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EXPLORING INTERDISCIPLINARY COLLABORATION IN THE DETAILED DESIGN PHASE OF CONSTRUCTION PROJECTS

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ABSTRACT

The foundation for successful collaboration in the detailed design phase of construction projects is aligning the knowledge and views of designers and contractors. In such design development meetings, architects, consultants, main contractor, subcontractors, and client representatives face several challenges in moving from conceptual designs to a documented set of shop drawings. This phase represents the peak of participants' interactions including exploring and refining design solutions, explaining and reflecting on each other's ideas and concerns, and negotiating design and cost decisions. Collaboration is often presented in the literature as practices that provide the platform for successful interaction and the achieved outcomes, but with minimal concern about actual interactive processes. Theoretically, collaboration has been studied from a variety of perspectives grouped into normative and practice-based approaches that have enhanced the research field at the inter-organisational macro-level, but there is no consensus on a framework to measure collaboration empirically in the field. Therefore, the aim of this paper is to explore the common themes describing interdisciplinary collaboration in the literature and develop a framework explaining the conceptual relationship between them. The proposed framework provides a preliminary step towards understanding the dynamic nature and stages of the interdisciplinary collaboration in the detailed design phase.

KEYWORDS

Collaboration, lean construction, detailed design, interdisciplinary teams

INTRODUCTION

Since the Latham (1994) and Egan (1998) reports in the 90s, collaboration within construction teams has been understood as pivotal for improving efficiency and productivity, albeit that recent statistics suggest little or no improvement in productivity

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over the past 20 years (ABS 2018). Several scholars have stressed the need for effective collaboration between designers and contractors to address fragmentation which is an ongoing problem in the construction industry (Gunasekaran & Love 1998; Koskela 1992). Complex construction projects often involve the creation of temporary interdisciplinary teams that are made up of participants drawn from a wide range of disciplines and organisations. Participants from diverse backgrounds have different values, attitudes and goals, which affect their interactions and their ability to resolve conflicts, communicate effectively, and exchange knowledge (Baiden, Price & Dainty 2006; Emmitt 2010). Collaboration in this setting demonstrates how participants tend to work together to find better, more streamlined ways of delivering what the client needs despite their diverse perspectives.

The interdisciplinary collaborative process was defined by Gray's seminal work (1989, p. 5) as "the process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their limited vision of what is possible". To reach this level of synergy in construction projects, interdisciplinary participants work towards achieving a mutual understanding by exchanging knowledge and information to jointly deliver the best solution that meets their common goal of maximising client value. These collaborative efforts are different from other interactive forms such as cooperation and coordination; inter-organisational cooperation is not commonly related to aligning a vision or goal and information is only shared when needed (Mattessich & Monsey 1992) and coordination requires a more formal planning approach than cooperation because it focuses on the alignment of goals and sharing some risks among groups (Schöttle 2014). The relationship between participants is more intense and stronger in collaboration as a shared goal and culture based on trust exists among participants that enable them to tackle project constraints and maximise outcomes.

Several scholars examined the enhancement of collaboration through non-traditional procurement approaches such as the integrated project delivery (IPD) (Franz & Leicht 2012; Kent & Becerik-Gerber 2010; Thomsen et al. 2009) and lean project delivery (LPS) (Ballard 2008; Forbes & Ahmed 2010) that fundamentally focus on the early involvement of contractors in the design process to improve constructability and cost estimation, and reduce design iterations. Similar benefits are achievable in a more common project delivery method used globally and in Australia, the design-build approach, where contractors provide better value for money by working closely with the designers. Even though this is an ideal scenario, not all construction projects have perfect collaboration throughout the whole design phase because of opposing interests between architects and designers, and contractors. At the conceptual design phase, contractors' constructability information allows the designers to be more informed about cost ramifications of their design options. However, there is a change point as the design progress through the detailed design phase because contractors' focus becomes cost and schedule centric, which contest with creative and innovative nature of architects' work (Forbes & Ahmed 2010; Sødal 2014). Given the long duration of the whole design process, it is unrealistic to study all the design phases in detail. Therefore, the detailed design phase has been chosen to be the central focus of this research because it represents the peak of designers and contractors' interactions to develop the design intent to be a physically achievable reality.

THE NEED FOR EFFECTIVE COLLABORATION IN THE DETAILED DESIGN PHASE OF PROJECTS

Interdisciplinary teams face a number of challenges that affect their ability to collaborate effectively. Common problems are poor communication between members, deficient or missing information for making timely decisions, and lack of coordination between various design disciplines (Mryyian & Tzortzopoulos 2013). These process problems in collaboration are reflected in the quality of design documents produced, which causes unnecessary design iterations that do not add value to clients or subsequent disciplines in the supply chain (Ballard 2000; Ballard & Koskela 1998). For instance, a recent study on the cost of quality failures (deviation, defects, nonconformance and rework) found that design change in scope, errors and omissions in documentation contributed to 13.9% of the cost of nonconformance (Love, Teo & Morrison 2017). Similar design documentation problems are demonstrated in major trade packages such as steel and concrete causing delays on site that have associated costs. Case studies have illustrated these problem in missing information on the exact location of penetrations in steel beams to accommodate mechanical, electrical and plumbing (MEP) services (Smith 2010), and crowded rebar connections that are only realised at later stages of the detailed design phase causing negative design iterations (Luth 2011). These problems show that designers need to be mindful that the information they create will be used by many other parties such as main contractors, subcontractors and fabrication suppliers.

Lean philosophy in construction emphasises that time should be spent upfront in the design process because once construction has begun, it is expensive to change the design (Ballard 2008; Forbes & Ahmed 2010). Lean management strategies rely on a comprehensive model that brings project process under control, improve information flow, recognise and cope with uncertainty, and deliver value to the client (Koskela 1992). These strategies advocate integrating the design and construction phases to realise these values and to ensure that design can be produced cost effectively (Koskela et al. 2002). Incorporating construction details in the design process requires a systematic approach as it comprises two knowledge groups: product (design) and process (sequencing and plans) knowledge (Ballard & Koskela 1998). A number of solutions have been proposed to help merging design and construction knowledge such as developing frameworks that detail design information required at each stage of the design phase (Pulaski & Horman 2005). Another approach incorporates use of boundary objects as full-scale mockups of the proposed building to thoroughly test constructability, which helps understand the complexity of the design intent and enhances inter-organisation cooperation (Naar, Nikolova & Forsythe 2016).

UNVEILING COLLABORATION DIMENSIONS IN THE DESIGN AND CONSTRUCTION LITERATURE

Collaboration between designers and contractors in the design phase is not an easy or straightforward process. Their diversity brings differences in objectives and interests. Their collaboration is expected to involve different interaction patterns including exploring and testing design ideas, explaining and reflecting on each other's ideas and concerns, and negotiating design and cost decisions. Dimensions describing interdisciplinary collaborative practices in the detailed design phase are identified from a review of the design and construction literature particularly lean construction. Some of these dimensions represent factors likely to enhance collaborative efforts, others focus on active process, and the rest are concerned with collaborative outcomes.

Enhancing dimensions

Some recurring themes in the literature tend to cluster around enhancement that help in preparing the suitable environment for collaboration to take place such as *co-locating team members* in one common space. The term co-location is sometimes used interchangeably with the practice of using a "big room" equipped with tables and screens to project 2D drawings and 3D models. Co-location maximises the opportunities to collaborate and interact easily to solve problems that occur throughout the design phase and increases the desire to discuss project issues in real time (Alarcon, Christian & Tommelein 2011; Denerolle 2013). However, physically co-locating participants involved in the detailed design phase might not be the optimum solution for all firms involved in a project because of cost and time implications. To mitigate this, design development meetings are suggested at regular intervals (e.g. weekly), especially for newly formed teams. .

Sharing information among participants is the foundation for coordinating design and project information. It is particularly relevant to the detailed design phase because participants need to access the most up-to-date information about design progress to evaluate design solutions and respond to requests for information (RFIs) (Luth 2011). This collaboration dimension can best be described as a common means of accessing passive project information. This classification is needed to differentiate between project information and another type of active information that participants exchange in collaborative design discussion including, for example, inquiries about design details, dimensions, or structural elements locations.

Defining roles and responsibilities of participants is a key requirement of collaboration because it clarifies participants' contributions in meetings and how the sequence of the design process is expected to unfold (Mattessich & Monsey 1992). *Team diversity* is another collaboration facilitator, which is demonstrated by including main contractors and specialty subcontractors in design discussions at an early stage. This approach merges experiences and speeds up responses to technical inquiries. This dimension was evident in applying lean tools such as set-based design, and choosing by advantage (Arroyo, Tommelein & Ballard 2012) where the process of exploring design alternatives included a rigorous analysis of proposed options carried out by designers, the contractor and relevant subcontractors such as steel fabricators and placers.

Active process dimensions

Another group of themes explaining the active process dimensions is also highlighted in the literature as important for collaboration. *Aligning cost incentives* brings together participants' interests when discussing design options to improve value (Zimina, Ballard & Pasquire 2012). Incentive alignment methods have different forms such as bonuses linked to adding value to the project, rewards for innovation and outstanding performance, and bonuses based on improved quality. These methods are feasible in the presence of formal relational agreements (Lichtig 2010). In other traditional procurement methods where contractors are not engaged earlier in the project, or where a number of separate contracts are used, these bonus approaches are harder to implement. However, aligning the views of designers and contractors in the same discipline can still be achieved through regular workshops allowing them to develop a common understanding of each other's technical and management constraints and collectively find suitable solutions (Denerolle 2013).

Collective decision-making is another dimension describing collaborative working processes. It refers to the involvement of participants who possess the required skills and knowledge to address a wider range of potential solutions before agreeing on a specific design solution (Arroyo, Tommelein & Ballard 2012). Decisions are more accurate and rationalised if participants who have the decision-making authority are present in detailed design meetings and engage constructively without having to refer to their superiors. Examples of sound decisions are illustrated by bringing together designers and contractors to investigate suitable design and installation solutions for main structural frames (Nguyen, Lostuvali & Tommelein 2009) and choosing between different beam-column joint alternatives to address construction constraints (Parrish et al. 2007).

Interactive coordination is a collaboration dimension describing working processes. It involves engaging downstream stakeholders in discussions to encourage innovative thinking to pursue improvements in the construction processes on site (Alarcon, Christian & Tommelein 2011). Contractors can contribute to the discussion by providing their input on constructability, which allows designers to make better decisions with fewer design iterations. Examples of contractors' feedback on technical problems include evaluating prefabrication options, solving MEP clashes, and testing structural frame installation before construction begins to improve workflow on site (Luth 2011). These benefits of accessibility and comprehensibility of design information have been associated with the use of Building Information Modeling (BIM) (Aram, Eastman & Sacks 2013; Azhar 2011). Several case studies documented the implementation of BIM in different design disciplines. For instance Arayici et al. (2012), detailed the substantial influence of BIM in architectural practices in terms of better communication with other stakeholders and refining design options. The advantages of BIM in clash detection of MEP services were prominent in improving coordination between designers and contractors in terms of exploring prefabrication options and reducing the number of design changes (Staub-French & Khanzode 2007). While these studies provide valuable insights into the adaption of digital technology in the AEC industry, their contribution in studying the interactive collaboration focused on quantifying the achieved outcomes. Construction projects are governed by different variables, for example, procurement and delivery methods, size and complexity of the building, and diversity of organisations involved, which increase the difficulty of linking collaboration solely to technology applications. However, a common theme in these approaches is that BIM is a progressive digital tool that mediates interactive collaboration between participants involved in the design development phase.

Outcomes dimensions

Value for money is regarded as the main collaboration outcome because it represents the client's objective, which is achieving the best design for the money spent. This concept is present in any procurement type because the client is the main principal who brings participants together in construction projects. Other outcomes are also legitimate, for instance, designers work towards achieving the design intent if the proposed building has special aesthetic features. Similarly, main contractors focus on controlling common project management constraints such as program timeframes and budget limits, while accommodating design requirements. Subcontractors are keen to get instant responses to their design inquiries to reduce the time spent waiting for processing RFIs, and receive faster decisions on their proposed design options (Denerolle 2013). Lastly, *trust in expertise and capabilities* among participants is a collaboration outcome dimension. It develops over time after a number of successful collaborative interactions among participants occur and hence creates a sense of belonging to the team that encourages team members to generate ideas and collaboratively solve problems (Baiden, Price & Dainty 2006). However, in construction projects, participants have insufficient time to develop trust due to time pressures and limited experience working together, which might affect the negotiation and interaction in meetings. For instance, participants might feel unsure that their concerns were considered or adequately discussed before decisions were made, which could extend negotiations on critical design issues (Emmitt 2010).

Based on the previous discussion, the above dimensions are themes identified as being important for collaborative interactions in interdisciplinary teams. Even so, what is missing from the discussion about enhancing, active and outcome dimensions is a framework that pulls them all together in a mutually explanatory way.

THE LACK OF A HOLISTIC FRAMEWORK FOR EXPLAINING COLLABORATION

This section provides a brief overview of collaboration frameworks from the inter-organisational domain. The seminal work done by Thomson (2003) in investigating the roots of collaboration theoretical perspectives identified two literature streams, the normative approach that focuses on incorporating collaboration into strategy design, and the practice-based approach that is concerned more with identifying collaboration antecedents. The normative stream searches for ways to improve existing organisation networks to cope with increasingly complex problems. Examples of theoretical perspectives resembling this approach include organisation networks (Powell 1990), and collective action (Ostrom 1998). This normative approach views collaboration as a strategy for survival to cope with the growing needs for new organisation forms, thus they were concerned with what ought to be with little attention to how the collaborative process takes place.

The practice-based stream builds on the normative literature and adds new theoretical perspectives that encouraged working towards theory development based on collaborative perspectives. This literature stream introduced frameworks focusing on inter-organisational relationships for combining resources (Ring & Van de Ven 1994) and collaborative perspective that advocates diversity in skills to deal with highly uncertain complex problems (Gray 1989; Huxham 1996; Thomson & Perry 2006; Wood & Gray 1991), which adds to the concept of stakeholders' interdependence (Thomson 2003, p. 90). These scholars share a view that work done on collaboration focus more on antecedents leaving the active process the least understood and often presented as outcomes. However, each of these different frameworks addresses part of the collaborative processes; Ring & Van (1994) framework is better at explaining the cyclic link between negotiation interactions, commitments, and implementation through an iterative assessment of these three processes. Another framework goes deeper in explaining the processes of collaboration discussions (Gray 1989). Thomson & Perry (2006) build on these frameworks and identifies collaboration administration dimensions that managers need to know beforehand managing the tension inherited in negotiations among participants. While these theoretical perspectives do not provide consensus or offer a holistic framework to measure collaboration empirically to move towards theory building (Thomson 2003), these studies provide a rich research foundation for investigating interdisciplinary collaboration and support the creation and adaptation of frameworks to explore interactive collaboration processes (discussed in the previous section).

