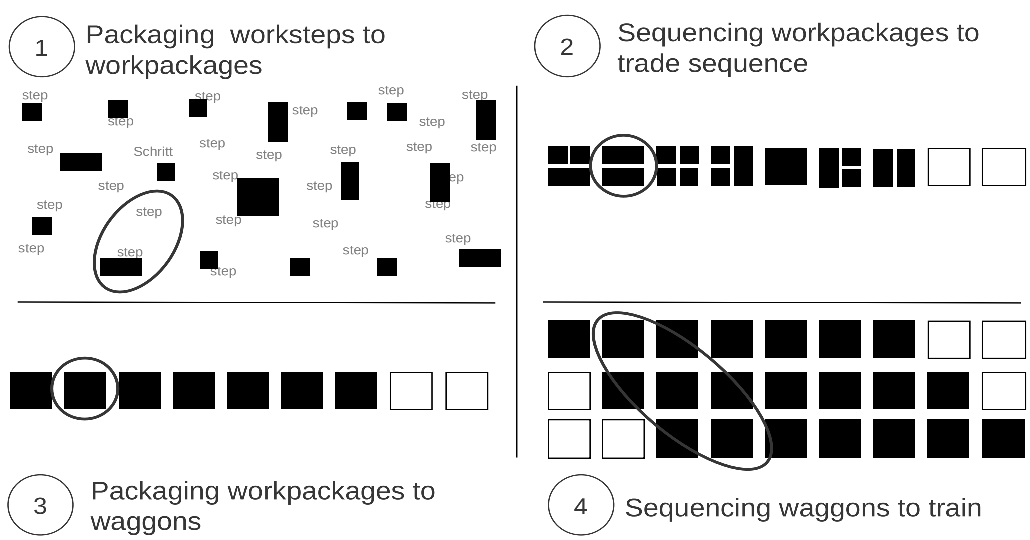

Figure 3: Double packaging and double sequencing

In this approach Takt Control is described independently. The collection of datasets and indicators (Binninger et al., 2017a, p. 6), as well as the adaptation of processes during the construction, are described in Takt Planning and Takt Control (cf. Binninger et al., 2017b). The integration of the customers regarding the construction direction with the defined milestones has been considered in the foundations and also in the twelve steps of implementation.

On the basis of the introduced technical Takt Planning and Takt Control approach, the methodic proceeding for a simple use of the three Takt dimensions; Takt time, Takt process and Takt location, is presented.

METHODICAL APPROACH

Takt Planning and Takt Control is divided into different levels of itemization with the objective of a reduction of complexity and for a differentiation of common rules (Dlouhy et al., 2016). These levels serve as well for a targeted and structured communication.

MACRO LEVEL

The macro level of the three-level method serves as communication and decision basis for the customer. It contains information with reduced depth of detail, which is needed for strategic decisions referred to the total building process. The information of the lower levels is bundled and coordinated on a project combining working method. The level is used to optimize the construction phases among each other and with the leading and successive stages. The complete but simplified representation of the construction project gives the possibility to the builder (construction client) to have a decisive and transparent overview. The takted areas of the construction project are described as a train of work with wagons. The wagon defines a kind of shell of a Takt area in a given Takt time, which defines the Takt. In this way, a working Takt is described by a wagon. The priority of the area is determined, from the perspective of the client, on the macro level. Takt time and Takt area are defined in the macro takt plan and if necessary adjusted in the norm level after their planning.

- **Time**: Milestones define the priority of the client
- **Process**: functional areas define the number of different process sequences, from which a minimum of trains of work is derived. Within a train of work, the process is represented in wagons (see figure 3 – step 3 and 4).
- **Location**: functional areas define areas, which contains different performance steps.

In figure 4 a Taktplan on the macro level is shown with a weekly Takt time, ten Takt areas as well as one train of work. For an simple communication with the client the phases as structure (yellow), cladding (green) and finished (blue) are marked in colours without representing the detailed work content (Oprach et al., 2017).

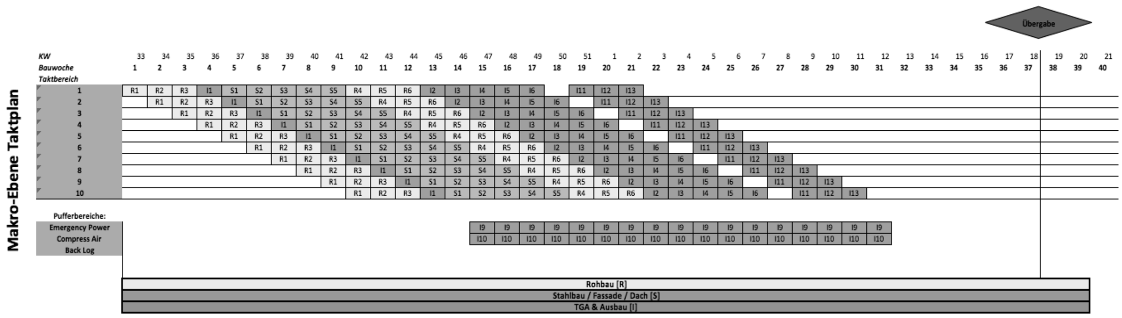

Figure 4: Taktplan on Macro level (Oprach et al., 2017)

NORM LEVEL

The norm level of the three-level method illustrates the processes of the construction coordination with a middle degree of detail (see figure 5). Information and requirements, out of the macro level, become attuned to the project and the construction progresses are planned and coordinated. Single processes and their interfaces were optimized, what allows a stable flow on the progress. They describe the Takt Planning on basis of a temporal and spatial preliminary decision based on the macro level. In the norm level, the wagons of the macro level are detailed by working packages per trade. For every working package of the process sequence, all the working steps are identified for the micro level. By changes of manpower, combinations of Takt areas, or by type and number of the used tools and machines, the single work packages can be harmonized. The result is a work sequence of trades consisting out of work packages with defined capacity and investments. The work package gives statements on required materials and machines, as well as on other capacities linked to the Takt. Non-replicable work packages, are not part of the Takt and are defined as *Workable Backlog*. Those could be preferred, used as work compensation parallel to Takt Planning or put after.

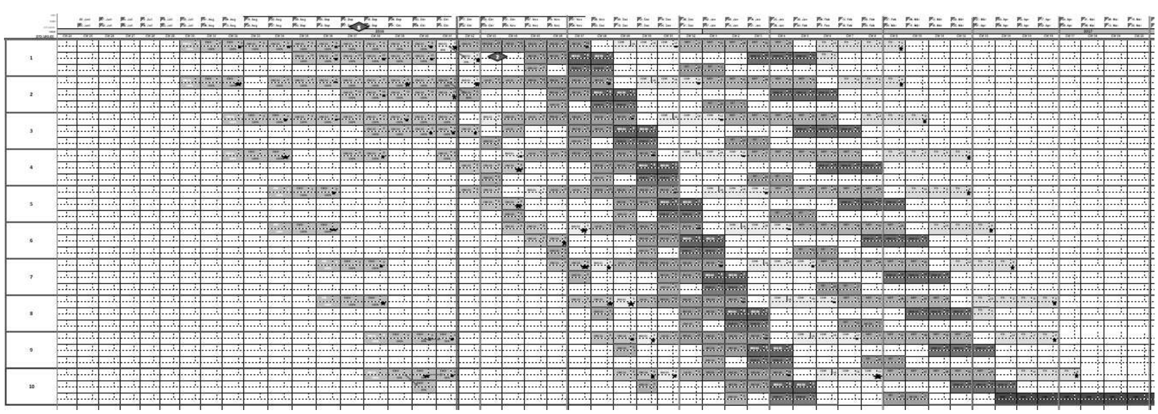

Figure 5: Taktplan on Norm level (Oprach et al., 2017)

- **Time**: Takt time
- **Process**: Work packages (figure 3 – step 2)
- **Location**: Takt area

MICRO LEVEL

The micro level is the lowest and at the same time the most detailed level of the three-level method. It represents the actual proceeding processes of the value adding level and controls the short-cycled implemented work (see figure 6). Instructions are given from the norm level and the micro level gives back data and information to the upper levels. Thereby, the itemization of the work packages out of the norm level on work steps as well as the Takt Control of the construction project takes place. The Takt Control is led by short-cycled meetings. Comparable to the meetings of the shopfloor management of the stationary industry, the information out of the Takt status meetings are recorded on a takt control board for visualization, documentation. If necessary they are converted into indicators (Binninger et al., 2016a, p.7f.). Shopfloor could be translated as place where value is added or workspace. Shopfloor-Management describes the leading and steering of these place where value is added(cf. Peters, 2009, p. 217).