Development of a framework explaining collaborative processes in the detailed design phase of construction projects

The above discussion supports the proposition that there is a gap concerning a holistic theoretical framework that helps to explain collaborative processes. To reconcile this gap, the study looked at three aspects that were found important for developing a framework that brings together the collaborative dimensions identified earlier. These aspects are the presence of antecedents, dissecting the collaborative process, and the need for participants' diversity. Given that the frameworks explained in the above section investigated collaboration at a macro-level, the antecedents identified focused on a reciprocal need for resources between organisations to deal with complex problems (Thomson 2003, p. 32). However, the dimensions identified earlier as enhancements dimensions demonstrate the concept of antecedents when applied at a micro-level as factors regulating participants' interactions before starting their design discussions. Moving to the collaborative process, Gray's (1989) generic model describing interdisciplinary collaborative efforts was found suitable for adaptation in construction because it relies on a number of key concepts. These concepts view interdisciplinary collaboration as a negotiated process that shapes participants' interaction to reach an acceptable agreement and takes into consideration the need for diversity concept to solve complex problems (Gray 1989, pp. 229, 31). These concepts are evident in construction projects because participants' collaboration revolves around solving design problems to develop the design from conceptual to construction detail level. To achieve this, other design partners, the subcontractors, step in to complete the design, which aligns with the need for diversity concept. In design discussions, several negotiations occur to refine proposed design options to achieve design integrity within budget limitations. A representation of Gray's generic model is shown in figure 1 below.

Figure 1 Representation of Gray's model (1989)

Gray's (1989) postulated that collaborative efforts generally proceed through three major phases in a linear fashion: problem setting, direction setting, and implementation. The first problem-setting phase starts with identifying stakeholders then defines the problem by providing a broad analysis to improve the quality of solutions, aligning views during negotiation, and taking each participant's interest into account in agreements. This approach is needed in design discussion because participants need to develop a common understanding of each other concerns regarding the design task they are investigating in terms of design, cost, and program constraints. The second phase is the direction-setting that begins when participants evaluate the proposed solutions and align their interest to reach an agreement on the best solution and consequently explore ways to refine and implement it (Gray 1989, p. 74). To achieve this, both design and construction knowledge needs to be integrated to refine design solutions and explore means of improving constructability. The final implementation phase has two indicators: the first one is objective as it documents if participants reach an agreement and whether it was implemented, while the other indicator is subjective because if participants are not satisfied with the collaborative processes, they are unlikely to accept the outcome (Gray 1989, pp. 256,7). Participants need to experience progressive success to be motivated to sustain their collaborative efforts (Mattessich & Monsey 1992). This view is relevant in construction projects because they usually have long timeframe to reach completion and the interdisciplinary team is expected to interact collaboratively in weekly or fortnightly meetings throughout the detail design phase.

Given the above discussion, the model presented in figure 1 provides the linear direction of collaborative processes. It is considered beneficial as a broad framework for pulling together the previously discussed collaboration dimensions including *enhanced, active and outcome* dimensions. However, an outstanding issue concerns how these dimensions fit into this framework. The previous dimension of enhancements does not exist in Gray's model but still seems important because it provides pre-settable features of a collaboration that has yet to take place. Thus, they are considered as the first stage of the framework. The next step focuses on filling the vertical components of the collaborative processes. To do so, collaboration dimensions are rearranged to fit with the description of each phase of the model. The active process is distributed across the first two stages of the model presented in figure 1, the problem and direction settings. The problem setting is the stage where participants are expected to define the problem and align their views to explore possible solutions. Two active process dimensions fit with this description, *the interactive coordination and aligning views in cost-related issues*. The collective decision-making dimension resembles the direction setting phase as participants work towards reaching an agreement on the best solution. Lastly, the outcomes dimensions can be split into objective ones measuring what participants achieved such as *value for money, design integrity, and improving working processes*. The subjective measure is represented by the *developed trust in expertise and capabilities*. The arrangement of these dimensions is displayed in the proposed collaboration framework in figure 2.

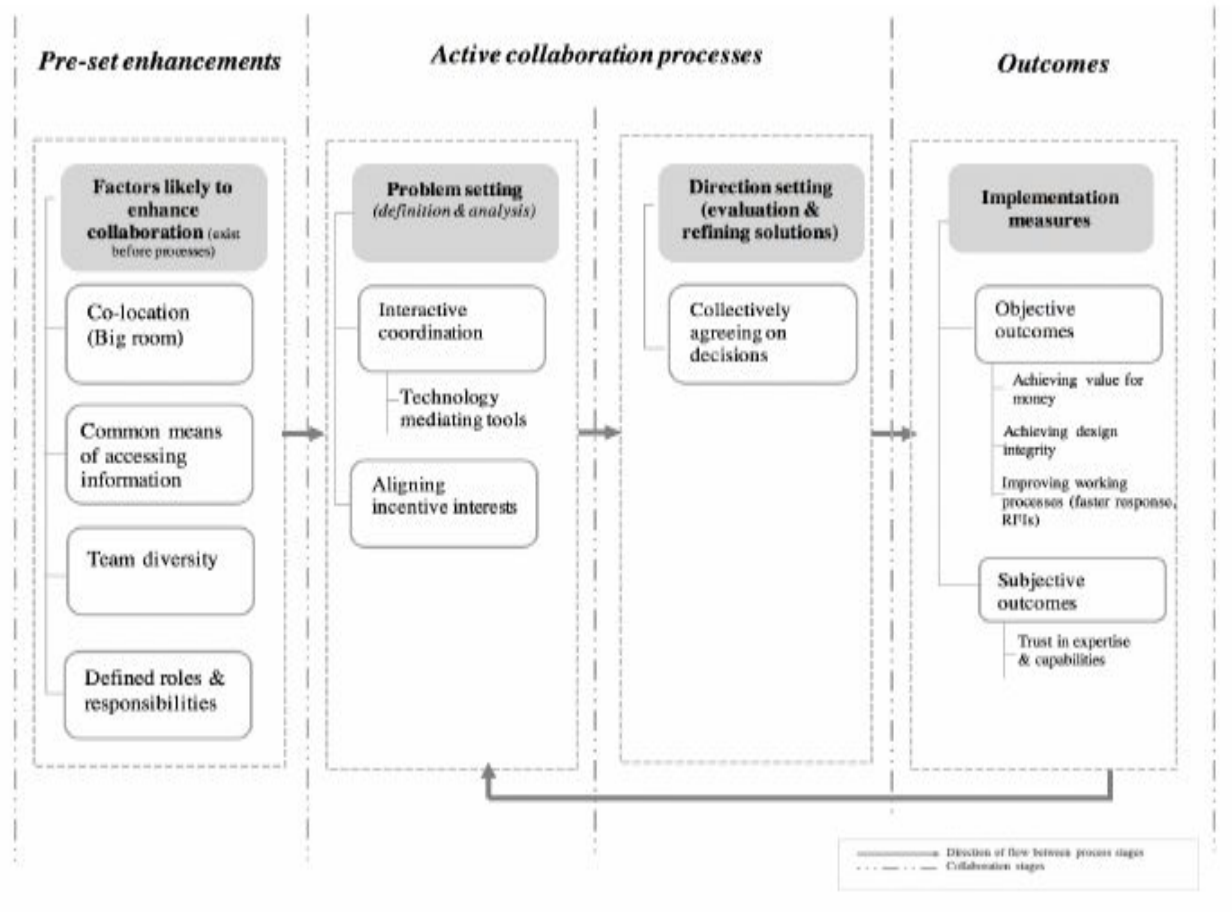

Figure 2 Proposed collaboration framework

The framework in Figure 2 highlights the important, but neglected area of active collaboration processes, what participants actually do in these discussions. Such a framework will assist with the difficult task of measuring collaboration, which is a relatively subjective and unpredictable concept. The subjectivity is strong because the construction industry relies heavily on humans when compared to other industries such as manufacturing. Given the diversity of participants involved in the detailed design phase, a variety of collaboration perspectives are expected to emerge. Collaboration is not a predictable process, as participants in construction projects cannot say in advance that a specific meeting will be collaborative or not. However, participants might expect that a certain task will be difficult to resolve due to design complexity or late changes. In these situations, designers are unsure how other design partners, such as subcontractors, will perceive their ideas or design change request, which might affect their collaboration.

Aligning with this fluctuation between easier and more difficult design discussions, studies have confirmed that collaboration is not a constant process but changes over time (Thomson & Perry 2006). Considering these symptoms of collaboration and the gap in the literature in describing collaborative processes, the proposed framework enables a detailed investigation of the collaborative processes by employing a practice-based longitudinal study approach using empirical methods of inquiry. Practice-based studies are particularly applicable in such complex and dynamic settings (Clegg et al. 2018) as they focus on providing a better explanation of what participants actually do in their working practices.

CONCLUSIONS

The design and construction literature identify a number of dimensions describing collaboration enhancements and outcomes; however, there is a lack of knowledge about actual practices, or what participants do in the active collaboration process. To address this gap, this study builds on the existing theoretical approaches related to inter-organisational relationships by proposing a framework that combines literature findings to explain collaboration. The proposed framework reveals a lack of detail in areas such as *problem setting* and *direction setting* suggesting that these could be rich areas for further development and understanding. More research is needed to capture and analyse active collaboration actions in order to profile good and bad collaboration. A longitudinal practice-based approach is proposed to enable studying the events and conditions that encourage or constrain collaborative efforts. The intention for developing this framework is to apply it to empirical case study focusing on participants working practices in design development meetings. Through this study, the framework will provide a holistic means of evaluating the collaboration practices among interdisciplinary project teams and validating the associated outcomes.

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SOFT ELEMENTS IN COLLABORATIVE PROJECT DELIVERY METHODS

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ABSTRACT

Lean construction seeks to improve project performance through maximizing value and reducing waste. As a way of improving project performance, collaborative project delivery methods have been presented as a potential solution. The foundation of collaborative PDM is that they seek to align all participants to well understood and agreed on project goals. However, collaborative PDM is more person-dependent than traditional delivery methods. Hence, this paper aims to increase this understanding of soft elements in collaborative PDMs. A qualitative case study was chosen for exploring the phenomena of soft elements in collaborative PDMs. The combination of literature, documents, and interviews was selected as the basis for data collection. The study has identified that collaborative PDM imposes specific demands upon project managers and owner's representatives and that formal elements have a significant impact on the soft elements in the project. Soft elements need to be viewed in light of the delivery method, and as indicators of the continuous relationship between members of the project organisation. Therefore, soft elements such as Top management support, Trust, Shared goals and motivation, Attaining the right people, Openness/transparency were all identified as necessary for such an approach to be successful. A critical success factor for soft elements lies in whether the management has enough resources to continuously follow-up. Especially in regards to which elements being implemented and nourished.

KEYWORDS

Lean construction, culture & people, soft elements, collaboration, project delivery methods.

INTRODUCTION

Today's construction industry is both fragmented and specialised as only a few if any, industry actors have the necessary competence in-house to complete projects without involving external specialists or contractors (Oakland and Marosszeky, 2017, pp.3-22). Over the last decades, there has been a focus on streamlining the construction process, by digitalization and innovation. One management movement, Lean Construction (LC), have developed a three-part framework to address the challenges related to modern construction

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that includes 'Operating system' (often referred to as Lean Management methods), 'Commercial,' and 'Organisational.' This paper focuses on the organisational part of the triangle, more specifically as to how to organise to align the interest of the client and the supply-chain (Oakland and Marosszeky, 2017, pp.3-22).

Collaborative project delivery methods are relatively new in the context of the Norwegian construction industry, and the approach is often labelled 'Partnering' (Wøien et al., 2016; Hosseini et al., 2016). The development of the Partnering approach is often attributed to the early nineties and described as a commitment to trust, collaboration, and excellence on the part of all the participants involved in a project (Larson and Gray, 1994). From being mere conceptual, collaborative project delivery has developed into applied methods such as the Australian *Alliancing* approach (Walker, 2002), and the American *Integrated Project Delivery* approach (Matthews and Howell, 2005). While many claims that collaborative project delivery methods represent an appealing solution to the challenges of today's industry, this approach also involves challenges.

Success is prescribed to be closely related to the ability to commit to trust, collaboration, and excellence on the part of all the project participants (Pishdad-Bozorgi, 2017; Challender, 2017). The ability to commit to collaboration requires great emphasis on the project's soft elements. Soft elements are, in literature, defined by Cheung et al. (2003) as "(…) behavioural aspects such as trust, honesty, communication, and relationship". Yeung et al. (2007a) define it as "(…) related to the relationship between the people in the project". If hard elements are defined as discrete, quantifiable and easily observed, soft elements exist more towards the qualitative end of the spectrum. Any human interaction will have a degree of trust and honesty, and in many aspects, hard elements are used to support this. Hence, soft elements are best defined as a combination between Cheung et al. (2003) and Yeung et al. (2007) Soft elements are qualitative indicators (e.g., trust, honesty) of the continuous relationship between members of the project organisation.

The interest in collaborative project delivery methods has increased in recent decades. According to the World Value Survey, countries such as Norway, Sweden, and Finland scores among the top on cross-country comparisons of self-reported trust attitudes (Esteban Ortiz-Ospina and Roser, 2019). The open attitude has created opportunities for exploitation within the framework of traditional project delivery in Norway (Lohne et al., 2017; Engebø et al., 2018; Engebø et al., 2016). However, the high level of interpersonal trust in society also constitute an appropriate foundation for adopting collaborative project delivery methods in construction projects. This paper contributes to research on Lean Construction by presenting an empirical investigation into how a public client view and monitors the soft elements in collaborative project delivery projects. The purpose of this study is to investigate soft elements in collaborative project delivery projects through the following research questions:

1. Why do clients use collaborative project delivery methods?
2. What soft elements characterize a collaborative project delivery project?
3. How can clients better facilitate the soft elements in projects?

The research questions have been considered using document analysis, and semi-structured interviews. The document study was used to analyse the internal and public documents used in the implementation of partnering. A total of ten semi-structured interviews of project managers working for a large professional public client in Norway were conducted.

METHODOLOGY

The study took the form of a case study with the intent to report on and explore the phenomena of collaborative project delivery methods through the lens of project managers working for a large professional public client in Norway. The study was initiated by conducting a literature review. The databases used were Oria (The university's electronic literature database), Engineering Village (Compedex), and Google Scholar. Then keywords/ search phrases were selected, for example, "Construction AND success AND soft elements," "partnering AND soft elements." Then, the literature was supplemented with the searches within the IGLC Conference paper Database and the Lean Construction Journal, to identify potential knowledge gap in the lean literature when it comes to soft elements and project delivery methods.

The case study is according to Creswell and Poth (2017) a suitable research design for exploring phenomena using a qualitative approach. Therefore, the combination of documents and interviews were chosen as the basis for data collection. Selecting more than one type of empirical data makes it possible to investigate the research problem through different lenses, which should strengthen the analysis (Yin, 2014). Thus, the document study is included to bring a mean for triangulating the data, providing context and additional empirical evidence into the analysis (Yin, 2014). The data collection was carried out during the Spring of 2018. The interviewees were selected due to their experience and interest in collaborative project delivery, but also because of involvement in introducing, in general, new processes or ways of doing things within their organisation. The initial recruitment was conducted through a contact person provided by the organisation studied, and later through the network of the first interviewees.

A total of 10 interviews were held, where most of the interviewees were project managers, using semi-structured interviews (Kvale and Flick, 2007; Blumberg et al., 2011). A document study was also conducted, analysing documents such as contracts, meeting reports, guidelines, notes, etc. (Yin, 2014; Tjora, 2012). In particular, the document study focussed on the Guideline for using collaborative project delivery methods developed by the Norwegian Contractors Guild, as well as an internal guideline used by the professional public client. The document study was valuable for providing context, especially the 'Internal Guide' gave insight into how collaborative project delivery methods were perceived by the organisation studied.

The approach generated a rich dataset, permitting for the understanding of the phenomenon under study, whilst leaving the participants' perspectives intact, (Leech, 2002). On the other side, the particular approach is demanding for the researcher as it is dependent on the ability to listen, asking sound questions, and follow-up questions (Yin, 2014; Blumberg et al., 2011). Additionally, the in-depth approach implied a small sample size. Thus, the researchers acknowledge that the opportunity to draw broad generalisations from the dataset also is correspondingly limited. In this way, the results must be viewed in the context of the local situations and conditions studied in Norway.

THEMATIC LITERATURE REVIEW

The project management literature uses a variety of terms for defining project delivery methods. Wearne (1989) uses the more generic term contract strategy describing the process of procurement and the organizational and contractual policies chosen for the execution of a project. Expanding upon phenomena of contract strategy, this paper adopts the following definition of a project delivery methods: "*A system for organizing and financing design, construction, operations and maintenance activities that facilitates the delivery of a good or service*" (Miller et al., 2000).

COLLABORATIVE PROJECT DELIVERY METHODS

As stated in the introduction, *collaborative* project delivery have evolved from being a more generic concept (i.e., *Partnering*), into real-world methods such as the Australian *Alliancing* approach (Walker, 2002), and the American *Integrated Project Delivery* approach (Matthews and Howell, 2005). Regardless of the labels used, the same fundamental concept seems to apply, more collaboration between actors and organizations involved in construction projects (Eriksson, 2010; Yeung et al., 2007b). Though the concept has existed for more than 20 years, a consensus regarding the methodology has not been established yet (Eriksson, 2010). Using the term 'Partnering,' Eriksson (2010) identifies the following core components: bid evaluation based on soft parameters, compensation form based on open books, and the usage of start-up workshop, joint objectives, follow-up workshops, teambuilding, and conflict resolution techniques (Eriksson, 2010).

In the lean literature, collaborative project delivery is often labelled *Integrated Project Delivery* (IPD), also referred to as Lean IPD, IPD-ish, and IPDlite. As with the Australian *Alliancing* approach, IPD is an approach aimed at aligning project objectives with the interests of key participants (Matthews et al., 2003). IPD has distinguished itself from traditional project delivery by focusing on the so-called Lean Triangle (Alarcón et al., 2013). Thus, the approach seeks to differentiate itself from today's common project design and management practices through emphasising integration in the organisation and process design and management (Fischer et al., 2014). While the IPD method stands out by using a specific contractual arrangement, Partnering and IPD-ish methods seek to imitate the perceived benefits without conflicting with procurement laws- or standards (Kim et al., 2016). This is the case in Norway, where national procurement laws- and standards still are used in collaborative project delivery. As IPD is gaining momentum in the industry, some case studies have started to emerge from around the world. Rached et al. (2014) studied IPD implementation of IPD methods in the Middle East, stating that some cultural barriers specific to the region need to be taken into consideration when implementing IPD methods. Forero et al. (2015) investigated the implementation in Colombia and found that the main barriers were lack of knowledge and information about the IPD methods. As for China, adversarial relationships, legal issues, and lack of owner willingness were perceived to be the main implementation barriers (Li and Ma, 2017). In Peru, accountability, trust, and respect needed to be strengthened to create real commitments required for successful implementation of IPD (Gomez et al., 2018).

In Norway, preliminary findings indicate that projects could benefit from focusing more on building relationships to create a collaborative project culture (Aslesen et al., 2018). Haugseth et al. (2014) describe collaborative project delivery as a way of facilitating a lean construction process where less time is wasted on disputes, and more value is added to the project. The most common collaborative project delivery method is a so-called ‘samspillsentreprise’ (in Norwegian, it is a variation of IPD), defined as a collaborative delivery method characterised by early involvement of the actors, dialogue, trust, and openness (EBA, 2017). Furthermore, such projects can be organised either as “Collaboration with Design-Build” (in Norwegian, “*Samspill til totalentreprise*”) where the actors collaborate in the development of the project from the programming phase into a pre-project with a target price. Then the contractor takes over the responsibility by signing a Design-Build contract. The second variation, “Collaboration with incentives” (in Norwegian, “*Samspill med incitement*”), where actors collaborate in the development of the project from the programming phase into a pre-project with a target price. Then, the project is carried out as a billing work, with the agreed allocation of potential over/undercutting of the set target price (as a so-called pain/gain share mechanism, see for example Zimina et al. (2012)).

As described above, collaborative project delivery methods are described in the Lean literature. However, reports regarding soft elements seem somewhat underreported. IPD appear to drive cultural change within participating organisations, including influencing behaviour and attitudes, company processes and working practices (Suttie, 2013). However, the transition to more relational-based approaches also appears to create a new set of challenges. Schöttle and Gehbauer (2013) state that there exists resistance against change in the construction industry, supporting the claim by arguing that people are quite reluctant about the implementation of new strategies and processes such as IPD. Also, traditionally trained project manager seems not to be equipped to deal with the relationship-based approaches that involve early involvement from contractor and specialty trades and strong multi-disciplinary collaboration (Seed, 2014). Similarly, Knapp et al. (2014) discuss the critical role of being the owner’s representative and how wrong incentives related to this role can render the entire process to failure. Lastly, IPD projects prerequisite organisations having a culture that easily accommodates change encourages innovation and collaboration, or the other way around, the IPD process may influence the perception of participating organisations (Suttie, 2013).

For example, Kulkarni et al. (2012) state that collaborative project delivery methods produce a more reliable cost outcome for public owners. However, soft elements seem not to be well studied in the context of collaborative project delivery; the literature is often limited to stating that teamwork, transparency, trust, collaboration, communication, etc., are all needed to implement such an approach to project delivery successfully. Furthermore, the literature acknowledges that relationship-based approaches impose specific demands upon project managers and owner’s representatives. Thus, expanding upon the statements made by Suttie (2013), Seed (2014) and Knapp et al. (2014), this paper seeks to fill this knowledge-gap by study project managers working as owner’s representatives on projects using collaborative project delivery methods.

RESULTS AND DISCUSSION

WHY DO CLIENTS USE COLLABORATIVE PROJECT DELIVERY METHODS?

The interviewees stated that the strategic motivation for choosing a collaborative project delivery method was mainly to involve the contractor in an earlier stage, as well as to increase interaction between all parties involved. In theory, this should set the stage for a win-win situation where the contractor can dictate influence (i.e., lower the risk in the construction phase concurrently as the client is more assured that the contractor understand the overall uncertainties related to the project).

It is often stated that collaborative project delivery methods have a positive impact on the project's performance based on the delivery method's ability to reduce conflict (Oakland and Marosszeky, 2017, p. 101-116; Fischer et al., 2017, p. 365-390). The interviewees were somewhat divided, some agreed, while others argue that it provoked more conflict. However, some explained that while greater openness leads to more disagreement "over the table," the fact that the disputes are brought to the table and discussed in a thorough manner is a positive change. This differs from turnkey contracts, where you send and process change messages. However, neither the interviews nor the document study reveals this as the primary motivation, meaning that the focus is not primarily on improving the relationship between actors in the project. This is reflected in a statement from an interviewee, maintaining that his company does not fear conflict since the company operates in a conflict-laden industry. This idea is further enhanced by the guidelines (internal), where it is explicitly stated that a collaborative project delivery method should be implemented to optimize the design process in regards of time, cost and quality parameters. Thus, the guidelines implicitly state that contractual elements are enough for the creation of the needed collaborative effects.

It was identified that there are significant differences within the organization for choosing to use a collaborative project delivery method. On one side is the result-driven motivation regarding involving the contractor earlier in the project, while on the other hand there is a process-driven motivation through changing the management method from *controlling* to *including*.

Although the top management of the organization has general guidelines on how project is to be carried out, the project manager has significant influence as to how to choose to carry them out. This implies that the project manager enjoys a large degree of autonomy when selecting a delivery method, something that naturally creates a large degree of variability regarding project delivery methods within the organization.

For example, in Table 1, we see two project managers and which tools they use to achieve collaboration in the project. Drawing a broad picture, we recognize that project manager 1 wants better and closer collaboration with the participants in the project, while project manager 2, in line with management guidelines, mainly wants to use a collaborative project delivery method to involve the contractor as early as possible. The effect of the different approach may be the most visible in the construction phase in which project manager 2 choose to enter into a fixed price contract with the contractor and perform the construction phase as a turnkey contract. The interviews indicate that there is a trend towards conducting projects with turnkey contracts for the construction phase, i.e., in line with the approach chosen by project manager 2.

Table 1: Project Management approach to collaboration

Project Management approach	Project Manager 1	Project Manager 2
Overall motivation	Closer collaboration	Early contractor involvement
Personal involvement in the project	100%	One of several projects
Contract type	Target Price	Fixed price
Relationship with contractor	Transparent	Clear interface/ boundaries
Collaboration	Open	Tidy/ orderly

WHAT SOFT ELEMENTS CHARACTERIZE A COLLABORATIVE PROJECT DELIVERY PROJECT?

The literature provides an exhaustive list of soft elements needed for successful collaborative project delivery. The project managers stated through the interviews the following as being the most critical soft elements for collaborative project delivery: Top management support, trust, shared goals and motivation, ownership of the collaboration process, attaining the right people and openness. The project managers believed that a successful collaborative project delivery project started with support from top management, then getting the right people, it then goes into credible involvement of all parties, lastly establishing mutual objectives or mutual understanding, and openness between all involved parties. All these soft elements need to be present to build the trust required. Table 2 summarises the critical soft elements identified through the interviews.

Table 2: key soft elements identified

key soft elements identified
Top management support
Trust
Shared goals and motivation
Attaining the right people
Openness/ transparency

The project managers emphasized the importance of establishing trust between actors in the projects. Trust was thereby described as a basis for being able to carry out the desired collaborative processes. The prerequisite was perceived to be a minimum or rather a credible involvement of all parties, to establish a robust decision-making process. Lack of trust was described through situations where the parties argued for decisions that primarily benefitted themselves or their agenda, not the project. Therefore, without establishing trust between all parties, the project lacks a fundamental principle, often referred to as mutual objectives or mutual understanding.

Furthermore, the project managers described some inter-relation between the soft elements. For example, the relationship between competence and trust was explained through an anecdote about an inexperienced assistant project manager that struggled to obtain the trust of the contractor because the contractor doubted the capability of the assistant project manager. Also, the results show that openness requires established shared goals and motivation, as well as project participants with adequate abilities in communication so that proper communication flow are sustained throughout the project. Furthermore, several of the project managers mention the problem that actors are unable to put aside their agendas when developing shared goals for the project. The element shared goals and motivation also depends on a commitment to the collaboration process. The process depends on project participants who want to work for the project as an entity and not just themselves and their mother organization. The project managers maintain that this perspective is person dependent; some seem locked to the traditional way of conducting a project. As emphasised by Cheng and Li (2002), support from top management is crucial for establishing a collaborative environment in every project. However, some of the interviewees stated that top management is often not active or involved on a project level. The establishing of a collaborative environment is therefore almost exclusively initiated- and led by the project manager, giving them an extra dimension of responsibility. This claim is supported by (Larson, 1997), claiming that this is harmful to both the organisation's culture and project delivery.

The study uses the term hard and soft elements. Hard elements are those that are stated in the contract, and that, with- or without intention, contribute towards more collaboration in the project delivery. Soft elements are the so-to-say outcome of either the process-specific tools or methods implemented. Because of this categorisation, another category of elements, "collaborative tools" was introduced, which are those elements that specifically intend to enhance soft elements such as trust, creating ownership, top management support, etc. Thus, the collaborative tools seek to bridge the gap between the contractual (hard) and interpersonal elements (soft). For example, start-up seminars/ workshops are defined as a collaborative tool because it intends to improve the interpersonal relationship between the actors bound to each other in the project through contract.

HOW CAN CLIENTS BETTER FACILITATE FOR THE SOFT ELEMENTS IN PROJECTS?

As revealed, current practice implicates much responsibility for the project manager. While the organisational guidelines for collaborative project delivery provide a broad framework as to how to conduct collaborative project delivery, the project managers are often left to themselves. This results in the project managers being largely entrusted to themselves in the establishment of specific game-rules for their projects. For the organisation, this leads to a large degree of variability from project to project in their collaborative project portfolio. On the positive side, this approach provides project managers with a large degree of autonomy and influence on their projects as they can coordinate the project in a way that matches their personal qualities as managers. On the negative side, the project managers must use a lot of time and resources to plan and design the project rules- and systems for each project. It was also pointed out that if the project rules- and systems rules were not given enough attention in the project start-up and initial phase, this had the potential to impact the project for a long time negatively. Sometimes such issues had to be solved by bringing in external advisors to clarify and facilitate the project rules.

The study found that clients may gain from following-up the project initiation phase, for example through developing a concise framework and guideline for the establishment of the project organization. As stated by Cheng and Li (2002), the most critical factor in the start-up is support from top management. The project managers interviewed indicated that they were not given enough time at the start of the project to discuss and prepare, together with the actors, the form of collaboration needed and wanted. Furthermore, they felt that being just given the formal guideline without proper training, or professional support also contributed negatively. This can be solved using specific collaborative tools such as teambuilding activities, start-up seminar/ workshops or meetings.

Second, the client should implement collaborative tools as an addition to contractual elements to facilitate collaboration. During the interviews, the project managers were challenged about how they follow up on the soft elements. Often the answer was that they did not have specific tools to work with. One of the reasons given to why there is so little focus on soft elements is that they are hard to measure. When asked to provide a rating on trust in their projects using a 5-point Likert scale, some project managers had in-depth answers as to why they gave the score they did while others did not. Some even explained it as a gut-feeling they had. Seen in the light of soft elements existing towards the qualitative end of the spectrum, the lack of a clear explanation seems reasonable.

CONCLUSIONS

This paper contributes to research on Lean Construction by extending the knowledge about soft elements in collaborative project delivery projects. The study shows that a collaborative project delivery method put specific demands on the client organisation, particularly on how they should view and monitors the soft elements.