- **Time**: amount of work of the work steps
- **Process**: Work Steps (figure 3 – step 1)
- **Location**: SSU

Figure 6: Work package on Micro level (Oprach et al., 2017)

In sum it can be said, that the micro level the data input of single trades in the planning serves. In the norm level the harmonization takes place. The macro level is used for the simplified representation and communication of the construction progress, from the perspective of the customer. The differentiation of the three levels in Takt Planning guides the planner from a variety highly detailed data and information to a holistic and simplified description (see figure 7). The same differentiation of the three levels within Takt Control gives the possibility to identify the cause-source and their effects in a fast way, caused by deviations. Here in the micro level root causes are documented, with the upper two levels the effects on time, area and process change can be easily detected by scaling up. Due to appropriate indicators, deviation from the plan can be quickly and efficiently highly aggregated up to milestones. The Takt control based on the three levels is done and proved by the authors in several projects.

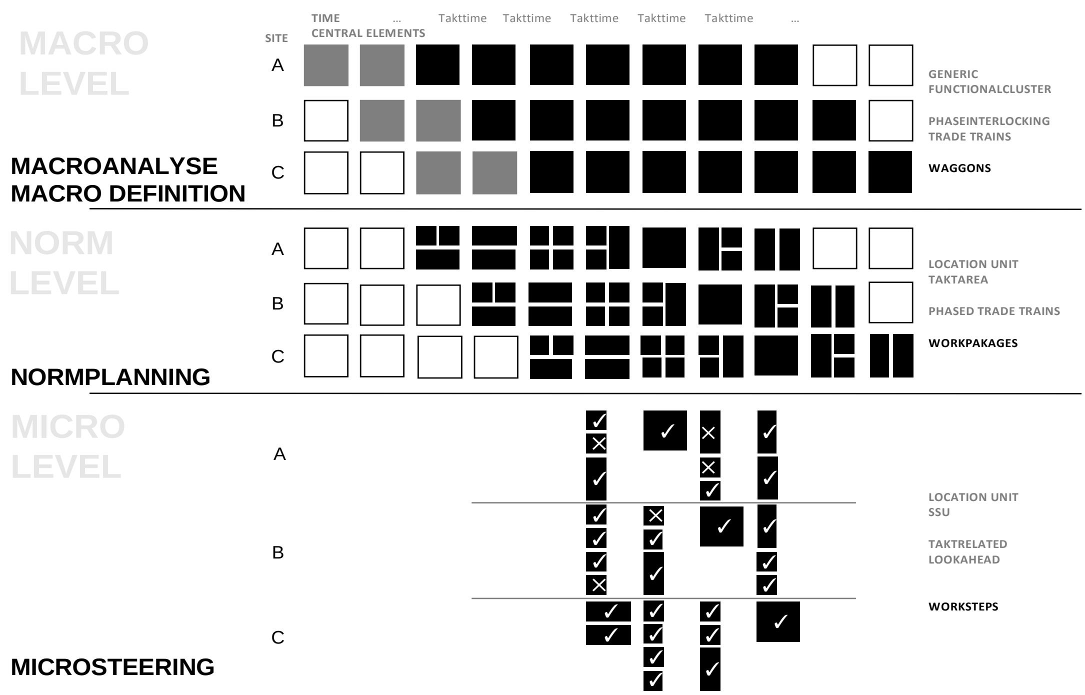

Figure 7: The three-level model

INDICATOR AT THE THREE LEVEL

Micro level: The PPC_Micro (percentage planned completed) on micro level specifies the compliance of the planed working steps. Furthermore, reasons of neglects on working steps can be shown (e.g. lack of manpower, or preliminary work).

Norm level: The PPC_Norm on norm level specifies the compliance of the planed working packages. The performance progress of the entire project, the single areas or the single trades can be evaluated by this.

Marco level: As on the micro and norm level, the compliance of the milestones can be measured and a project related buffer management can be executed. The transparence in the project enables the representation of superior indicators on the total flow, stability, efficiency and on the value of the total project.

DISCUSSION AND CONCLUSION

Takt planning and Takt Control is seen in a lot of projects as a very complex and rigid procedure: The trades are individually optimized and, in each case, harmonized with the construction site flow by a complex buffer dimensioning. In case of changes of the plan, the updating of the Takt plan causes a lot of working steps. Due to this effect trades as forced to adhere to a rigid Takting. In another case the Takt plan doesn’t represent the real image of the construction due to variations. The complexity of Takting is mostly caused by mastering of the three dimensions. These are Takt time, Takt process an Takt location. To be able of simplifying and mastering all of the three dimensions, different abstraction and communication levels are needed. With the help of the Three-Level

Method and by the double packaging and sequencing a possible solution can be created as shown in this paper. The dimensioning on the three levels is accommodated in different abstraction levels. Thereby every level can be taken individually, but a change within one level causes mechanisms in the other levels. Indicators at all three levels provide guidance on a disturbance of the construction workflow and imply measures to update the Takt plan.

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THE REVIEW OF REWORK CAUSES AND COSTS IN HOUSING CONSTRUCTION SUPPLY CHAIN

Mehdi Shahparvari[1] and Daniel Fong[2]

ABSTRACT

Rework in construction projects can cause significant waste of cost and time. Within lean construction practice, rework minimisation is of most interest among project managers. However, less attention has been paid to investigating rework reduction or avoidance in the housing supply chain. Given the increasing costs incurred due to rework generation, innovative approaches to reduce and avoid rework throughout the housing supply chain has never been more urgently required. Elaborating the root causes of rework is essential as it clearly highlights the role of various supply chain contributors. This paper investigates the root causes of rework in construction projects in general and in housing projects in particular. More specifically, the impact of rework on the entire housing supply chain will be explained.

KEYWORDS

Rework reduction, Housing Construction, Lean Construction, Housing Supply Chain, Lean Strategies.

INTRODUCTION

The UK housing supply chain has often been criticised for the poor quality and performance of its products and the inadequacy of its production process (Pan, et al., 2008). The Construction industry in 2014, contributed around £100 billion to the UK economy (equivalent to 7% of the GDP), from which the housing sector contribution was approximately 40%. Traditionally, the UK housing construction industry has not improved its productivity to deliver such value, and it has been one of the largest construction economic challenges encountering the UK construction industry.

Construction is one of the major industries worldwide and is commonly recognised as having high levels of 'waste'. The term 'waste' is defined as 'anything that is not

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required to create value for the customer/client or end-user. Therefore, it can be viewed as something of a paradox that waste reduction has not become a dominant strategy with regard to improving productivity in this industry (Bolviken and Koskela, 2016).

The elimination of waste has been essentially used as a key driver for improvement in the manufacturing industry. However, despite its great achievement, it has not been as prevalent in the construction practice and literature (Koskela, et al., 2012).

After introducing the lean concept to the construction industry in1992 by Koskela, there were many attempts and practices to implement Lean Construction (LC) across the industry to eliminate 'waste' and add 'value' to the projects. Nevertheless, there has been a lack of clarity within the construction sector surrounding the concept of LC. Yet the majority of the industry has failed to implement LC (Bolviken and Koskela, 2016).

One of the major 'wastes' in housing construction projects is 'rework'. The term 'rework' describes the work that has to be done for a second time. Rework affects both the costs and schedule throughout the project. Construction sites have complex environments which multiple trades and suppliers need to work at the same time and with different business objectives. In such environments, the likelihood of errors and mistakes wouldoccur. The cost of rework in construction projects has been estimated as high as 12% of the contract value, which can be a large amount of the revenue (Love and Edwards, 2005; Burati, et al., 1992).

COST OF REWORK IN CONSTRUCTION PROJECTS

Almost all the existing cost estimates for rework are expressed as a percentage of the total project cost (Taggart, et al., 2014). Recent studies by Love and Li (2000), Love, et al. (2004) and Hwang, et al. (2009) indicate that rework costs ranges from 2-6% during construction and an additional 3-5% during the maintenance. Love (2002) suggests that many of these costs are hidden in the process and could possibly be near to 25% of the total. These rework issues normally are generated in one part of the process, but they are often not detected until a later stage, thus increasing the costs (Koskela, et al., 2006).

In Egan's (1998) report on the UK construction industry, he indicated that 30% of construction cost is related to rework. The USA based Construction Industry Institute has projected that the loss of rework can be as high as $15 billion for industrial construction projects (Rogge, et al., 2001). Egan's (1998) Rethinking Construction report, highlights that a 20 % annual reduction in the number of defects at handover is required as a driver of sustained improvement (Sommerville, 2007). Moreover, there have been several reports that suggest rework can be found at different locations around the world in counties, such as; Australia (Love, et al., 1999), China (Kumaraswamy and Dissanayaka, 2000), and Chile (Serpell, et al., 2000) meaning that these countries are confronting mutual problems (Sommerville, 2007).

The financial and economic impact of rework in construction varies widely per project, with costs reaching up to 70% of the total project costs. Love and Edwards (2004) showed that earlier work on rework might result in less costs (that is between 3% and 15% of a project's contract value). Barber, et al. (2000) reported that rework cost might be as high as 23% of a contract value. Simpeh, et al. (2015) on the other hand found that the total rework costs could have a high variation with a range from 0% to 75%.

Josephson, et al. (2002) suggest that rework costs should be considered on three levels to obtain a comprehensive view:

- Direct costs: the cost of defect elimination for the defects found before or after handover.
- Checking costs: the costs of checks, inspections and return visits to complete defects.
- Prevention costs: the costs of preventive measures and the system.

There have been cases where indirect costs of rework were 22 times greater than the direct costs (Love and Edwards, 2004).

Considering rework as 'waste' of material, time and budget, which can be associated with the lack of quality control and /or the lack of collaboration through design and construction, urgent need for efficiently involving new approaches such as 'lean', in the housing supply chain is highlighted.

LEAN APPROACH IN HOUSING SUPPLY CHAIN

Lean thinking aims to increase value in every process step in production. The concept has been transferred to the construction industry from manufacturing principles, first by Koskela (1992). He termed the concept as 'Lean Construction (LC)'. Although the construction industry is very different from manufacturing, housing construction, as a unique sector in construction, provides the closest analogy to car production (Winch, 2003). The industrialised housing can be compared with car manufacturing regarding similarities exists in their production strategies, as suggested by Gann (1996) and Barlow, et al.(2003). Its distinctive features, including controllable production flow, high production volume (repetitiveness) and large inventory of work process, make the application of lean thinking favourable for the housing supply chain (Yu, et al., 2009).

The majority of the construction industry has failed to implement LC, and despite certain remarkable achievements, it has not been as prevalent in the construction practice and literature (Koskela, et al., 2012; Bolviken and Koskela, 2016). More specifically, Mossaman (2009) stated that lean has not been implemented in the UK because of fragmentation. Sub-contracting and fragmentation in construction means that there is little motivation for project teams to learn together as it is highly unlikely that they will work together again.

The housing construction industry has a large supply chain and is characterised by high levels of fragmentation. Harris (2013) has shown that for a typical large housing project (within a range of £20 to £25 million) the main contractor may be directly managing around 70 small enterprises as subcontracts. For a regional project, the subcontract size may be even smaller. This is clear evidence of the scale of fragmentation in the industry, which also confirms the extensive engagement of small medium size enterprises (SMEs) in the housing supply chain in the UK as subcontractors.

There have been attempts by some clients to create opportunities for SMEs as subcontractors through partnering agreements, but these generally only involves the major players (Mossman 2009). To conduct a LC deployment research beyond some specific LC techniques, Tezel, et al. 2017 suggested to take into account the entire supply chain and sector context as well as project governance structure.

ROOT CAUSES OF REWORK

Traditionally, the source and cause of construction rework have mostly been considered as the responsibility of the main contractors. However, this is a simplistic view of the complex problem. Some of the rework problems handed to the site operatives are beyond the contractors control. Project designer, product manufacturer, contractor and subcontractors, materials handling, procurement and site construction practices can all contribute to the reduction of construction rework.

The focus in most house construction practices is on fixing the problems (that is, the faults in the particular house) at the end of the construction and before handing over to the client. However, if the source of the problem is not examined and the cause is not identified, there is no guarantee that the problem will not to be repeated in the next project.

Shammas-Toma, et al. (1996) classify the defects which appear during construction but are caused prior to construction, such as during the design process or at the point of production. Josephson and Hammarlund (1999) noted that operatives must have the necessary knowledge and motivation for correct execution of the task. Among several factors that contributed to higher defects levels, they highlighted 1) contractual pressures in terms of cost and time 2) late involvement of end user; and 3) delays in decision-making by client. Love, et al. (2009) indicated a 'lack of supply chain coordination' as one of the prominent factors causing defects.

The outcome of a comprehensive literature review (Fayek, et al. 2004; Mossman, 2009; Love, et al., 2010; and Arashpour, et al., 2014) on the contributors and root causes of rework in construction projects is presented in Figure 1.

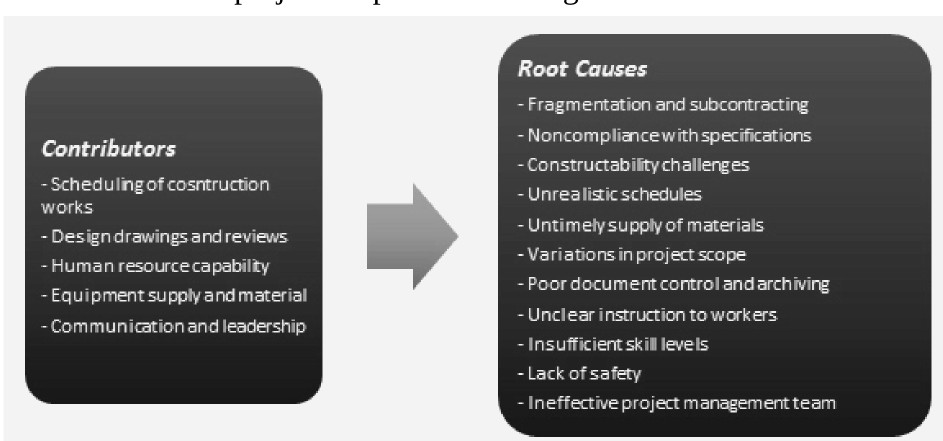

Figure 1: Contributors and root causes of rework in construction projects

The research by Dissanayake et al 2003 also categorizes rework components into five main causes as below:

1- Human resource capability
2- Engineering and reviews
3- Leadership and communication
4- Construction Planning and scheduling
5- Material and equipment supply

Further research is suggested on the level of contribution in rework generation of the aforementioned categories. This can help researchers and industry to emphasis more on the most crucial category which contributes to the rework generation most.

CURRENT PRACTICE FOR REWORK MINIMISATION

Previous works on rework reduction and avoidance in construction projects have identified the following two key practices for construction organisations seeking to minimise rework:

- Rework reduction by using various measures at the early stages of the design process including standardisation and dimensional coordination, limitation of design modifications and provision of detailed designs (Poon, 2007).
- The use of prefabricated products to reduce rework generation on site, which consequently contributes to cost savings and higher quality (Love, et al., 2004; Zhang, et al., 2012).

Researchers have concluded that there is a gap between theory and practical implementation of the suggested practices for rework minimisation by construction firms.

Lingard et al. (2000) claimed that the attitude of being ‘resistant to change’ as part of the common culture in the construction industry is a major barrier to effective implementation of rework minimisation practices.

The study by Teo and Loose more (2001) indicates that the unique nature of each project, the fragmented character of the project organisations and poor coordination and integration between various participants are the main barriers for successful rework minimisation.

Academic conversations indicate that many barriers to efficient rework minimisation revolve around underlying behavioural and structural characteristics of the construction supply chain in general and SMEs as subcontractors in particular.

For further research, study on approaches for prevention of rework is suggested. Researchers have raised quite few suggestions, some approaches include visualization-enabled technologies such as: Modular construction, lean construction, constructability reviews between design and construction team, relationship based procurement method and most importantly utilising building information modelling (BIM).

REWORK WITHIN THE ENTIRE SUPPLY CHAIN

Rework is being produced by the actions of the entire housing supply chain through design, manufacturing, demolition, construction, distribution and refurbishment. Reworks caused by various actors in the supply chain are different in terms of amounts, causes, composition and levels of integration. Each actor plays a role in reaching the minimum rework, but the actions and their relative contribution may vary in accordance with their ability to deliver. Significant reduction in rework will only be possible if they are assessed and managed within the entire supply chain.

The level of rework generated in a project is inevitably influenced by the attitude of key players (Faniran and Caban, 1998). As clients set the standards of quality to which the project team must comply, they normally have the greatest influence over rework minimisation practices. However, efforts for rework minimisation will not be successful if those downstream the supply chain do not buy-in to effective rework minimisation strategies (Dainty and Brooke, 2004; Teo and Loosemore, 2001). Within this argument, the fragmented and unstructured nature of the construction industry might be seen as a significant barrier to embedding the culture of rework minimisation within the entire supply chain.

Further study by London (2008) has identified a deeper level of complexity in the construction industry. He argued that although subcontractors may not work with the same suppliers or customers on every project, they typically are located within a cluster of professional networks, which are develop and maintained over several years. Thus, there is an indication that there are indeed long-term relationships among the various actors of the supply chain who have various degrees of influence over each other in their attitude and behaviour towards the adoption of efficient rework minimisation strategies. Therefore, it is of importance to gain a deeper knowledge of how this takes place throughout the supply chain that is specific to the housing sector. Consequently, greater opportunity for innovation to take place in rework minimisation will be provided.