The study has identified a wide variety of reasons as to why project managers decide to implement collaborative forms of project delivery methods to their projects. Another critical insight is that contractual elements have a significant impact on the soft elements in the project especially regarding which elements being implemented and nourished. Therefore, soft elements need to be viewed considering the project's overall delivery method. The most prominent soft elements were *Top management support, Trust, Shared goals and motivation, Attaining the right people*, and finally *Openness/ transparency*. Soft elements are indicators for the relationship and interaction between actors in the project. Thus, they are needed to create and sustain a continuous relationship between members of the project organization, as is the purpose of using a collaborative project delivery method. A critical success factor lies in whether the client's management has enough resources to continuously follow-up. Therefore, the top management should provide the necessary support to the project managers by providing means to use specific collaborative tools such as start-up meetings and workshops and having practically applicable and easily understandable guidelines. The choice between using the "Collaboration with Design-Build" method as opposed to "Collaboration with incentives" has proven to have a significant impact on the necessity for the project manager's involvement in the project, and thereby, the ability to affect soft elements and project culture. Consequently, such methods should only be chosen if the organisation can assign project managers with the right competence to the project. The right project managers for such projects are those who understand the relationship-aspect of project delivery and have enough time and resources to commit to the project properly. The 'right people' were also described as those who were not too accustomed to the more "rigid" Design-build method. They possess attributes such as being welcoming toward more 'openness' and setting 'common goals.'.

This research has identified that collaboration is carried out on a different basis, which leads to significant differences in project delivery. Consequently, further research can include other clients as this may identify substantial differences in how various organisations emphasise the importance of soft elements and how this promotes project delivery. Additionally, there is a field open to study the effect specific contractual, organisational and technological elements have on the soft elements.

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A CONCEPTUAL EXPLORATION OF A COLLABORATIVE ENVIRONMENT IN THE CONSTRUCTION INDUSTRY WHEN WORKING WITH TEMPORARY SOCIO-TECHNICAL PROCESSES

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ABSTRACT

Previous research on construction projects showed that low productivity characterizes the construction industry, repeatedly explained in terms of the industry's complex and fragmented nature. However, few studies have approached the production problem in terms of the entire industry. This paper consequently elaborates on the challenges and the importance of a collaborative environment in the construction industry because construction is complex, with the main operations produced within temporary and socio-technical systems. Through a conceptual exploration, this paper combines theories on networks, boundaries, open systems, and loose and tight couplings to assesses the consequences of temporality and how integrated project delivery (IPD) tighten couplings in the industry. Finding show that because projects are temporary, they challenge the multilevel connections of networks needed for the industry's evolution to become more productive. However, theories on open systems and tight and loose couplings indicate that IPD enable a cooperative network environment. Thus, the boundaries of cooperative delivery models will enable a stronger link between change and process, industry and projects, needed for a socio-technical process in construction.

KEYWORDS

Collaboration, time compression, loose and tight couplings, socio-technical systems, integrated project delivery (IPD).

INTRODUCTION

In this digital era, productivity growth in the richest countries has not matched investments in technology (Harris 1994; Rotman 2018). The term *productivity paradox* has been used to describe this phenomenon (Macdonald et al. 2000). To address the situation, previous research in the field of productivity has focused on single-level production (Harris, 1994)

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and how to increase productivity and the use of digital tools on individual, group, or organizational levels. A principal assumption has been that increasing productivity in one part of a network will contribute to the network's overall productivity.

Research on construction is often initiated from the project management discipline. The discipline is a fairly young research area, which first has been devoted to a project focus (Önday 2016; Skyttermoen & Vaagaasar 2015). From that perspective, a construction project is defined as the project organization, the process, and the finished product (Eikeland 2001), and for a limited time, the project is an agent of change in the construction firm. Furthermore, to untangle the productivity paradox, the previous decade of research on construction projects has broadened from its traditional focus on static processes to examine projects as an ongoing creation, as a verb not as a noun (Lundin & Söderholm 1995; Skyttermoen & Vaagaasar 2015). Hence, collaboration has become an important topic in the study of projects (Gohary & Karrbom Gustavsson 2012; Lahdenperä 2012), and new, collaboration-based delivery models have been introduced to solve the productivity paradox, leading to a need for collaborative environments in the construction industry.

Koskela (2000) stated that the construction industry has insufficient productivity, mainly due to project complexity: time limits and multilevel interdependent units are complex characteristics that have been discussed for several years (Dubois & Gadde 2002; Koskela 2000). Specifically, Gidado (1996) explained this complexity through a multitude of interactive elements, and this assumption has been studied through theories of organizational boundaries that assistant in a project, but it has not been studied at an industry level, where project boundaries interrelate (Gohary & Karrbom Gustavsson 2012).

Little attention has been paid to the need for collaboration between a construction project and its industry network to increase productivity (Skyttermoen & Vaagaasar 2015). This is partly due to a lack of focus on how organizational boundaries interact in the construction industry's network, and few attempts have been made to broaden knowledge about the link between intervention at one level and the impact on productivity at another level. Strengthening this understanding could provide an important step in transforming the construction industry more collaborative and productive, especially as projects become more complex and therefore work must be accomplished collaboratively.

In response to the need to investigate how the industry can become a collaborative environment, the research question is: *Can we talk about a collaborative environment in the construction industry when working with temporary socio-technical processes?* Two objectives were formulated to address the question raised: (1) assess the characteristics of temporality in the relationship between a project and the construction industry as a network, and (2) view integrated project delivery (IPD) through the boundary theory of loose and tight couplings.

The unit of analysis is a potentially collaborative construction industry, and the study is primarily concerned with coupling the construction industry with a network of projects. The study takes the ontological stance of Critical Realism. Hence, the aim is to elaborate the possibility of a collaborative environment in the construction industry, not to claim that the presented theoretical framework is the only explanation.

METHODS AND SCOPE

The method of this study is a semi-structured literature review guided by the research question. The review started with Scott's (2006) work on organizations and organizing. Theoretical and empirical papers were then identified through in-clouding keyword searches in databases and manually checking reference lists. Given the breadth of topics, the search was later limited to articles that explicitly targeted the construction industry. Limited studies were found on a collaborative environment in the construction industry, leading to a focus on studies from an organizational theory perspective.

A central issue with this study is the extensive literature it briefly covers, limiting the in-depth study of reviewed theories. Thus, the paper is conceptualized as an overview of theories suitable to approach the research question that is raised.

This paper unfolds in the following way: section one addresses the complex nature of construction through projects conceptualized as *temporary* and *socio-technical systems* (STSs). The second section elaborates on the complexity issue by discussing projects in the construction industry, assessing boundaries in the industry, and devoting particular attention to how boundaries affect a collaborative environment. The last part of the paper is dedicated to the discussion and conclusion of the study.

1. THE COMPLEX NATURE OF CONSTRUCTION

Research on the construction industry as a complex and dynamic system has become important to help understand the current problem of low productivity (Baccarini 1996; Bertelsen 2013; Dubois & Gadde 2002; Koskela 2000). Baccarini (1996) stated that the construction industry could be considered the most complex undertaking in any industry, and according to Gidado (1996), that complexity seems to evolve.

Complexity is a widely used but not well-defined term. Baccarini (1996) specified that complexity should not be confused with size and uncertainty. For Gidado (1996), the components that define the complex nature of construction are *"…the employed resources, the environment, the level of scientific and technological knowledge required and the number and interaction of different parts in the work flow."* This study embraces Gidado's (1996) two-part categorizations of complex components: (1) components that originate from the environment and resources employed and (2) components that stem from the interdependence of tasks. The two categories intersect, but the categorization helps to gain a deeper knowledge of each component. The first category can be studied to understand individual tasks in a production process. However, to elaborate on the consequences of projects being temporary and STSs in terms of a collaborative environment in the industry, this study is limited to the second category. Thus, this study focuses on two aspects of project complexity to elaborate on a collaborative environment in the construction industry: (1) projects as temporary organizations and (2) projects as STSs.

1.1 TEMPORALITY IN THE INDUSTRY NETWORK

One way that researchers have coped with complexity in the construction industry is to view the overall industry as comprising permanent and temporary networks (Dubois & Gadde 2002). This study adopts Biesenthal et al.'s (2015) use of the noun *temporality* when describing the condition of being limited in time. Construction firms are permanent, whereas projects are defined as temporary organizations with a start and an end (Biesenthal et al. 2015). Projects are agengts of change in an organization, where the task is to transform an idea into a product in a given amount of time (Skyttermoen & Vaagaasar 2015).

This paper adopts a network perspective to study interacting units in the construction industry (Ruan et al. 2013). For example, network theory can be used to explore the flow of information, knowledge, and materials; it can also determine how trust and cooperation are established between permanent and temporary networks (Scott 2006). How both permanent and temporary organizational boundaries are structured (collaborative or hieratically) determines how resources flow and can be utilized in the overall network. In the second section, this paper focuses the network perspective to literature on organizational boundaries to explain how the connection between different network types affects a collaborative environment in the overall network.

Interaction in alliances has grown as its own subfield in the network approach (Scott 2006). The formation of alliances is an alternative to vertical integration when discussing organizational boundaries. Network analysis helps to understand why construction firms choose their partners, how time affects the relations, and what benefits specific relations create. This could potentially help to elaborate on the consequence of temporality for a collaborative environment in the construction industry.

1.2 A Socio-Technical Environment

Because Gidado (1996) stated that technological knowledge and interdependency in a workflow contributes to complexity in construction, this complexity can be explained with an STS approach grounded in system theory. The definition of an STS is that the interactions between people and technology introduces a social aspect (Coenen et al. 2009). Hence, one's understanding of project performance can only improve if social and technical aspects of a complex network are treated as interdependent parts.

The construction industry is transforming with the digital era (Macdonald et al. 2000). The most challenging problems the industry faces today are at the intersections of human behavior and engineering innovation. Baxter and Sommerville (2011) stated that a cultural shift among engineers in the industry must occur if STSs in projects are to succeed. Today, the connection between change in management in the industry and engineering in a project process is too weak. Technology requires collaborative work. Despite this, the literature has described the industry in terms of two distinct processes: one for workflows in a project, another for management change in the industry. The lack of a dynamic and jointly developed process could potentially hinder productivity.

2. PROJECTS WITHIN THE CONSTRUCTION NETWORK

2.1 Boundaries between Permanent and Temporary Networks

Organizational theorists have defined organizational boundaries as an object-like frame used to manage the organization's relationship with its environment (Gohary & Karrbom Gustavsson 2012; Katz & Kahn 1978). When studying the construction network, boundaries exist for teams, temporary organizations (projects), and permanent organizations (firms) (Scott 2006). Hence, in this paper the term *boundaries* must be understood in the context it is mentioned.

Organizational boundaries serve a variety of purposes in the construction industry: as buffers or bridges between permanent and temporary organizations (Gohary & Karrbom Gustavsson 2012). As complexity increases, one should not view boundaries as a by-product of the organization but as a frame that evolves through negotiation and interaction (Kerosuo 2006).

There are different approaches to the study of boundaries within and among organizations (Gohary & Karrbom Gustavsson 2012). Kerosuo (2006) has combined four perspectives when studying boundaries in action on a micro- and a meso-level. One perspective studies boundaries to explain institutional change (Scott et al. 2000), another through organizational learning (Wenger 1999). Wenger (1999) offered another approach, focusing on actors that establish boundaries through the establishment of mutual engagement, and Long (2001) explored how to chain an organization's micro- and macro-levels via actor theory.

To bridge the meso- and macro-levels of construction projects and the construction industry, respectively, this study uses the open system theory. This theory explains that the conditions of a system and its environment are closely connected (Scott 2006). For example, a construction project cannot be collaborative in a non-cooperative environment. Katz and Kahn (1978, p.242) suggested two approaches to the open system: (1) *"…the problems of organizations could be viewed as a function of the type of structuring in which they occur"* and (2) studying the interdependence of an organization and its environment.

In this study, open system theory is limited to the theory of loose and tight couplings in the construction industry. Loose couplings have been used to understand the productivity paradox within industries similar to construction—industries with significant investments in technology without consequential production growth (Scott 2006).

Dubois and Gadde (2002) used the theory of loosely coupled systems to study how the relationship between permanent and temporary networks implicates productivity and innovation in construction projects. In this study, the theory is used to explore collaboration. Dubois and Gadde (2010) stated that projects are the actions that connect construction firms. Within projects, teams are tightly coupled, whereas firms are loosely connected through project (organizational) boundaries. In their study, they also argued that mixed couplings negatively affect the industry overall, because interactions in projects do not provide long-term orientation or learning.

Orton and Weick (1990) have the best-known definition of loose and tight couplings when describing the degree of interdependence among organizations. They describe that tight coupling implies direct dependency between components. Behavior thus influences the network in an immediate, constant, and significant manner. However, a consequence of loose couplings, confirmed by Scott (2006), is that increased productivity from tight couplings does not necessarily equate to increased overall productivity in the industry.

2.2 Integrated Project Delivery

IPD is among the most common collaboration-based delivery models designed for construction projects (Lahdenperä 2012). With IPD, project success occurs with a contractual agreement between principal actors (e.g., owners, architects, builders, consultants, and contractors) who are involved early; who make collaborative decisions; who jointly offer innovation and control as well as respect, trust, and transparency; and who share risks and rewards (Cohen 2010). In this paper, project success is defined as increased project productivity, ref. the definition of the productivity paradox.

This study adopts El Asmar et al.'s (2013) definition of a project delivery model: a system that determines the relationships between stakeholders through the timing of their engagement in a project. Figure 1 presents two delivery models: the traditional design-build delivery and the IPD model. As illustrated in Figure 1, design-build models are designed with organizational boundaries working in favor of the firm (marked with a clear line), contributing to a hierarical relational structure. In contrast, stakeholders working in IPD has a joint organizational boundary where traditional boundaries of the firm gets less significant (stipled lines). Thus, according to Cohen (2010), relations in IPD is dynamic.

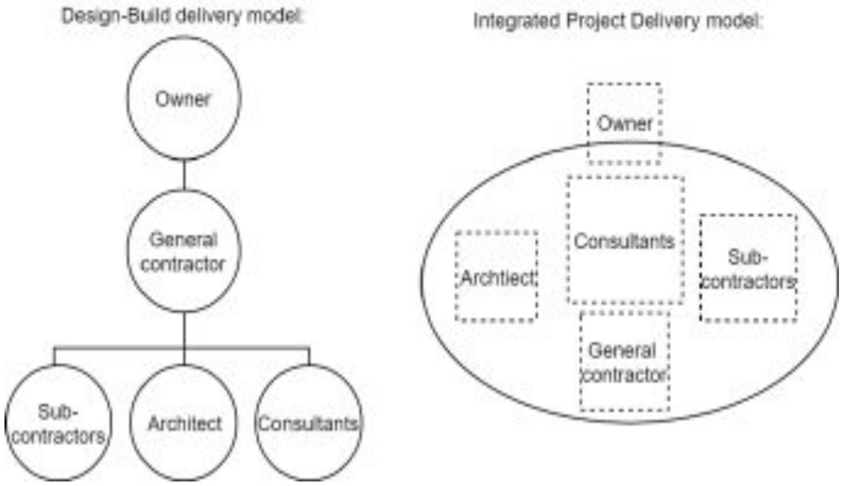

Figure 1: Differences in the structure of design-build and IPD models (free from El Asmar et al. 2013, p.2).