ENGAGEMENT OF SMES AS SUBCONTRACTORS IN THE LEAN HOUSING SUPPLY CHAIN

Fragmentation and subcontracting in the construction industry act as an obstacle to the deployment of LC in general and rework minimisation in particular (Asefeso, 2014; Taggart, et al., 2014). It has been observed that, fragmentation and subcontracting in housing construction hinder the incentives for project participants to efficiently implement lean towards producing affordable quality housing.

In practice, subcontractors view the main contractor as their ‘client’ and they have little concern for the ultimate project customer and other subcontractors with whom they have to interact (Karim, et al., 2006). Defects often go unnoticed or are not communicated as the result of this lack of integration with other subcontractors. As a consequence, the impact of late defect detection can be multiplied (Koskela, et al., 2006).

SMEs are the largest group in the construction supply chain (Morton and Ross, 2008) engaging as subcontractors in housing projects. However, the engagement with subcontractors for LC and rework reduction has been limited to date. It has been reported that only large companies which are in the top 1% of companies by size in the UK have taken the lean pathway (Tezel, et al., 2017). Some of the general arguments regarding the lack of LC deployments and rework minimisation in smaller-sized enterprises (across the construction industry in general) have been found as follows:

- As an impeding factor for partnering for LC, there are the prevalent lack of trust between SMEs and their larger clients (Briscoe, et al., 2001).
- Normally, there is lack of spare resources at SMEs to invest in innovation (Alves et al., 2009).
- Efficient LC deployment and rework reduction should integrate SMEs into the process, to eventually reduce the transaction costs of the entire industry, and; not only the main contractor (Miller, et al., 2002).
- Large clients need to actively support SMEs regarding trainings and resources to develop capabilities in innovative approaches (Feng and Price, 2005).
- Generally, there is a lack of belief regarding the mutual benefits in LC and supply chain integration practices (Dainty, et al., 2001).

In the housing supply chain in the UK the SMEs have been chosen as subcontractors for short terms by the Tier 1 companies, often on the basis of minimum price with fixed-priced contracts. Moreover, most of the time contact with the main clients for process improvement efforts and rework minimisation is shaped and directed by Tier 1 clients, and subcontractors have rarely been in direct contact with the main clients. Due to the nature of work, the subcontractors have to implement their on-site operations in short working windows to prevent delays in the project and disruptions to the supply chain. Given this context, one of the main client’s strategic aims is to efficiently implement rework minimisation strategies across the whole housing supply chain, including all the subcontractors. Therefore, it is essential to establish an efficient lean-based framework for the entire supply chain by embarking on the role of subcontractors and their engagement to rework minimisation practice. This can be achieved by a comprehensive study to understand the current condition and future directions of rework minimisation in the SMEs as subcontractors in the UK’s housing supply chain.

CONCLUSION

This paper investigated the significant problem of rework generation in housing construction projects. The root causes of reworks were reviewed and it was concluded that the entire housing supply chain should be studied to accurately point the source of rework. This is necessary to avoid or minimise rework for future projects. Fragmentation and subcontracting was identified as one of the major causes of rework generation in the housing supply chain. An efficient lean-based framework to be used within the supply chain by embarking on the role of subcontractors and their engagement to rework minimisation needs to be established for an efficient lean housing supply chain.

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TEACHING CHOOSING BY ADVANTAGES: LEARNINGS & CHALLENGES

Ganesh Devkar[1], Jyoti Trivedi[2], and Devanshu Pandit[3]

ABSTRACT

Choosing by Advantages (CBA) is a promising lean tool for fostering collaboration, value generation, cost optimization and reduction of waste in the design phase of construction project. This paper describes the experience with teaching of this tool to the students of masters programme in Construction Engineering and Management in an Indian university. As part of the exercise of Choosing by Advantages, the students were asked to select design problems for a construction project. The students group comprised of engineers and architects, which facilitated the role play of real life industry stakeholders - contractor, designer and client. A participant observation of the role play was conducted to understand their learning from this CBA exercise. The analysis indicated that the students learned about necessity of collaboration, design complexity and systematic decision making. Although, the concepts can be articulated in much better manner after overcoming the cognitive barriers and perceptions about prevailing construction industry environment.

KEYWORDS

Lean construction, choosing by Advantages (CBA), collaboration, action learning

INTRODUCTION

The fundamental premise for improving workflow and processes in a construction project with lean philosophy hinges on collaborative efforts among stakeholders, value creation for the client and waste removal(Howell 1999). There are different tools that have been devised for bringing in transformational changes in the design, construction and operation phases of a construction project(Ballard et al. 2002). The application of lean tools and techniques in the construction phase has been more widespread than in its design phase (Munthe-Kaas et al. 2015). Among the different tools for lean design management, the Choosing by Advantage (CBA) method holds great potential owing to imbibing and/or

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forcing collaborative processes in the design process and value maximization process for the client. (Suhr 1999). It is thus important to elucidate the benefits derived from lean philosophy to emerging construction managers such as students of construction engineering and management programme. This will provide an impetus to the propagation of lean ideals in the construction industry. In this context, this paper discusses the learnings and challenges in teaching CBA. This paper comprises four section. The second section provides an overview of CBA method and its application in the construction industry. The research setting is discussed in the second section. The third section provides a background of research methods while learnings and challenges are discussed in the fifth and sixth sections respectively. The paper concludes with the seventh section.

CHOOSING BY ADVANTAGE

The CBA is a collaborative, visual and transparent decision making system developed by Jim Suhr (Suhr 1999). There are specific terms: factor, criteria, attribute and advantages, known as CBA vocabulary. Arroyo et al (2013)described terms in the context of the construction industry as follows:

- Alternatives Two or more construction methods, materials, building designs, or construction systems, from which one or a combination of them must be chosen.
- Factor: An element, part, or component of a decision. For assessing sustainability, factors should represent economic-, social-, and environmental aspects. It is important to note that CBA considers money (e.g., cost or price) after attributes of alternative shave been evaluated based on factors and criteria.
- Criterion: A decision rule, or a guideline. A 'must' criterion represents conditions that each alternative must satisfy. A 'want' criterion represents preferences of one or multiple decision makers.
- Attribute: A characteristic, quality, or consequence of one alternative.
- Advantage: A benefit, gain, improvement, or betterment. Specifically, an advantage is the beneficial difference between the attributes of two alternatives.

The above definition shave been followed in the CBA exercise conducted in this study. CBA has been discussed widely in the lean community –both among practitioners and academicians. Parrish and Tommelein(2009)have discussed the application of CBA for selecting a design for steel reinforcement. Jim Shur and Paz Arroyo have encouraged the application of CBA method among practitioners through workshops and training. Arroyo et al. (2014) have compared the CBA method with the widely used Weighting Rating and Calculating (WRC) method. Their comparison is based on selection of a structural system for a campus residential building and it shows that although both methods lead to same decisions, the CBA method creates transparency and builds consensus in the decision making process. These authors have also showcased application of CBA method for selection of ceiling tiles from the perspective of global supply chain (Arroyo et al. 2013).

CBA is one of the lean methods / tools that can be applied in the design stage of a project. There are many such potential tools that are useful across lifecycle of construction project and it is very important to impart knowledge about these tools to novice construction professionals. The academicians must ensure integration of lean philosophy into the existing curriculum of civil engineering programs in India. The authors have performed an analysis of the curriculum of a master's programme in construction engineering and management in India, in terms of the incorporation of lean construction courses. The analysis showed that most academic institutions do not have courses or lessons on lean construction related topics. In this context this paper shows how lean tools can be included in the civil engineering curriculum in order to enhance learning in this area.

RESEARCH SETTING

The CBA method was taught to the students of M.Tech (Construction Engineering and Management) programme at CEPT University in India. This programme lasts two years and spans four semesters. The first three semesters have a studio course which becomes a central core for a particular semester. The studio course aims to bring real life problems into the class room and equips students to solve these problems with the application of theoretical concepts. In reality, it attempts to bridge the gap between theory and practice. The first semester of this programme includes a studio named "Construction Project Formulation and Appraisal". The aim of this studio is to equip students with necessary knowledge and skills for performing appraisal of construction project from the viewpoint of finance, economics, design and engineering.

In our study, there were 23 students in this studio module. Of these 23 students, 7 students had prior educational degree (Bacherlor's) in Architecture (known as B. Arch) while the rest had an undergraduate degree in Civil Engineering (known as B.E/B.Tech – Civil). Many of these students had work experience of 2 to 3 years. Of these 23 students, six groups were created and each of these groups had a student with BArch qualification and with work experience. The group were designed to foster cross learning among students of different educational backgrounds, to hasten the learning trajectories of students without work experience, and to transition students with work experience into the learning mode by raising questions / queries on set practices in construction industry.

The instructors provided a list of potential projects to be appraised in this studio. This list contained projects from varied sectors like solid waste management, roads, water supply, sports facilities and real estate. These projects were either in the proposal stage, indicated as in pipeline stages by government departments or private developers, or were at the preliminary stages of construction. The projects were allocated to the groups based on their interests. The groups were expected to perform appraisal of assigned project by collection and analysis of primary as well as secondary data. The primary data was collected from interviews with stakeholders like project proponents, public sector organizations involved in approval and implementation of project, industry groups, think tanks and non-governmental organizations. The secondary data was in the form of traffic survey, minutes of meeting, census and demographic parameters, governmental policies and contracts. The following appraisals were typically carried out by each group: demand and market assessment, technical analysis, legal compliances, project conceptualization and planning, financial analysis, technical analysis, project structuring and procurement strategy, stakeholder analysis, environmental impact assessment, risk analysis and project controls. Based on the availability of primary and secondary data, each group performed in-depth analysis or assessment of a few topics, although, the instructors ensured breadth in terms of areas to be typically analysed. Following is the list of projects selected: Four laning of Mehasana - Himatnagar highway, Vadodara Exhibition and Convention Centre, Sea water based desalination plant for industrial water supply in Kutch region, Redevelopment of Motera stadium and Maritime museum at Lothal.

To begin with the student groups investigated the project characteristics covering factors like location, transport connectivity and stakeholders associated with the project. These factors helped in carrying out locational analysis that focused on advantages and disadvantages associated with actual project site as well as other potential sites. After completion of this analysis, the studio discussion focused on technical analysis. It comprised development of design brief, proposed design and target value design. The students collected information pertaining to bylaws, standards and specifications, site characteristics and guidelines relevant for design development. They also analysed the design features of existing projects having similar scale and area. For example, the group working on Vadodara Exhibition and Convention Centre understood the spatial requirements (area and capacity) pertaining to conference hall, auditorium, open art gallery, open lawn and other facilities. Further, this group studied the bylaws of Vadodara Municipal Corporation and Government of Gujarat, structural codes for steel and reinforced cement concrete (RCC) members and operation and maintenance guidelines. The design features of existing Mahatma Mandir Convention and Exhibition Centre at Gandhinagar in Gujarat, India were studied. At the end of this exercise, the group developed a design brief of the project.

The student groups presented the design brief and feedback was provided by instructors for further refinement. The design brief was also shown to domain experts for comments and feedback. Further, the students were told to identify design problems, in consultation with the instructors and domain experts, related to their respective projects. There were different design problems faced in the project, however, the student groups selected the key problems that had implications from the perspective of functionality and performance of project, and cost implications to the overall project. Subsequently, the student groups identified alternatives for each design problem. These design problems are shown in Table 1.

At this stage, the concepts of “Target Value Design (TVD)” and “Choosing by Advantages (CBA)” were introduced to the students in the form of class room presentation and discussion, and circulation of reading material for improving conceptual understanding and application of these concepts. The concept of “Target Value Design” was discussed briefly while elaborate discussion was conducted for “Choosing by Advantages (CBA)” method. The reading material comprised of many papers published in previous IGLC conferences, discussing examples of CBA and TVD (Arroyo et al. 2013; Arroyo et al. 2014; Emuze and Mathinya 2016). The exercise of CBA in this studio was used to drive learnings on the front of collaboration, communication, problem solving and value maximisation in the design process. The steps for CBA mentioned by Arroyo et al (2013) were followed: 1) identify alternatives, 2) define factors, 3) define must / have criteria for each factor, 4) summarize the attributes of each alternative, 5) decide the advantages, 6) decide the importance of each advantage and 7) evaluate money data. A role play was introduced in conducting this exercise.

Table 1: Design Options

Project	Design Problem	Design Options
Four laning of Mehsana Himatnagar Highway	- Choice of recycled material in sub base layer - Choice of street lights - Choice of crash barrier	- Reclaimed asphalt, steel slag, glass, plastic - Solar powered LED lamps, Sodium Vapour Lamps, Mercury Vapour Lamps - W-Beam Metallic, Concrete, Cable
Vadodara Exhibition and Convention Centre	- Choice of material for partition walls - Choice of sewer drains - Choice of pavement for parking	- Brick, precast hollow crete, gypsum board - Hume, HDPE, DI - Hot mix asphalt, precast paver blocks, concrete
Desalination plant for industrial water supply in Kutch region	- Choice of energy source for the desalination plant - Choice of pump technology - Choice of material used for pump manufacturing	- Non-renewable, photovoltaic, wing Membrane - Reverse osmosis, ultra filtration, nano filtration - Stainless steel, carbon steel, cast iron and copper nickel alloy
Redevelopment of Motera Stadium	- Selection of stadium roof material - Choice of parking alternatives	- PVC, PTFE (Tefloncoated fibre glass) - Surface, Conventional multilevel, automated multilevel
Integrated solid waste management project for Vadodara	- Choice of roofing material - Choice of pavement of transfer station - Choice of liner system	- Steel roof, eco roof / vegetative roof, modified bituminous membrane, foam filled composite panels - RCC pavement, post tensioned RCC pavement, bituminous flexible pavement - Compacted Clay + geo membrane liner system, Geo bentonite + geo membrane liner system
Maritime museum at Lothal	- Choice of cladding material - Choice of parking lights - Choice of flooring	- Metal, stone, glass fibre reinforced, glass - High pressure sodium vapour lamps, energy efficient fluorescent tabular lamps, LED lamps - Vitrified tile, ceramic tile and wooden

The members of each students group were divided into three roles: client, contractor and designer. The role of designer was assigned to students having bachelor's degree in architecture while students having work experience and no experience played the roles of contractor and client, respectively. The rationale behind the assignment of these roles was to harness educational background and experience of a student to play the role effectively. For example, the student with a work experience can foresee and visualize the construction process of a project easily and effectively. Each student playing a specific role in a group was told to identify the factors. Subsequently, a discussion was initiated by the instructors about the design problem and appropriate factors for comparison and decision making. The students were asked to paste sticky notes on the white board mentioning the name of factors and describe them to other group members. The students identified the factors having similar understanding and listed these factors separately on the white board. Further, the student playing the role of owner took the centre stage and students playing the role of designer and contractor addressed two questions: 1) Did the owner fail to take any factor into consideration?, and 2) Why it is important to consider the factor proposed either by designer and contractor in the design process. The instructor facilitated this consensus building exercise to ensure that the most relevant factors make way to the final list (Refer Figure 1).

The students were asked to make the final list of factors in an excel spreadsheet, and decide on "must have" or "want to have" criteria for each factor. The students looked for availability of standards and guidelines relevant for each factor, which would qualify the criteria as "must have". In case of unavailability of these documents, the students arrived at the "want to have" criteria in consultation with industry professionals and discussion among team members. After describing the criteria for each factor, the attributes and advantages for each alternative were mentioned by the students in the spreadsheet (Refer Figure 2).

The student members representing owner, contractor and designer deliberated on the most important advantage offered by each alternative and finally the selected advantage was highlighted in the spreadsheet. This deliberation involved perspectives of student playing role of designer and contractor on how advantages offered by specific alternative creates value maximization for client and the student playing the role of client was required to provided his/her opinion about the perspectives offered. A scale from 0 to 100 was used for scoring importance of the advantages; the most important advantages were scored first and it is followed by scoring of remaining advantages. The total of importance score of advantages for each alternative was calculated by summing up the importance score of each attribute. Finally, the students attempted to plot the total importance of advantages against the cost for each alternative.

RESEARCH METHOD

This participant observation method has been recognized as a most important core research method, with the strength of "collecting data first-hand". The instructors involved in this CBA exercise played multiple roles. Firstly, they played the role of "teacher" with the primary objective of teaching the application of CBA in the design process at hand. Further, they played the role of "facilitator" for the role play exercise wherein collaboration and communication was facilitated. From the perspective of research method, the instructors also played an important role of "observer". Baker(2006) has described various roles of observer as Nonparticipation; Complete Observer; Observer-as-Participant; Moderate or Peripheral Membership; Participant-as-Observer, Active Participation, Active Membership; Complete Participation;and Complete Membership. Based on this typology, the role play by the instructor seems to equate to "Moderate or Peripheral Membership" wherein the researcher helps to "maintain a balance between being an insider and an outsider, between participation and observations" (Baker 2006).