IPD has been described as an answer to the need for collaboration and the room for innovation in the construction industry (Lahdenperä 2012) because it deals with interdependence through alliances (Scott 2006). In addition, IPD is characterized with advanced communication technology. Thus, IPD requires actors to work outside the boundaries of their traditional roles as constructed in the design-build delivery model. However, the extent to which this collaboration-based organizational boundaries affects the overall construction industry remains unclear in the literature.

3. DISCUSSION

Rotman (2018) stated that the richest countries in the world are struggling with low productivity, and Koskala (2000) claimed that this is also a reality in the construction industry. Hence, the industry must change to continually prosper. To face this challenge, Harris (1994) noted heavy investments in technology. However, based on insights from this paper, technological investments are not enough; the industry must stimulate work patterns that extend technological innovations from temporary projects to form permanent innovations for the entire industry

The aim of this theoretical exploration was (1) to assess the characteristics of temporality in the relationship between a project and the construction industry as a network and (2) to view IPD through the theory on loose and tight couplings. The main discussion is whether a collaborative environment can be created in the construction industry when the main operations are produced within temporary organizations and STSs.

3.1 The Link between the Industry and Temporary Projects

The first question to be addressed in this discussion is why research has tended to separate the temporary project from the permanent network of the construction industry. When elaborating on the coupling between permanent and temporary components, the dominant research model that separates temporary projects from the permanent construction industry makes little sense. Previous attempts to increase the productivity of construction projects have been limited to the traditions of project management theory. Thus, researchers have understood projects without consideration of the projects' environment (Harris 1994). Skyttermoen and Vaagaasar (2015) discussed whether this contributes to a gap in knowledge. Nevertheless, the link between the permanent construction industry and temporary projects has received little attention from researchers. This may be due to the fact that project management theory is still new (Önday 2016), and thus nuanced understandings of tighter collaborations have yet to occur for that theory.

In addition, Dubois and Gadde (2002) argued that to cope with the complexities of the construction network, the industry has been divided into permanent and temporary networks. This approach compliments that of project management theory. Gidado (1996) explained the need to understand the construction industry as a complex system and to categorize the complexity in ways that are not overwhelming. However, the need for manageable pieces does not necessarily require the omission of a project's environment.

Gidado (1996) argued that because construction projects are agents of change, working within a limited timeframe, construction projects involve complex processes. Based on this logic, the structure of construction projects today may be too complex for a multilevel understanding. Nevertheless, Gidado's arguments about complexity contribute to the assumption that temporality itself is not the cause of a project's focus; but the organizational boundaries that are working in the construction industry as a network. Furthermore, despite Gidado's separation of complexities, he described the components as interacting. Hence, links between temporary and permanent networks must be studied. If complexity is to be handled in a collaborative environment, boundaries should be structured as bridges not barriers (Gohary & Karrbom Gustavsson 2012).

According to Kerosuo (2006), research on boundaries often differentiates between macro- and micro-levels. When addressing the productivity problem from an open system approach, an organizational problem can be explained through its environment. Katz and Khan (1978) argued that the relationship between an organization and its environment is interdependent and must therefore be understood together. The fact that projects are temporary hinders the integration of permanent organizations among the project's production processes.

From a short-term perspective, it remains unclear if conceptualizing the construction industry as a collaborative environment is possible. Harris (1994) exposed the assumption among researchers that increased productivity at one level will contribute to the overall productivity at the level of the environment. This assumption could contribute to the marginalization of research needed to understand multilevel networks.

Undoubtedly, multilevel networks contribute to the construction industry's complexity. According to Baccarini (1996), the industry will become even more complex. Thus, one must approach the productivity paradox from a multilevel perspective. Furthermore, the complexity of multilevel networks in the construction industry must not be confused with the complexity of a single project. Otherwise, Baccarini's warnings not to confuse size and uncertainties in a network will go unheeded.

3.2 DOES IPD TIGHTEN THE COUPLING IN PERMANENT NETWORKS?

Dubois and Gadde (2002) stated that a combination of loose and tight couplings are problematic for the construction industry because that mixture benefits a temporary project more than it benefits a permanent industry that needs to learn from its projects. Moreover, Scott (2006) elaborated that network theorists have taken greater interest in the interactions between alliances. Instead of using vertically integrated change, alliances can tighten couplings when behavior influences the network immediately, constantly, and significantly. Based on these statements, there is a need to address the general interaction structures established in the industry today.

Based on the literature review in this paper, IPD has emerged as a result of the need to tighten the industry's couplings due to socio-technical developments. Instead of accepting a fixed model of complexity in the construction industry, IPD researchers have stressed that early and dynamic boundary definitions can increase productivity (Cohen 2010). Cohen also characterized IPD-structured projects as joint developments with boundaries negotiated through interactions, as Kerosuo (2006) recommended.

Boundaries for collaboration-based delivery can be more dynamic than general contracting, as evident in Figure 2. This figure combines Figure 1 with boundary theory and Gadde and Dubois's (2010) theory on loose and tight couplings, illustrating, first, how boundaries develop as a product of collaboration in IPD and not as the static frame of a project owner, as in general contracting. Second, Figure 2 illustrates the different evolutions of strength in relations. Much attention has been paid to the separation of design and construction in the field of construction delivery models (Cohen 2010; Lahdenperä 2012). As Figure 2 shows, IPD can create a more stable connection among the primary actors in a project (the cooperative relations get ticker with time).

In addition, STSs introduce a need for greater collaboration in the industry. Coenen et al. (2009) argued that digital transformations add a social aspect to a project's processes. Sommerville (2011) extended this discussion to a macro-level and stated that the industry must change to harness the potential of technology. Thus, relationships in the industry must be tighter to better correlate technological change and workflows. The tighter couplings are provided in IPD, as evident in Figure 2. The project boundary is a joint development, which opens up for a flow of information and technological change.

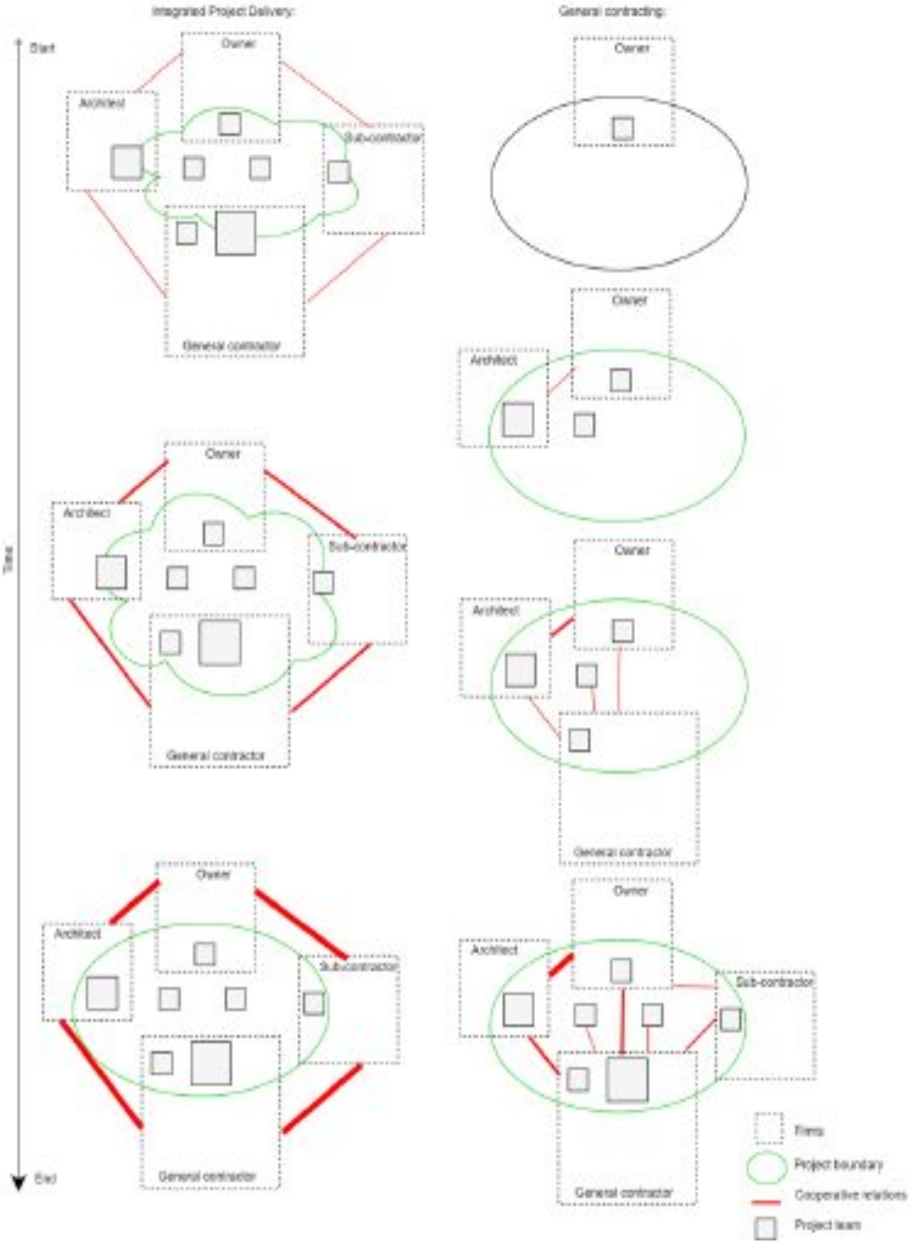

Figure 2: Strength of relationships and boundaries in IPD and general contracting.

An unanswered question in the theory of networks is whether collaboration is more important than structure when discussing multilevel interactions. This question must be answered. Because boundaries play an important role in the construction industry (Gohary & Karrbom Gustavsson 2012), researchers have argued that collaborative delivery models blur boundaries in ways that induce engagement (Cohen 2010). But what happens to these relations when the projects end? Few studies have addressed the impact collaborative projects have had on the construction industry's permanent network. If tight couplings lead to more interdependence, coordination, and hopefully more information flows, then tight couplings might extend into the larger network when a temporary project ends. One possible effect could be static collaborative patterns among firms in the industry. This effect can create hinders for new firms to establish in the industry.

CONCLUSION

This exploratory paper elaborated on new ideas about the challenge and the importance of collaboration as a result of project temporality and projects as STSs. Theories on boundaries were discussed to demonstrate the possibility for collaboration in the construction industry.

This article raised the following question*: Can we talk about a collaborative environment in the construction industry when working with temporary socio-technical processes?* Theories indicate that the combination of loose and tight couplings favor short-term projects but not necessarily the construction industry's overall network. Because projects are STSs, a closer connection must occur between a project and its environment to better link change to the workflow. Couplings are tightened in projects that use IPD, even though temporality still makes it difficult to establish long-term relationships in a collaboration-based construction industry.

Theoretical implications: The contribution to knowledge lies in the deepening of understanding if collaboration-based delivery models (e.g. IPD) could provide tighter couplings in the construction industry.

Further research: This study was a literature review and was thus not the full answer to the question that it raised. Future research must address how negative effects of temporality can be handled, so that the industry gain from increased productivity as a result of the tightened couplings of IPD. In addition, the theoretical framework created in this paper needs to be brought down to the level of actual practice, interviews and observations. This is where new theories can be applied. If the ideas in this paper were to be strengthened through empirical studies, they would have significant managerial implications.

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DOES CHOOSING BY ADVANTAGES PROMOTE INCLUSIVENESS IN GROUP DECISION-MAKING?

Annett Schöttle[1], Randi Christensen[2], and Paz Arroyo[3]

ABSTRACT

In a construction project, decisions should be made by the team member or group which is best prepared to handle the decision. Often this is not the case due to hierarchical structures, time pressure and a lack of trust. Previous work showed that a significant number of female Lean practitioners found their ideas and input were not taken seriously. Empowering people in an organization and in the field means to include them in the decision-making process. Choosing by Advantages (CBA) is a structured multi-criteria decision-making method that bases decisions on the importance of advantages among different alternatives. In CBA advantages are anchored to relevant facts, so decision-makers can make a sound and inclusive decision. In previous work it was reported that CBA is transparent and traceable for people not involved in the decision-making process. In conclusion, the authors found evidence that CBA promotes inclusiveness to overcome groupthink and promotes psychological safety, but no direct evidence was found to overcome gender bias.

KEYWORDS

Choosing by advantages, collaboration, decision-making, inclusiveness, psychological safety.

INTRODUCTION

The construction industry is coming to rely more and more on integration between different parties – such as architects, owners, general contractors and subcontractors - so that they work as one team on a project (Matthews and Howell 2005). The integration of the different team members needs a high level of coordination and structure across the various processes such as decision-making. By reviewing several different studies, Collins and Guetzkow (1964) generalize that, in comparison to individual decision-making and synthesized[4]

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[4] This means that each group member first makes their own decision, and then these are discussed in the group and a final overall decision made.

group decision-making, interactive group decision-making results in higher quality decisions, because of higher resource availability, as more and better alternatives can be discovered. On the other hand, skilled individuals could get slowed down in a group, because they have to listen to less skilled group members. Furthermore, the more people are interactively involved in the decision-making, the more effort and time is necessary to decide (Collins and Guetzkow 1964). Another fact that should be considered is the relevance of social motives such as acceptance or relationships that impact the individual's behaviour when working in a group (Collins and Guetzkow 1964). Construction projects contain a series of team decisions, including strategic decisions, because they affect different parties. Although decision-making is key for project progress, group decision-making is not thoughtfully designed in projects (Schöttle et al. 2018). Often responsibility, structure, documentation, reporting and time track are not defined upfront, making it difficult for the team to decide and receive decisions on time. Schöttle et al. (2018) point out how a decision-making process should be designed by analyzing four projects, and recommend applying Choosing by Advantages (CBA) as the decision-making method in diverse groups. CBA is a multi-criteria decision-making method that bases decisions on the importance of advantages among different alternatives. In CBA, advantages are anchored to relevant facts, which are called attributes of the alternatives, so decision-makers can make a sound decision (Suhr 1999). CBA presents several benefits in the literature, but how it affects inclusiveness for group decisions has not been studied.

This paper will analyse how to include the different team members when making group decisions by focusing on three issues: (1) avoiding groupthink, (2) promoting psychological safety, and (3) hearing ideas from gender-diverse groups. The research question is therefore: Does CBA promote inclusiveness to overcome group thinking, promote psychological safety, and avoid gender bias? In this paper, in order to answer the question, first the literature is analysed to understand the three issues. Second, a combination of case study and action research is used to collect data ex-post and ex-ante of the implementation of CBA. Third, the findings from action and case study research are jointly discussed based on the findings from the literature. Finally, we conclude in the last section by reflecting on the limitations of this study.