Figure 1: Discussion on advantages of alternatives

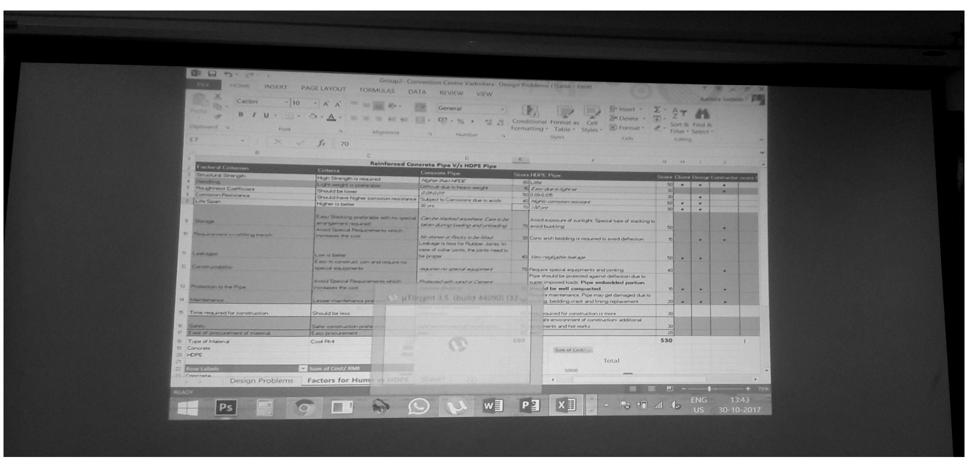

Figure 2: Evaluation of cost data and selection of alternatives

The objective of the CBA exercise was to investigate the extent of learning in the areas of 1) benefits of early involvement of contractors in the design process, 2) collaboration between designer and contractor for delivering value to the client, 3) striking balance between value, cost and advantages related to design option. The instructor played the role of an "insider" and participated in the CBA exercise to guide the role play and entire process for maximizing the learnings in the mentioned areas. At the same time, the researcher became an "outsider" and observed the extent to which the learning actually occurred. The information pertaining to extent of learning was gathered with the help of questions that were asked to the students and observations during the CBA exercise. The questions focused on extent of learning on the fronts mentioned earlier. The instructors noted the comments of students, provided in response to the questions, during the CBA exercise and suggestions given by students. The comments along with observational notes for each student group were collated and analysed to gain insights into the learnings and challenges in implementation of CBA exercise in classroom environment.

LEARNINGS

The key learnings by conducting CBA exercise is as follows:

IMPROVED UNDERSTANDING ON NECESSITY OF COLLABORATION IN DESIGN PROCESS

The advantages of collaboration between designer, contractor and client in the design process became evident with the role play of the students. Typical notion of design process being driven and steered by designers with minimal or lack of inputs from contractor came under scrutiny during the preparation of the final list of factors for selection of design options. The journey from protecting factors identified by each student representing a specific role, to arriving at final list helped the students to appreciate the collaborative nature of design process. During the presentation of factors identified by each student, representing a specific role, the students became aware of different perspective of design problem. For example, attributes like constructability, sourcing of materials / technologies / equipment and operation and maintenance were commonly put forth by student playing role of contractor. The students playing the role of client and designer understood need to consider these aspects at the design stage. Similar scenario was observed with the factors identified by the students playing the role of contractor and client. This laid the foundation for consensus building required for arriving at the final list of factors. While students were relatively open to "let go" the non-relevant factors and / or revise the factors identified by them, the major breakthrough of CBA exercise happened at this stage wherein students realized the importance of defining value for the client and participation of key stakeholders – client, designer and contractor in value identification and maximization process.

EASING COMMUNICATION FLOWS AMONG DESIGNER, CLIENT AND CONTRACTOR

The students understood that identification of factors, advantages and criteria is just half the journey and it is important to communicate their relevance to other key stakeholders and arrive at conclusions. During the CBA exercise the student was expected to bring perspective and analysis in line with the assignment role, and communicate the relevance of specific factor in line with value creation perceived by other members. It was observed that the students took extra efforts by collecting facts and figures related to a design problem for playing a role assigned to them and learned to communicate this information from different perspectives. The flow of communication among different disciplines during the design process is cornerstone for reducing waste in design and engineering process. In this context, the learning of students, gave them first-hand experience with not only effective communication but also in ingraining of diverse perspectives helps in arriving at design solution.

ITERATIVE AND COLLABORATIVE NATURE OF VALUE DEFINITION

The lean construction indicates that the constructed facility should deliver value to the client. After listing of factors on the white board by each student representing a particular role listed the factor, the discussions that eschewed focusing on how a particular factor adds value to the client, helped the students understand following: 1) value cannot defined by the single stakeholder associated with the project; it is a collaborative process and 2) the process is not sequential in nature with phased involvement of different specialities / functional areas but an iterative process with questioning of traditional notions and practices.

CHALLENGES

The step of evaluating cost data for each alternative indicates the transition of the design process within the realm of cost sensitive and driven nature of construction industry. The rationale behind plotting of cost against total advantage score is to relook at advantages offered by each design option and make a decision that ensures value maximization to the client. The availability of reliable data on cost of each option is very critical at this step. The students faced hurdles in seeking reliable cost information for few design alternatives owing to reasons like proprietary and confidential nature of cost, few or no projects using the proposed design alternatives, and long drawn process of collating cost information of different components to arrive at unit cost of design.

The reading material provided to students included papers on potential areas of application of CBA. However, there are no case studies as yet that explain the application of CBA in real life scenario and articles providing views of industry professionals that have used CBA method. The availability of these documents would have enriched the class discussion and instilled greater confidence in the minds of students about usability of CBA in cost conscious and non-collaborative construction process.

CONCLUSION

The CBA exercise discussed in this paper showed that students obtained enhanced understanding of collaboration and communication flow required between key stakeholders – client, contractor and designer during design process of construction project. These stakeholders principally strive to bring clarity on value to the client and its maximization. The students realized that the CBA offers structured approach for value maximization at the design stage without diluting the much required collaboration and communication among stakeholders.

The lean philosophy has been gaining attention among construction professionals and academicians. The imparting of knowledge about lean construction along with classroom activities simulating real life environment of construction project for construction management students is important. In this context, this paper provides guidance on conducting CBA exercise in a classroom environment. There are a few limitation of this study. First, this study used the participant observation method, with the "instructor" roles of both participation and intervention. Therefore, there could be possibility of bias in observation and analysis. Secondly, the learnings reported in this study are influenced by various contextual variables like educational background of students, work experience, and prior knowledge of subject area.

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AN EXPLORATORY STUDY ON LEAN TEACHING ADOPTION RATE AMONG ACADEMIA AND INDUSTRY IN INDIAN SCENARIO

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ABSTRACT

Construction sector is undergoing a paradigm shift with the adoption and implementation of new technologies concepts. One among these concepts is Lean Construction, which improves productivity, allocation of construction drawings, detailing, time management, costs control, people management and safety at construction sites. For the effective adoption of Lean construction, professionals require basic understanding of the concepts. To facilitate this, construction and engineering management programs need to introduce Lean concepts in their curriculum, educating students about relevant thoughts and philosophy. The Lean approaches would take them a notch higher concerning productive future career prospects in the construction industry.

For this study, data has been collected from various colleges and universities of South India. Research data was collected through semi-structured questionnaires in addition to semi-structured interview. Results of this study provided extraordinary views which is beneficial for curriculum designers and even the top management of construction. The main aim of the study is to determine the current scenarios of Lean teaching and practicing in the industry and demand rate/ awareness about the Lean Teaching. This paper helps in understanding the current status of Lean adoption in academia and also in construction industry.

KEYWORDS

Lean Theories, Teaching, Construction Management, Engineering education, Game learning

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INTRODUCTION

Construction industry in India is one vital source of socio-economic growth. The workforce involves not only the professionals but also skilled, unskilled workers from various places, irrespective of gender. Construction industry offers more employment and contributes towards the national GDP. Current Indian economy is of 2-5 trillion USD which is about 7.4% (2018-19). Growth expected is at 8 -15% which proposes extra expenditure on infrastructure projects of 5.97 lakh area with outlast of 2.04 lakh area for smart cities, allocation of 1.48 lakh crores for Indian railway and targeting almost 9000kms of highway construction within the end of 2018. The government is providing more support for infrastructure, and construction sector hence both the urban and rural areas are to be taken into account.

BACKGROUND

TEACHING METHODOLOGY ADOPTED IN INDIA

Teaching starts at the age of 3 years at kindergarten schools where trained teachers conduct visual aids, models, and interactive sessions. Various boards offer different curriculum up to 12th standard, namely State Board, Central Board of Secondary Education, Indian Certificate of Secondary School, Anglo-Indian in different states and union territories. For graduate studies (Under Graduate /Post Graduate) there are numerous institutions and universities, colleges under government scheme and aided colleges with financial support and self-financing colleges with autonomous status and deemed to be universities in private sectors. Each institution or college or university adopts a different curriculum to ensure that the education imported is in line with market requirements.

ENGINEERING EDUCATION

Before independence of India, there were only Government Engineering Colleges and Government Aided Engineering colleges affiliated to the State Government Universities to award the degree under standard norms. As per the current status, there are 3345 engineering colleges across India which can accommodate 1473871 students with 63 Under Graduate disciplines with the major category of Civil, Mechanical, Electrical, Electronics, Computer science, Information Technology, Bio-Technology. The growing need in the industry saw the evolution of the engineering and information technology and many engineering colleges had been established. To develop the job-oriented programmes, both the industry and academia should be considered (Ross B. Corotis, and Robert H. Scanlan,1989). More than traditional learning methods, teaching through projects work, tutorials would meet the educational objectives. (Betts and Liow 1993). In Civil Engineering Education, the teaching methods are seeing a marked change moving from chalk and talk to systems-based learning, online courses, self-paced courses, which are more significant innovations (Duncan and Mckeachie 2005; Vesilind 1991). Educational objectives and evaluating of coursed design on the par with the curriculum has been tailored to make the student industry ready in the global platform has been set

(Martin et al. 2014)as there will always be a relationship between work exposure at the line graduation and employability in all sectors (Murphy et al. 2009)

LEAN TEACHING

"Lean Construction (LC)" is the application of the Lean concept that was primarily initiated from Toyota Production System (TPS) to construction sector, focused on creating value on client's requirement. Human behavior with regards to the transition from a traditional way philosophy of manufacturing to the practicing of the Leanconcepts had taken into consideration. Resistance to change in adopting the Lean philosophy inhibits an organization. Both management and employees are the motivational catalyst for Lean organizational change (Keyser et al. 2016). Lean teaching in the classrooms is to be considered only if there is a proper understanding, awareness, and knowledge towards Lean in construction. (Koskela et al. 2002). There are various other factors that influence productivity concerning it, adopting new technology and new concepts will increase productivity of engineers (Anandh and Gunasekaran 2016; Kiruthiga et al. 2015)

As specified there are different service sectors like Health care, IT etc. from manufacturing industries to construction industry that adopted the strategies of Lean theories. Lean thinking should be incorporated to construction management platform (Jacobs et al. 2012) The paradigm shift is always trying to dislodge an organization system, practices and regular work. Many universities in western countries have understood the demand in the real construction field and have been giving courses on Lean concepts for both undergraduates and postgraduates students (Tsao et al. 2013). Always, a new way of thinking about Lean is a good appeal to demonstrate Lean teaching in the construction industry which includes, discussions, teamwork, assignments, practices, expertise talk, site visits, and textbooks (Tommelein 2004). Even the countries where teaching Lean concepts towards construction practice are ongoing are facing un clarity of knowledge regarding demand rate and principles behind it. (LCI).

Implementing tools and techniques will reduce or avoid the effect on the productivity of civil engineers, there will always be a healthy relationship between the working conditions and professional support concerning job satisfaction which implies the adoption of new techniques into practice too. (Anandh and Gunasekaran 2017; Anandh and Manna Simon 2017). A set of Lean skills and qualifications that are relevant for construction, is required. There is a lack of Lean skills and known mainly for entry-level professionals as the company is expecting professionals with knowledge of both soft and hard techniques of Lean. (Alves et al. 2016). There are differences in teaching approaches, experiences and lessons learned from course offered. In addition, the method of teaching Lean requires, combinations of reading, lectures, discussions, simulations, exercise and field trip and guest speakers. Online methods will be more useful in supporting classroom teaching. There are challenges by using Lean concepts in construction in real time (1) there are many meanings when applied to construction industries (2). Having academics continually working with industry practitioners to keep working on new concepts aided with tools along with this, thoughtful insights in gaining learning process LC may have gazed as fantasy in the real construction sector (Murphy et al. 2009; Tsao et al. 2013).

AIM AND OBJECTIVE

The need of the hour: Extensive research to explore the importance of Lean teaching and its subsequent implementation in academia and industry.
The objectives of the study involve

- To analysis/capture the awareness &demand of Lean construction in academia and industry respondents.
- To seek insights concerning Lean construction teaching from the prerogative of the teaching faculty and civil engineers in the south Indian scenario.

RESEARCH DESIGN

In this project, both qualitative and quantitative approaches were used to research design, email-based survey, and direct interview with experts from both academic and construction industry. The study was appropriately focusing on the teaching fraternity pertain to civil engineering and construction engineering management, civil engineers in real time projects and Lean experts. In academia, the target audiences were the Heads of Department, Professors, Assistant Professors, faculty who completed the Under graduation in civil engineering along with post-graduation in construction engineering and management, any person specialized in teaching Construction management and research scholars. Various universities /engineering colleges in the southern part of India and very few from universities abroad were invited to participate in a survey including construction industry project managers, civil engineers, and Lean practitioners. A similar exercise was carried for academia, in the industry too; the southern part of India and few from abroad being invited for the survey. The exposure rate of Lean Teaching/Practicing is higher comparatively in abroad (Singapore, USA and Australia) than in India. In total 180 individuals were asked to participate in the study. Yield response rate of 62 %, i.e. 110 involved themselves in completing the survey with great and useful insights. The basic information obtained from the respondents is given in Table 1.

DATA ANALYSIS

All the data assimilated was analyzed using the statistical package for the social sciences (SPSSV20.0) Software for chi-square test and discriminant function analysis and Microsoft Excel for pictorial representations. This was successful in providing an overall view about Lean teaching and practicing in south India.

RESULTS AND DISCUSSION

The outcomes from the detailed analysis were recorded, and detailed representation is depicted in Fig 1. It is evident that teaching Lean concepts is nearly 50% and 30.8% not practiced and 19.2% may be practiced shortly. The teaching, however, is not directly through courses but in the form of projects and research work only. Relevance rate also gazes into a new way for Lean teaching in Indian construction industry. It implies that 85% are aware of it. But it does not appear in the curriculum directly. It was noted that conferences/ workshops, magazines, Journals, blogs, online portals are the sources of Lean exposures.

Table 1: Demographic Profile

S.No	Particulars	Frequency	Percent
	Gender		
1	Male	75	68.2%
2	Female	35	31.8%
	Age Group		
1	28-38 yrs	50	45.5%
2	39-48 yrs	50	45.5%
3	above 58 yrs	10	9.1%
	Qualification		
1	Under Graduate	5	4.5%
2	Post Graduate in Engineering	70	63.6%
3	Post Graduate in Management	25	22.7%
4	Ph.D	10	9.1%
	Overall experience: (Years)		
1	0-5	55	50.0%
2	5 – 10	40	36.4%
3	10 -15	10	9.1%
4	> 15	5	4.5%
	Designation		
1	HOD	10	9.1%
2	Assistant Professor	45	40.9%
3	Professor/Senior Professor	30	27.3%
4	Doctoral Research Scholar	10	9.1%
5	Civil Engineer	5	4.5%
6	Lean practitioners	10	9.1%
	Total	110	100%

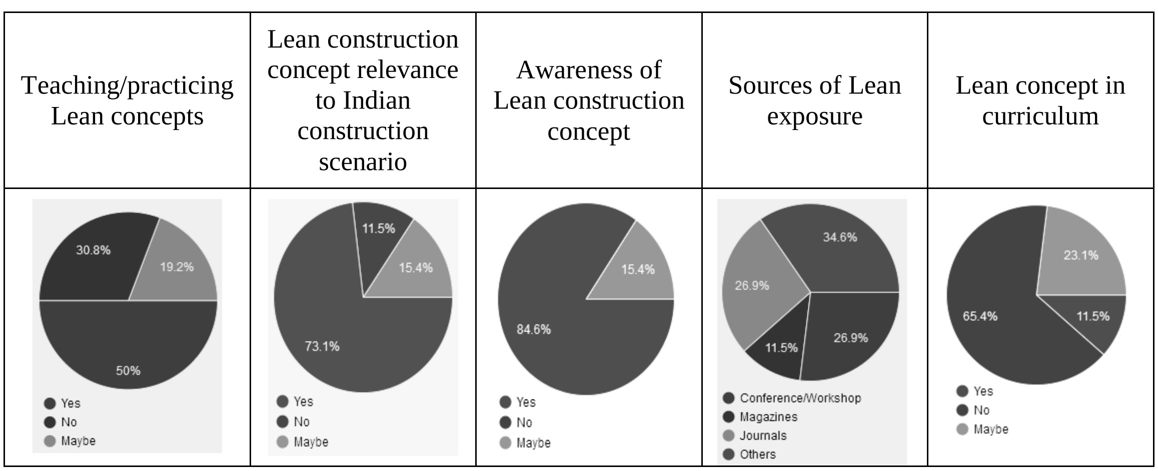

Figure 1: various aspects from the outcomes of respondents

DISCRIMINANT FUNCTION ANALYSIS (DFA)

Factors discriminant people who are aware and unaware of the Lean Construction Concept.