LITERATURE REVIEW

INCLUSIVENESS IN DECISION-MAKING

According to the Cambridge Dictionary, inclusiveness is "the quality of including many different types of people and treating them all fairly and equally". In group decision-making it is important to include the right team members in the group decision-making (Collins and Guetzkow 1964). Shore et al. (2011) define inclusion as "the degree to which an employee perceives that he or she is an esteemed member of the work group through experiencing treatment that satisfies his or her needs for belongingness and uniqueness" (p. 1265). The individual perception of inclusiveness depends on workplace climate, leadership and human resources practices (Shore et al. 2011; Randel et al. 2016). In terms of leadership, Nembhard and Edmondson (2006) define leader inclusiveness as "words and deeds by a leader [...] that indicate an invitation and appreciation for others' contributions"

(p. 947). Leadership inclusiveness has a tremendous impact in creating an environment where the individuals of the decision-making group feel included. Shore et al. (2011) argue that groups which value and respect diversity (high belongingness) as well as appreciate diversity as a resource (high value in uniqueness) have a high degree of inclusion. In comparison, if belongingness and the value of uniqueness are low, exclusion results (Shore et al. 2011). According to Patrick and Kumar (2012), managing diversity successfully "can lead to more committed, better satisfied, better performing employees and potentially better financial performance for an organization" (p. 1). Given the context of construction projects around the world, with a high concentration of males in decision-making roles and hierarchical organizations, the authors decided to study inclusiveness focusing on three issues: (1) avoiding groupthink, (2) promoting psychological safety, and (3) hearing ideas from gender diverse groups. The following sections present a literature review on these issues.

Groupthink

There are many decision-making biases identified in the literature, such as status quo tendency, halo effect, anchoring, group thinking, sunk cost, confirmation bias, social bias, cognitive bias, gender bias and noise, leading to poor decisions. Groupthink is especially relevant to the topic of inclusiveness because it is caused by a lack of diverse thinking. Janis (1982) analyzed the group cohesiveness and the decision-making of a group and initiated the term groupthink as the "mode of thinking that people engage in when they are deeply involved in a cohesive in-group, when the members' striving for unanimity overwrite their motivation to realistically appraise alternatives courses for action" (p. 9). Ellis and Fisher (1994) describe groupthink similar to Janis (1982), as "the phenomenon that occurs when members of a highly cohesive group disregard [alternatives]" (p. 308) to maintain unanimity. It is the pressure to conform to norms of the in-group (Janis 1982; Ellis and Fisher 1994), a "collective pattern of defensive avoidance" (Janis and Mann 1979, p. 129). Thus, it is the tendency of concurrent seeking, the avoidance of disagreement and argumentation (Janis and Mann 1979, 1982; Johnson and Johnson 2009), it leads to illusion, and causes mistakes that easily could be avoided (Forsyth 1990). In consequence, defective decision-making results, because of mindless cohesion, pressuring nonconformists, a failing to reward critical thinking, a tendency for justification (Ellis and Fisher 1994), self-censorship of deviations, stereotyped views, protection from adverse information (Janis and Mann 1979) and so selective bias in using facts, incomplete check for alternatives and factors, no consultation of experts (Janis 1982), insufficient risk assessment, poor data collection and information processing, and the failure to participate (Johnson and Johnson 2009). According to Janis and Mann (1979), the root causes of the listed symptoms besides the previous named cohesiveness[5], are insulation of the group

[5] Cohesiveness is the strongest root cause that leads to groupthink. It emerges when members of the group are friends, have positive attitudes concerning the group, high identification with and commitment to group values and goals (Forsyth 1990).

("insulated from criticism" (Forsyth 1990, p. 299)), directive leadership, decisional stress, and a lack of methodical procedures for assessment. If only one root cause exists in a group, the group is not adopting groupthink, but "if two or more of these factors are present […] the likelihood of groupthink becomes much greater" (Forsyth 1990, p. 301). Thus, decisions are not analyzed critically (Putnam and Stohl 1996), because discussions regarding disagreement just disappear (Forsyth 1990), and contingency plans are not provided (Janis 1982). Avoiding group thinking is key for making good decisions in construction projects.

Psychological Safety

Lack of psychological safety occurs when project team members are unwilling to speak up freely, because of disapproval, negative consequences, or the concern that they will be seen as incompetent (Edmondson 1999; Nembhard and Edmondson 2006). The reactions they think they will receive are based on a lack of feeling respected and a lack of confidence (Edmondson 1999). This also impacts learning from failure and makes it obvious that psychological safety and learning from failure are strongly related to each other (Hirak 2012). Nembhard and Edmondson (2006) found out that leader inclusiveness can have a positive impact on psychological safety in teams. Hirak (2012) analyzed the correlation between leadership inclusiveness and psychology, gathering data via a survey in a large hospital, and confirmed that leaders with a high level of inclusiveness create a working environment with high psychology safety. The results were confirmed by Randel et al. (2016). Promoting psychological safety is key for decision-making in construction projects.

Gender Diversity

In the decision-making literature it is argued that, the more heterogeneous/diverse a group is, the more effective the decision will be, because different perspectives will be discussed, and incorrect answers not accepted (Johnson and Johnson 2009). Nevertheless, there are two sides of the coin. On the one hand, diversity can increase the group productivity, because of heterogeneous information and higher problem-solving potential. On the other hand, it can decrease the productivity, because of interruption and interpersonal conflicts (Collins and Guetzkow 1964). Gender diversity is linked to the question of whether a bias exists in a group and if it affects the group performance. Although respect for people is one cornerstone of Integrated Project Delivery (IPD), just last year, the first International Group for Lean Construction (IGLC) paper was published in the topic of gender and inclusiveness. For the paper, Arroyo et al. (2018) collected data using an online survey to understand if gender bias occurs in construction projects that apply Lean. The authors found that in general women feel more affected by positive or negative gender bias in comparison to men. Furthermore, almost 63 % of the woman reported that their ideas are not taken seriously. In depth, women commented that they were: ignored/not listened to, spoken over/interrupted, men repeated their idea and got support/credit for it, and not recognized for their idea. Moreover, 71% of female Lean practitioners reported that their ideas are not taken seriously. This might be due to their awareness of questioning the status to improvement (Arroyo et al. 2018). Reflecting on the results almost one year later, we argue that, because women's ideas are not taken seriously, their opinions might not be taken seriously either during group decision-making in the owner, architecture, engineering and construction (OACE) industry. In reference to the literature, our argumentation can be reinforced. For example, Johnson and Schulman (1989) conducted an experiment with students from UC Santa Barbara to analyze the effects of gender proportion in group decision-making. The students were divided into 85 four-person groups (15 only male, 16 only female, 15 with 3 men and 1 woman, 19 with 3 women and 1 man, 20 with 2 men and 2 women). Then a problem was handed to the groups on which they had to decide as a group within 30 min. After they had made the decision, each member had to evaluate every other member– including him or herself – regarding task and socioemotional activity. The results showed that both men and women experienced gender bias when their sex was in the minority; the effects were to the disadvantage of the women and to the advantage of the men[6] (Johnson and Schulman 1989). Elsass and Graves (1997) argue that the different communication style of women in a male-dominated group can "lead to underestimation of their capabilities" (p. 955) and a gender-related exclusion. Therefore, we argue that gender-diverse decision-making groups will make better decisions in construction projects.

CHOOSING BY ADVANTAGES

CBA is a multi-criteria decision-making method developed by Suhr (1999) that is based on a logical and clear structured framework and uses well-defined vocabulary to differentiate between alternatives (Schöttle and Arroyo 2017). The high degree of transparency that CBA provides help teams understand each other's perspectives and preferences, and makes it easier to achieve consensus during decision-making based on holistic perception of value and not sub-optimization, which aligns with the Lean idea of making decisions slowly by consensus and implementing rapidly (nemawashi). Different studies have already shown that CBA leads to constructive conversations, less frustration during decision-making, confidence about the decision result, and is traceable for a not involved party (e. g. Arroyo et al. 2017; Schöttle and Arroyo 2017; Arroyo and Long 2018, Schöttle et al. 2018). Moreover, transparent documentation of the decision helps to create a shared understanding and trustful environment (Schöttle et al. 2018). The literature has not yet studied whether CBA encourages inclusiveness with regard to the three issues we have studied in the literature. This paper aims to fill that gap.

[6] For women the top score in task activity decreased with a decrease in number of women in the group. For men this only happened when one man was in the group, but the score was still above average. In comparison, women scored below average when they were the only woman in the group. As soon as men formed the majority in the group, the top score was unaffected. In the case of the lowest score, women achieved lower scores than men regardless of the gender composition. In the minority groups, the lowest men's score was significantly higher than the lowest women's score. Only in the homogeneous gender groups was the lowest score not significantly different. In the case of the socioemotional activities, the highest and lowest scores did not show any evidence of being impacted by gender.

RESEARCH METHODOLOGY FOR CASE STUDY

The authors of this paper used different research approaches for the same project being studied. Action research was used to identify issues and intervene in the project based on findings (Dickens and Watkins, 1999). The action research involved surveys, discussions, meeting evaluation such as Plus Delta, and observations to improve the CBA training and facilitation. To determine the level of knowledge regarding Lean methods and tools such as CBA, a survey (Lean Awareness Survey) was sent to 267 members of the project team in November 2018. One hundred and sixty team members fully and 17 partly completed the survey. The main focus of the survey was not CBA, but the answers were used as indicators to improve the CBA implementation. In February 2019 another survey was handed out to the participants after a CBA session to deeply investigate if there is a difference regarding inclusiveness during decision-making when CBA is used as decision-making method or not, this time the authors used case study research approach for explanation building (Yin 2014). This survey focused on the topic of inclusiveness in decision-making by comparing decisions made with or without CBA (inclusiveness survey) by asking closed-ended and open-ended questions. Out of 15 participants, six completed the survey. The results of both surveys were then discussed with 10 trained CBA facilitators for a more general discussion on how well the surveys matched their perception and to incorporate this new knowledge into practice. Additionally, the CBA facilitators were encouraged to evaluate each CBA workshop with the participants in a Plus Delta exercise to improve practice. This feedback was also shared amongst the facilitators and is entered as data in this paper.

CASE: LOWER THAMES CROSSING

Lower Thames Crossing is a £5bn tunnel project beneath the River Thames east of London connecting Kent, Thurrock and Essex (north to south). The crossing under the Thames will be the longest road tunnel in the country and one of the largest bored tunnels in the world with a diameter of 16 meters. So far, it is the largest single road investment project in the UK. The Lower Thames Crossing will be open for traffic in 2027 and is currently in the preliminary design phase. During the preliminary design phase more than 650 people have been working full or part time in the integrated project team. The integrated design team consists of employees from the client, Highways England, and a Joint Venture between the engineering companies Jacobs, Arcadis and COWI. The gender split in the project team is 61% male, 27 % female, 11% prefer not to say and 1% responded ‘other’.

IMPLEMENTATION OF CBA

CBA was first initiated by the Lean manager in spring 2017 to assess a small set of complicated design decisions. The decisions consisted of several technical alternatives and required a cross-disciplinary assessment. During decision-making the decision-makers perceived CBA to be more efficient in comparison to decision-making in which CBA was not applied. More value-adding ideas were included, and the result of the decision was widely accepted by the team. Thus, these experiences led to the integration of CBA into the governance structure for the interdisciplinary assessment of alternatives.

Training of CBA facilitators started in spring 2018. To have a diverse facilitation team, facilitators were selected from different disciplines. By March 2019 the project had 15 trained CBA facilitators. In addition to the facilitation of the CBA workshops itself, facilitators identify decisions that need cross-disciplinary review and support an inclusive and structured process based on CBA. For complicated decisions or decisions which include several disciplines, it has been shown that three facilitators are needed in order to: (1) ensure progress, (2) make sure everyone is heard, and (3) to capture notes on the decision, actions, assumptions and risks. Until now (January 2019) approx. 25 CBA decision-making workshops have been held with support from one or more facilitators and an unknown number of decisions have been made without facilitation.

PROJECT FINDINGS

In the Lean Awareness survey, 26% of respondents reported that they have participated in one or more CBA decisions. Some of the comments given in the survey mentioned CBA: CBA workshops are great for gaining consensus across the project; CBA resulted in better quality of the decision, better quality, efficiency, togetherness; shared objective; better culture, transparency, and integrity; recognition of expertise. Workshop evaluations (Plus Delta) showed that participants feel that everyone is heard, and that juniors found it easier to speak up compared to seniors. There is no directive leadership in the room during CBA workshops as everyone is seen as equal and influence depends on the knowledge the individual brings to the table. For some senior participants this can at first be challenging, while others feel empowered by this change of hierarchy and influence. Introvert personalities have pointed out that they appreciate being given the opportunity to prepare before presenting and discussing the issues. This preparation within their own discipline also mitigates the risk of groupthink where one influential voice in the room could impact the decision without having documentation to back it up.

The inclusiveness survey was conducted based on a single CBA decision and contained an equal number of participants regarding female and male genders. As the number of respondents is small, the results can be seen only as indicative. The CBA experience of the respondents varies, from experienced CBA facilitators, CBA facilitators in training and participants in CBA decision-making. The respondents mentioned the following pain points of decision-making in general[7]: poor communication, lack of transparency, lack of clarity and common understanding, lack of technical understanding of decision-maker, very poor upward communication of pressing issues, lack of focusing on solving pressing issues, too much focus on meaningless reporting, poor documentation of exact decisions and the next steps to implement the decision, not identifying all appropriate stakeholders, missing inclusiveness, content quality against time, and not getting consensus on what the key criteria are, and their importance. The pain points go along with the situation where the participants agree to a group decision although they actually disagree with it. For those cases participants stated that they agreed, because it was easier to go along with the decision

[7] These statements reflecting on difference between CBA and traditional decision-making which is not clearly defined. The results do not conclude anything about the quality of decision-making in general on the project.

rather than admit that they did not understand it or that not all the information had been shared to enable them to do so. Furthermore, one survey participant stated that s/he just trusts others to make the right decision, because they have more experience. Based on the comments, it can be presumed that the decision-making was not transparent and understandable. Furthermore, disagreeing but accepting decisions when they make sense, leads to the question of the decision quality. One-third of participants answered the question of how easy it is to accept a decision when not using CBA with “don't know” and two-thirds with “moderate difficult”. This is also an indicator for the lack in understanding due to communication, documentation or information sharing, and for a missing feedback loop.