The discriminant function analysis is a very useful tool for:

(1) Finding the permissible variable to discriminate between different sets,

(2) Segregate the cases into different accurate sets.

In this study, the DFA was used to determine which variables discriminate between respondents based on their awareness about the Lean construction concept and the demand for Lean construction concept.

While performing a multiple set discriminant analysis, it is not required to specify how to associate sets to structure different discriminant functions. Some best blend s of variables is to be found, for that the 1) function gives the comprehensive discrimination betweensets.2) Offers second most, and so on. Moreover, the functions will be independent or equilateral, that is, theinput to the discrimination between sets do not overlay. Figuring out, perform a canonical correlation analysis is performed to determine the continuous functions and canonical roots (the term root refers to the Eigen values that are associated with the respective canonical function).

The result has given b (and standardized beta) coefficients for each variable in each discriminant (now also called canonical) function, and these can be explained as more critical, the normalized coefficient, more handouts of the respective variable to the discrimination between groups.

DFA estimation was assumed that the data (for the variables) represented a sample from a multivariate normal distribution. It was also believed that the variance/covariance matrices of variables were similar across the compared set. One more assumption of DFA was that the variables that are used to discriminate between other sets were not entirely inessential. The linear model has been performed for this DFA

$$Z = b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots + b_i X_i \quad (i = 1, 2, 3\ldots..7) \text{ (Awareness)}$$

$$Z = b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots + b_i X_i \quad (i = 1, 2, 3\ldots..8) \text{ (Demand)}$$

Where, Z= Total discriminant scoreX_I= Demographic Variables

Table 2: Wilks' Lambda (WL) values awareness and demand

Functional Test	WL	Chi-square	DF	Sig.
Awareness	0.498**	73.954	4	.000
Demand	0.428**	89.168	6	.000

The results of the DFA are shown in Table 2,3 and 4. The Table no.2 shows the test of discriminant function. The Wilks' Lambda value and the corresponding chi-square statistic are significant ($p<0.01$) at 99 per cent level.

Table 3: Results of Discriminant Function

Demographic Variables	**Discriminant function co-efficient**	
	Awareness	**Demand**
Teaching/practicing Lean concept	0.481 *	0.566 *
Gender	0.281 *	-0.085 *
Age (in years)	-0.230 *	0.000 *
Experience in present organisation	0.188 ^{NS}	0.141^{NS}
Overall experience	0.171 *	0.146 *
Designation	-0.147 ^{NS}	-0.273 *
Qualification	-0.036 ^{NS}	-0.005^{NS}
Awareness of Lean construction concept		0.374 *

Table 4. Classification of results with respect to awareness and demand

Classification Results with respect to awareness and demand												
Predicted Group Membership						Predicted Group Membership						
Lean construction concept			Aware	Unaware	Total	Perception on Demand		Demand	No-demand			Total
Original	Count	Aware	10	5	15	Original	Count	Demand	40	15		55
		Un aware	0	95	95			No-Demand	10	45		55
	%	Aware	66.7	33.3	100.0		%	Demand	72.7	27.3		100.0
		Un aware	0.0	100.0	100.0			No-Demand	18.2	81.8		100.0
a. 95.5% of original set correctly classified						a. 77.3% of original sets correctly classified						

The results of the discriminant function analysis and the discriminant score for each respondent was seen to be post-stratified into either aware or Un aware and demand rate of the Lean construction concept gives the how to know the effectiveness of discriminant function analysis. The classification results are given in Table 4. It could be inferred that 95.5 % concerning awareness and 77.3% concerning demand rate of original sets were correctly classified by this discriminant function model.

The data on qualification and overall experience with respect to level of curriculum design the teaching / practicing of Lean concept was analyzed by chi-square test is describes Table 5. The outcome of analysis acknowledged that is significant statistically($p<0.05$) association existing between both qualification and overall experience with respect to level of curriculum design the teaching / practicing of Lean concept.

The data on gender and designation wise response to the teaching / practicing of Lean concept was analyzed by chi-square test as seen in Table 6. The outcome of analysis acknowledged that is significant statistically ($p<0.05$) association exist between both gender and designation concerning teaching / practicing Lean concept.

Table 5: Level of curriculum design gives importance Lean concepts

	Qualification					Over all experience: (Years)					
	Under Graduate	Post Graduate in Engineering	Post Graduate in Management	PhD	Total		0-5	5-10	10-15	>15	Total
Low	5	30	10	5	50	Low	20	20	5	5	50
	10.0%	60.0%	20.0%	10.0%	100.0%		40.0%	40.0%	10.0%	10.0%	100.0%
Average	0	10	10	0	20	Average	15	5	0	0	20
	0.0%	50.0%	50.0%	0.0%	100.0%		75.0%	25.0%	0.0%	0.0%	100.0%
Medium	0	20	0	0	20	Medium	10	5	5	0	20
	0.0%	100.0%	0.0%	0.0%	100.0%		50.0%	25.0%	25.0%	0.0%	100.0%
High	0	5	0	5	10	High	0	10	0	0	10
	0.0%	50.0%	0.0%	50.0%	100.0%		0.0%	100.0%	0.0%	0.0%	100.0%
Very high	0	5	5	0	10	Very high	10	0	0	0	10
	0.0%	50.0%	50.0%	0.0%	100.0%		100.0%	0.0%	0.0%	0.0%	100.0%
Total	5	70	25	10	110	Total	55	40	10	5	110
	4.5%	63.6%	22.7%	9.1%	100.0%		50.0%	36.4%	9.1%	4.5%	100.0%
	Pearson Chi-Square = 51.229[a]						Pearson Chi-Square = 45.125[a]				

*-P < 0.05

Table 6: Teaching / Practicing Lean concept with respect to Gender and Designation

	Gender			Designation						
	Male	Female	Total	HOD	Assistant Professor	Research Assistant Professor	Doctoral Research Scholar	Civil Engineer	Lean Practitioner	Total
Yes	35	25	60	10	20	15	5	0	10	60
(%)	58.3	41.7	100	16.7	33.3	25.0	8.3	0.0	16.7	100.0
No	25	5	30	0	20	10	0	0	0	30
(%)	83.3	16.7	100	0.0	66.7	33.3	0.0	0.0	0.0	100.0
May be	15	5	20	0	5	5	5	5	0	20
(%)	75	25	100	0.0	25.0	25.0	25.0	25.0	0.0	100.0
Total	75	35	110	10	45	30	10	5	10	110
(%)	68.2	31.8	100	9.1	40.9	27.3	9.1	4.5	9.1	100.0
Pearson Chi-Square = 6.286*				Pearson Chi-Square = 55.000*						

*- P < 0.05

CONCLUSIONS

Based on the results, it can be seen that Lean construction awareness is high in the industry as Lean is considered as one of the effective Business model compared to the awareness in academia, where the premier institutes have relatively high exposure. Most of the colleges/universities does not offer Lean construction through their curriculum which directly impacts the development of the industry. When compared to senior faculties of the academia, younger professor's shows more interest in learning and teaching new concepts. The amount of research, teaching and practices adopted in the area of Lean construction in India is comparatively low with respect to other countries. It is also realized that Lean Construction is in the infant stage of growth and the availability of Lean experts is limited. It is also observed during the study that certain SME's has practices that aligns with Lean concepts, but the group is not aware of the Lean philosophy, which is a evidence for low awareness. Hence, this study would give wide publicity to the users and make them more comfort exposure.

RECOMMENDATIONS

In the Table.7 the insights of various respondents are narrated and recommended to both academia and industry for formulating Lean Teaching and practices

Table 7: Recommendations Insights

Academia	Industry
❖ Inclusion of Lean teaching in Civil Engineering curriculum at the UG level ❖ Inclusion of separate courses/ project for Construction Engineering Management courses ❖ Research works and paper publications to be increased in Indian context. ❖ Training programmes for Teaching Faculty – by experts to be organized. ❖ Initiative awareness programmes can be conducted for students ❖ Interesting game learning can be introduced.	❖ Policies/ standard can be implemented in construction companies at the contractual period itself ❖ Client driven and client awareness drive can be initiated ❖ Awareness should be created amongst all professionals in company though company magazines, journals ❖ Training for Civil Engineers ❖ Application can be developed for monitoring Lean progressing ❖ Short term executive courses can be conducted by experts ❖ Successful Lean stories can be shared to them ❖ International exposures should be showcased to civil engineers

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