Table 1: Overview of the inclusiveness survey respondents

Gender	Project position	CBA experience degree
Male	Workstream management/lead	Facilitator of and participant of a CBA decision-making session
Female	Workstream management/lead	Participant of a CBA decision-making session
Female	Workstream management/lead	Participant of a CBA decision-making session
Female	Engineer/Consultant/Senior practitioner	Facilitator of a CBA decision-making session
Male	Engineer/Consultant/Senior practitioner	Participant in CBA training and CBA decision-making session
Male	External contractor	Participant in CBA training and CBA decision-making session

The results show that when not applying CBA people did not speak up as they do when using CBA (see Table 2). The survey participants mentioned that this is an issue of having the opportunity to be present during the process and having the feeling that their contribution is relevant. This goes along with experiences such as being ignored, not being heard, being spoken over or interrupted the survey participants had when CBA was not applied. These experiences influence the team member in the behaviour of speaking up. Furthermore, missing a logical frame and transparency results in a lack of interaction with each other’s perspective as well as a missing facilitator that takes care of including every member of the decision-making group, especially regarding age bias. In comparison, when using CBA, survey respondents commented that they felt free to speak up, because the process encouraged and promoted speaking up, as well as including participants in group decision-making. The survey respondents also discovered that during the CBA session everyone involved spoke at least once and mainly for the same amount of time. This means that participants have a fair chance to speak up. One of the survey questions asked if the project provides an inclusive work environment regarding gender. All survey participants agreed that this is the case. Interestingly, only females reported that others repeated their own ideas and got support/credit for their ideas and that they do not feel they are recognized for their ideas when not using CBA. This aligns with the paper by Arroyo et al. (2018) and could be a sign of gender bias. Additionally, respondents agreed that the facilitator invited them to provide ideas, asked for the input of all team members, encouraged the members of the group decision-making to take the initiative, and valued the options of others equally. Thus, the facilitator played a key role in helping to include all group decision members during the CBA session.

Table 2: Summary of the inclusiveness survey results

	Without using CBA	Using CBA
Speak-up freely	– Variation from occasionally to always	– Yes
Respect regarding views	– High variation: somewhat agrees to somewhat disagrees	– Yes
Experience	– Ignored/Not listened to – Spoken over/Interrupted – Not being included – Females reported that others repeated their idea and got support/credit for it, and they were not recognized for their idea	– Respect among participants – Participants listen to each other – Supports speaking up – Participants' valued input – Other people's perspective could be understood easily (mostly very easily)

DISCUSSION

Traditionally in the construction industry, decisions are perceived to be made subconsciously and based on a few influential voices. It is a part of the culture to make decisions quickly and confidently. The pain points of the respondents show clearly that the usual decision-making suffers, because of not having the right people in the room, a lack in communication and information sharing, and a misunderstanding of perspectives during and after the decision-making, which cause problems in understanding the decision result. The logical structure and the transparent documentation through the agreed process help the team to avoid group thinking and to create psychological safety, because the team creates awareness regarding interaction and their effect on decisions. Also, different perspective and inputs were valued when using CBA. As one respondent stated, CBA "promotes inclusivity by nature of the more open invitation process". Furthermore, participants of CBA sessions have a strong learning curve in preparing the decision, because they are aware of issues impacting the decision. It was also observed that the engagement in CBA was higher in the second session. Furthermore, CBA impacted other processes such as value management assessments. Having dedicated resources for facilitation might lead to more inclusiveness independent of the decision method in play. By having a structured process that is recognized, the decision owners can resist the urgency to take the decision on the spot in order to meet a deadline. The facilitators in the room also allow the decision owner to participate on equal terms. This also allows the disciplines to prepare arguments, which gives the opportunity to disagree about the most advantageous outcome of the decision and still reach a shared recommendation. One unique feature of CBA is that discussion is not about which factor is more important, like safety, time, quality, etc.; the discussion focuses on what relevant differences exist between the alternatives. This avoids many conversations when, for example, a discipline lead argues that his or her discipline is the most important when in fact there is no difference in how the alternatives perform.

At this point it cannot be stated whether CBA helps to overcome gender biases, and future research needs to address this. However, in discussions, the CBA facilitators keep mentioning that CBA is a better way than having no agreed decision process. The impact of group cohesiveness is also unclear. What can be said is that, because of different group constellations in decisions, the impact must vary from group to group. The inclusiveness survey as well as the input from CBA facilitators could be biased towards CBA, as this was the only known decision method in the project. The negative feedback on traditional decision-making should also be considered carefully as this might be the result of the specific decision in play and not a general picture of how well CBA works. Even though the results from the data analysis provide an insufficient dataset to conclude on inclusiveness, it can be used indicatively to point to future research questions.

CONCLUSIONS

Inclusiveness is key to proceeding effectively during decision-making and to get a high-quality decision. CBA provides a strong structure and a logical manner that helps to understand the perspective of others, and indicates if information is missing or unclear. This helps to achieve a higher degree of inclusiveness. Based on the research it can be stated that the authors found evidence that CBA promotes inclusiveness to overcome groupthink and promotes psychological safety. The authors did not find direct evidence that CBA helps to overcome gender bias, but the CBA decision dynamic does allow everybody to speak up regardless of gender. Thus, more data is needed to confirm the presumptions. This paper is limited to one case study; therefore, more research to generalize findings is required.

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CONTRACTING FOR COLLABORATION IN CONSTRUCTION

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ABSTRACT

Construction contracts represent instruments that bind project participants together to deliver a project. The industry still uses delivery methods and related contracts that are more traditional in nature, e.g., design-bid-build (DBB), and promote a sequential design and construction process, which allows for little to no collaboration between project participants. Over the past 25 years, more collaborative delivery methods (e.g., Design-Build) have gained more adopters, and been touted as the solution to problems of the construction industry. The promotion of more collaborative environments stands front and center as a solution to the industry problems by promoting, via contractual terms, collaborative behaviors and processes. This study investigates the language of construction contracts by identifying keywords commonly associated with collaboration and comparing the incidence of these keywords in contracts for different delivery methods. Results indicate that DBB contracts have few to no mentions of collaborative words, standing to no surprise that DBB environments are less collaborative in nature. In contrast, Integrated Project Delivery contracts not only use keywords associated with collaboration, but actually employ them in clauses to promote collaborative behaviors and environments.

KEYWORDS

Contracts, collaboration, language, delivery systems.

INTRODUCTION

Construction contracts represent instruments that bind project participants together to deliver a project. Currently, the industry still uses delivery methods that are more traditional in nature, e.g., design-bid-build (DBB), and promote a sequential design and construction process, which allows for little to no collaboration between project participants. However, over the past 25 years, more collaborative forms of delivery methods, and their related contracts, have been gaining more space and adopters, and being touted as the solution to endemic problems of the construction industry including, but not limited to: resource waste, poor performance in terms of time, quality, and schedule, poor value delivered to clients. Design-Build (DB) promoted by the Design Build Institute of

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America (DBIA 2019), established 25 years ago, is arguably the fastest growing delivery method promoting highly collaborative environments in the United States. Whereas the Integrated Project Delivery (IPD) and the Lean Project Delivery System (LPDS) promoted by the Lean Construction Institute (LCI 2019) represent the runner-ups as they require the use of Lean tools, high levels of collaboration throughout the construction supply chain, and the use of collaborative tools in multiple processes, e.g., Target Value Design, Choosing by Advantages (Ballard 2008). Interestingly, in the United States, DBIA promotes its own series of contracts, which are highly integrated and standardized, to implement DB, whereas contracts to implement IPD are drafted by other organizations such as ConsensusDocs (2019) and private law firms.

The promotion of more collaborative environments stands front and center as a solution to many of the industry problems by promoting, via contractual terms, more collaborative behaviors and processes. While the delivery method is intended to create a culture of collaboration, are their related contracts being written in a way that requires collaboration? This study investigates the language of construction contracts by identifying keywords commonly associated with collaboration and comparing the incidence of these keywords in contracts for different delivery methods. Initially, a brief review of related literature is presented, followed by the description of the method used to conduct the investigation, and finally the presentation of results and conclusions.

CONSTRUCTION CONTRACTS AND COLLABORATION

This section reviews common delivery methods currently used in the construction industry and used during the analysis. The review supports the discussion rather than fully characterizes any of the methods involved. For the scope of this study, contracts associated with the following delivery methods (Sweet and Schneier 2015) were used:

Design-Bid-Build (DBB) – this is the most traditional of the delivery methods in use and comprises a sequential process where the owner initially hires an architect to develop the plans and specifications for the project. Once the design is deemed complete, the documents are used in a bidding process and the winning contractor gets to build the project. Due to the separation of the design and construction responsibilities in time and in contractual terms, there is not much incentive for collaboration as the architect and engineers design, and the general contractor builds. During the process, their communication is done via the owner as the architect and the general contractor are not contractually bound together.

Construction Management (CM) – the construction management modality usually takes two major forms: construction manager as an agent of the owner and construction manager at risk. In both cases, the owner hires an architect to develop the design and specifications. In the former, the construction manager represents an entity that represents the owner's interests, and owes fiduciary duties to the owner, that is, it acts in the best interest of the owner. In the latter, the construction manager takes the role of a general contractor, who oversees the work and might start during the design phase providing preconstruction services and constructability reviews for the project alongside the architect. In the CM at risk (CMAR) delivery system, the general contractor is at risk for the project performance, whereas in the pure CM (CM as Agent or Advisor), the manager is not at risk for the project's final performance.

Design-Build (DB) – this delivery method is best characterized by the single design-build contract signed between the owner and the general contractor+architect. The general contractor usually hires the architect or forms a joint venture with the architect to deliver DB projects. The DB entity is responsible for both the means and methods to build the project as well as the design, thus, promoting a constant conversation between these parties as the project is developed. Due to this arrangement, it is in the best interest of the parties to collaborate to avoid mistakes during design and construction because the DB entity is responsible for both during the delivery of the project. Additionally, these parties bring the best of their knowledge to the table to define systems and methods that best suit the owner's needs.

Integrated Project Delivery (IPD) – this delivery method is the most recent of all discussed in this paper; it integrates elements of the LPDS in its language and, most importantly, constitutes a multi-party agreement between the owner, the architect, the general contractor, at a minimum, and major specialty trades and suppliers involved with the project. Contracts used in IPD projects contain three main parts to define the organization of the project, its commercial terms, and the operating system that is used to conduct day-to-day activities based on largely on a cadre of Lean tools and principles (Darrington et al. 2009).

The use of more collaborative delivery methods requires different systems and incentives that support their implementation and behaviors that sustain the changes made to the construction process from design through construction, and hand over (Seed 2014, Aschcraft 2014). The University of Minnesota et al. (2016) have documented numerous practices and their effects on project teams and the final project delivered to the owner. Integrated teams spend months developing and refining not only the design of the project, but also the contractual agreement that will bind team members. During this time, team members get to know each other, align their goals, and define the best ways to deliver the projects. A similar process happens with teams working on progressive DB projects, where the design and price are progressively defined over time (DBIA 2017). The work of these teams ends up translated on specific design and construction documents, but also captured in contractual clauses that promote and sustain collaboration.

Considering these delivery methods and related practices outlined in their respective contracts, studies have documented the superior performance of DB over DBB, and CMAR (Konchar and Sanvido 1998) and, more recently, IPD over DB and DBB (El-Asmar et al. 2013), and IPD over DB, DBB, and CMAR (El-Asmar et al. 2016). Contracts for these delivery methods all address similar concerns regarding roles and responsibilities of the teams, risk management, document management, and commercial terms, among others. However, the working hypothesis of this paper is that the language used in these contracts differs from more prescriptive and compliance-related terms in traditional delivery methods, to language that is used to weave in collaboration in different areas of the project.

The language in these contracts is one of the elements that sets the tone for the collaboration among project stakeholders and the project's superior performance.

RESEARCH METHOD

The research method employed to conduct the analysis uses the same steps outlined in Alves and Shah (2018) for the analysis of construction contracts, used to implement different delivery methods, with the goal of identifying collaboration related words. Initially, the first author analyzed various forms of contracts used across the construction industry in an effort to determine if contracts can be used to create a collaborative environment where all the parties involved will work in together. A total of 32 contracts for different delivery methods were analyzed including: design-bid-build (DBB), Design-Build (DB), Construction Management (CM) at Risk (CMAR) and as Agent, and Integrated Project Delivery (IPD). The contracts evaluated were either obtained through online searches, or through contacts found online for various public entities and organizations.

The analysis of the contracts was performed using a series of keyword searches. From a legal standpoint, words and clauses in a contract have no inherent meaning, they develop meanings after people using contracts and their related instruments communicate with each other using contractual terms, thus, attaching meanings to these terms (Sweet et al. 2015). However, words have social and psychological meanings, according to Tausczik and Pennebaker (2010, p.30) *"(t)he words we use in daily life reflect what we are paying attention to, what we are thinking about, what we are trying to avoid, how we are feeling, and how we are organizing and analyzing our worlds.*"

The first round of searches was performed using the word "Collab" as the root of other words such as collaboration, collaborative, collaborate, collaboratively, and other variations. The second round of searches included words commonly associated with collaborative behaviors and processes, namely: joint* (joint, jointly), coop* (for cooperation-related words), together, and trust*. Additionally, a last round of analyses and discussion considered specific clauses, organized in the spreadsheet format, and the context where the keywords were used. The first author categorized the clauses that contained the keywords searched as collaborative clauses when the words were in fact used to promote collaborative environments and processes versus simply referring to terms (e.g., joint venture, joint checks) or titles of the clauses (e.g., collaboration responsibilities, participation in collaboration).

This study was developed as part of the first author's master's degree capstone project. It expands the findings reported by Alves and Shah (2018), and adds the word "trust" to the analyses. Limitations include: the sample size considering the 32 contracts analysed, the predominant focus on contracts used in the United States, and the subjective analysis carried out by the first author in terms of what words were being used specifically with a collaborative intent versus simply outlining a procedure, title or part of some term or practice.

ANALYSIS

This section presents the two rounds of keyword search and related analyses for the different contracts used in the delivery methods investigated.

FIRST ROUND – SEARCH FOR COLLAB* KEYWORDS

Considering the 32 contracts that were searched only 10 used any words with the root "collab." Of the contracts that returned words with the root "collab" in them, 2 were construction management (1 in each category), and 8 were IPD. There were 179 instances of words such as collaborate, collaboratively, collaboration, and other variations. Out of this number, 177 (99%) uses of the words specifically appeared in the IPD-related contracts, which represent about 31% of all the contracts analyzed (Table 1). This particular result, at first glance, suggests that contracts used in IPD projects are using a lot more collaborative words, while the other contracts analysed are not using specific words that directly call for collaboration.

- Table 1: Delivery methods and keywords – 1st Round

			Keyword (1st Round)
Delivery Method	**#**	**%**	**Collab***
Design-Bid-Build (DBB)	7	22	0
Construction Management (CMAR)	4	12.5	1
CM as Agent or Advisor	4	12.5	1
Design-Build (DB)	7	22	0
Integrated Project Delivery (IPD)	10	31	177
Total	**32**	**100**	**179**

A more detailed analysis of these contracts resulted in the following findings (Table 1):

Design-Bid-Build: seven contracts used for DBB were analyzed and returned zero words with the root "collab" in them.

Construction Management: a total of eight contracts used in the CMAR and CM as Agent or Advisor were analysed, however, only two of these contracts each had one single reference to a word with the root of "collab." In both contracts the word was specifically used in reference to expediting shop drawings. Both contracts use the word in the following manner: "*In collaboration with the architect or design team to implement procedures for the expediting of shop drawings and submittal approvals*." This type of statement does not actually reflect collaborative work, but rather indicate a procedure for document acceptance.

Design-Build: Seven contracts used in DB projects were analyzed and also returned zero words with the root "collab" in them. The fact that zero words with the root collab* were returned might support the appearance that these contracts are not collaborative by nature. However, additional keywords searched in the second round of the analysis returned different results, analyzed later in this paper.

Integrated Project Delivery: Ten contracts used in IPD projects were analyzed and eight had words with the root of "collab" used in them. 177 instances of the root appeared throughout the eight contracts, and over two thirds of the mentions were categorized as supporting clauses to promote collaborative environments. Some uses were written towards the selection of subcontractors who can work in a collaborative environment, using collaborative tools and methods; thus, depending on other clauses that established what collaboration meant in these contracts. The contracts indicated specifically how the architect, contractors, and owner would be required to work collaboratively and defined requirements to create a collaborative environment. The contracts even went so far as to allow termination of a subcontractor for not working collaboratively. This result supports the idea that IPD is designed to create highly collaborative environments in the construction industry.

SECOND ROUND – SEARCH FOR JOINT*, COOP*, TOGETHER, TRUST* KEYWORDS

The second round of searches resulted in higher uses of the searched words across all the contracts analyzed. The authors' analysis of the results are presented next, with results found in Table 2. The following findings resulted from the second round of analyses:

Design-Bid-Build: the searched words appeared only 10 times in the DBB-related contracts analyzed. The following statement exemplifies one of these instances: "*The Owner and the Architect shall cooperate with one another to fulfill their respective obligations under this Agreement. Both parties shall endeavor to maintain good working relationships among all members of the Project team..*" While this is a collaborative statement it still has a large grey area in that it only specifically calls for cooperation between the owner and architect, the two parties named in the contract, but not necessarily the additional parties later involved in the project via additional contracts. It also does not require anyone to work collaboratively but rather to try and maintain a good relationship among the project team. While it does seek to remove or control the contention of the contract, it is not fully collaborative.

Construction Management: The CMAR-related contracts returned 53 instances of the additional keywords, whereas the CM as Agent or Advisor returned another 28 instances. The word "cooperate", for instance, was used the most in the CM agreements to facilitate working together toward the interests of the project. One CMAR-related contract in particular used the word cooperate in what the first author deemed a collaborative manner six times in an effort to facilitate a cooperative environment. The remainder of the uses of the words were similar to the Design-Build uses, discussed later, in that trusts and joint ventures are used, or in respect to writing joint checks. These words are also commonly seen in the language of one item together with another construing the whole of something in regards to documentation or payments, exemplifying procedural requirements rather than collaborative processes, tasks, or environments. For instance, the writing of joint checks clearly addresses mistrust issues as the checks are issued to two or more parties that are aware that others are also named in the check and need to cooperate for it to be cashed.

Design-Duild: a total of 48 secondary keywords were returned for contracts in DB projects. These words were used specifically in reference to working in a cooperative manner and selecting subcontractors who will also work in a cooperative manner. There was also one reference to "*proceed on the basis of trust and good faith to permit each party to realize the benefits afforded under this Agreement*." The remainder of the uses of the secondary keywords were used in various other ways depending on the word itself. Examples are joint ventures, trustees, or trust funds, and "*working together with parties not privileged to the contract in order to correct deficiencies or work offsite*".

Integrated Project Delivery: as was seen in the primary search, the contracts for IPD projects returned results far different than all the other contract types. The secondary searches returned 186 instances of the searched words. The most common uses of the secondary words for collaboration were working jointly and in cooperation with the other contractors towards the goals of the project. While the chosen words are commonly used for joint checks, joint ventures, and taking documents together in the other contracts analyzed, in IPD-related contracts the idea behind these words was to create a contractual obligation for all the parties involved to work together in a collaborative environment.

- Table 2: Delivery methods and keywords – 2nd Round

Delivery Method	#	%	Keywords (2nd Round)				
			Joint*	Coop*	Together	Trust*	Total
Design-Bid-Build	7	22	3	3	4	0	**10**
CMAR	4	12.5	7	29	14	3	**53**
CM as Agent or Advisor	4	12.5	4	19	5	0	**28**
Design-Build	7	22	14	13	15	6	**48**
Integrated Project Delivery	10	31	114	24	36	12	**186**
Total	**32**	**100**	**142**	**88**	**74**	**21**	**325**

DISCUSSION

Table 3 reveals that not all contracts analyzed contained the keywords searched. For instance, in DBB-related contracts the keywords related to joint*, coop*, and together were found respectively in only 2, 2, and 2 of these contracts. For the CM-related contracts, only one CMAR tyoe and one CM as Agent or Advisor type had words related to the root collab*, whereas most of them (7 out of 8) mentioned the root coop*.

It is worth noting that in both rounds of the analysis, contracts for IPD projects presented a high number of collaboration-related words used as departing points for this study. Surprisingly, DB-related contracts, presented fewer related words than CM-related contracts. However, a subjective analysis conducted by the first author, by examining the clauses and the context where the keywords were used, indicated that in IPD contracts, these words are used to promote collaborative environments, versus simply referring to terms, e.g., joint venture, joint checks. These findings are analogous to Alves and Shah's (2018) study and Hamzeh et al's (2019) study, in that contracts for more traditional delivery methods are drafted around compliance and not necessarily written to promote collaboration.

- Table 3: Delivery methods and number of contracts where keywords were found

Delivery Method	#	Collab*	Joint*	Coop*	Together	Trust
Design-Bid-Build	7	0	2	2	2	0
CMAR	4	1	2	3	2	3
CM as Agent or Advisor	4	1	2	4	4	1
Design-Build	7	0	4	6	6	5
Integrated Project Delivery	10	8	9	8	9	6
Total	**32**	**10**	**19**	**23**	**23**	**15**

CONCLUSIONS

The evaluation of the contracts used in this study shows that many contracts associated with different delivery methods lack the use of words that allude to collaboration and promotion of collaborative processes and environments. While some of the contracts analysed do attempt to create an environment of collaboration with specific actions and processes, in some cases, the words are used in a superficial manner. Of all the contract types analysed, the IPD-related contracts were specifically written to create an environment of collaboration between all parties involved. Contracts for IPD projects seek to harness the skills and talents of everyone involved through collaboration and as such the contracts are written with collaborative behaviours in mind.

The working hypothesis proposed that language contained in contracts for certain delivery methods sets them apart in terms of how collaborative they are. Results suggest that this hypothesis is confirmed, but it is important to highlight one caveat: the simple number of collaboration-related words does not define a contract as collaborative. The specific context and clauses where they are used are also very important. Moreover, parties involved in projects with different delivery methods might choose to promote collaboration regardless of contractual obligations, whereas parties in more collaborative delivery methods might also selfishly take advantage of contractual tools as outlined in Do et al. (2015).

The findings suggest that contracts drafted for more collaborative delivery methods, such as IPD and DB, contain a higher number of keywords associated with collaboration and collaborative behaviors. These contracts, as indicated in the literature reviewed, result in projects with better performance, suggesting a relationship between the contract language and resulting project performance. However, a more detailed analysis reveals that appropriate language is necessary but not sufficient to support collaboration. Contracts for

IPD and DB projects are very intentional when specific tools and processes are suggested to foster collaboration among the parties involved. The theory reviewed also indicates that words have social and psychological meanings related to the environments where they are used and the background of those using them. It also suggests that words have meanings that convey messages related to social relationships, status, hierarchy, honesty and deception to name a few (Tausczik and Pennebaker 2010).

Accordingly, the theoretical and practical implications of this study indicate that word choices in a contract might determine, or at least contribute to, the relationships among project participants and influence project performance. Therefore, owners should be very intentional when defining language to be used in their contracts, in addition to including mechanisms to promote collaborative behaviors.

Suggestions for future studies include the consideration of a higher number of contracts and delivery methods drafted in other countries and languages, which would require an international team of researchers to conduct the analyses. Additionally, the use of artificial intelligence and discourse analysis software can be employed to capture the surrounding context where the words are used, to avoid relying on perceptions. The use of performance metrics to evaluate the actual results of the use of collaborative language in contracts is another suggestion for future studies.

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Dallasega, P., Revolti, A., Follini, C., Schimanski, C.P., Matt, D.T. (2019). "BIM-Based Construction Progress Measurement of Non-Repetitive HVAC Installation Works." In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), *Pasquire C. and Hamzeh FR. (ed.)*, pp. 819–830. DOI: https://doi.org/10.24928/2019/0152. Available at: <www.iglc.net>.

BIM-BASED CONSTRUCTION PROGRESS MEASUREMENT OF NON-REPETITIVE HVAC INSTALLATION WORKS

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ABSTRACT

Construction projects are often delivered over time and over budget. Deviations are often identified only during the finishing stages when improvement actions to recover from delays become limited. Building Information Modeling (BIM) will transform the construction industry to come in line with more digitally developed industries like manufacturing. However, up to now, BIM has been mainly used to support the information flow of the construction design process and limited effort has been invested to investigate how it could support the management of the construction execution process. The paper shows how BIM can be used to schedule and monitor non-repetitive construction tasks. The proposed approach shows how important information needed for scheduling (like the number of pieces to be installed in a certain location) could be extracted from the BIM model. Moreover, it shows how BIM could support a quantitative monitoring of the reached progress and how this information can be displayed in an intuitive way to the user. The approach was developed during the project COCkPiT (Collaborative Construction Process Management) and especially by collaborating with a Heating Ventilation and Air Conditioning (HVAC) company using as a case study a medium sized hospital construction project located in Northern Italy.

KEYWORDS

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BIM, lean construction, progress monitoring, non-repetitive, visual management.

INTRODUCTION

The delivery of projects on-time and within the original budget is often a challenging aspect in the construction industry. Budget overruns are often identified only during the finishing stages of a construction project when intervention options become limited. According to the authors, this is mainly caused by 1) the insufficient consideration of important information during the planning phase and 2) the inability to track the construction progress on-site in real-time.

Building Information Modeling (BIM) can be recognized as one of the main enabling technologies for digitizing the construction industry (Eastman et al. 2011). BIM holds great potential for sharing and visualization of information as well as for the consideration of changes in design and during the execution of a construction project (Forsythe et al. 2015; Jeong et al. 2016; Deshpande et al. 2014; Sacks et al. 2010). In fact, information is kept centrally in the model, which allows it to be shared transparently and to be accessed by all construction participants (Forsythe et al. 2015). According to (Alizadehsalehi and Yitmen 2016), "BIM can serve as a powerful baseline for progress tracking and for the visualization of discrepancies". In fact, because of its powerful ability to map the physical building into a digital environment BIM holds potential for the visualization of the construction progress because it can visualize and express information more intuitively (Jeong et al. 2016; Ding et al. 2012).

BIM will become mandatory in future construction projects. Considering the construction execution process, its management as well as the quantitative control of the progress holds great potential for efficiency improvements (Sacks et al. 2010; Jeong et al. 2016). Currently, in many cases after the design phase important information included in the building model are not used anymore during the execution of construction works. As a practical example, the total amount of components to be installed by a certain task on-site could be very useful to estimate in a reliable way the duration of the task itself.

The paper was developed within the COCkPiT (Collaborative Construction Process Management) research project and especially in collaboration with a Heating Ventilation and Air Conditioning (HVAC) company using as a case study a medium sized hospital construction project. The concepts of "pitch" and normalized workload approach (NWA) (Dallasega et al. 2016; Schimanski et al. 2018) represent the basis for this study. At this, the key factor is the "pitch" as the NWA's core element, which helps us to schedule, and monitor construction projects in a quantitative and timely way with a very high accuracy. However, preliminary attempts of application of the pitch in the HVAC-industry showed that the definition of a pitch for HVAC activities is not directly derivable. This is due to the large diversity of present activities, such as the installation of ventilation ducts or the laying wiring. Here the definition of a uniform unit of measurement, e.g. running meter or number of units, turns out to be very challenging. This is especially true since the activities within single task groups also prove to be explicitly non-repetitive. For example, horizontally running ventilation ducts as part of a ventilation system have to be planned and measured differently as the fire shutters or throttle valves located between those ducts.

In addition to this high degree of divergence, the approach for defining the pitch for individual trades is based on the collaborative study of floor plans, sections and views, usually in 2D plan printout format. In the HVAC area in particular, the identification of the individual ducts and pipes of the various trades crossing each other is a sophisticated task. The difficulty also increases if black and white printouts are used as usual. A well-known approach to circumventing these problems is widely acknowledged through the use of 3D models, most often as an inherent part of a BIM model. In the context of determining the pitch, a BIM model can therefore be regarded as advantageous in two respects: 1) to better understand the actual structure to be built (Mehrbod et al. 2019) and 2) for the identified tasks, the quantities to be handled can be determined very precisely and directly by means of model-based quantity take-off. As a result, the elements of the individual construction stages can be identified very decisively and in any number of units.

The main aim of the article is to show the potential to use BIM not only for the design but also for managing the construction execution process. Special emphasis is set on which kind of information should be extracted from the BIM model to support the planning, scheduling and monitoring of HVAC construction works on-site. Moreover, the paper investigates if the approach will allow to inform early on if there are plan deviations in a way to apply improvement actions to recover from delays in time. The proposed concept was applied in an HVAC supplier company from Northern Italy by using as case study a medium sized hospital construction project.

RELATED WORK

Within the world of academic research, the bibliography dedicated to the BIM topic in the scope of design phases and project variants is nowadays more than ever investigated and consolidated. In fact, there are numerous articles and publications dealing with the advantages of BIM for design changes, the easy creation of elevations and sections and the storage of information within a single 3D model.

However, BIM has been less studied considering the support to the execution part. Up to now, few articles have been described the interaction of BIM with other methodologies for execution management. Khan and Tzortzopoulos (2014) presented the implementation of the Last Planner System (LPS) weekly work plans in two BIM-based building design projects to achieve better workflow, reduce the waste of time on-site and monitor in a better way the production variability. Rezaei (2015) showed how BIM can be used to have a better overview for his Location Based Scheduling (LBS) estimations in 5D (3D model, construction scheduling and cost assessment) in a case study of a Private Villa in North Cyprus. Findings of the article are that BIM and LBS can be easily synchronized leading to shorter costs and execution times.

More recently, BIM has started to be investigated as a supporting tool for project management and quality control on-site. In fact, the 4D BIM approach adds an extra dimension of information to a project in terms of scheduling data (Eastman et al. 2011). This data is added to components that are going to be installed as the project progresses. This information can be used to obtain accurate programme information and simulations showing how the project will develop in the future. However, usually 4D BIM models are used for pre-construction planning and not for managing the execution process. Matta et al. (2018) describe the use of BIM-based sheets as a visual management tool to provide task instructions to the field. The approach was applied to a Chilean hospital construction project and the achieved results were the fulfilment of deadlines thanks to a reduction of response times for information requests. However, the authors point out that simply applying the technology is not enough, but it is essential to use it within a Lean collaborative methodology (Matta et al. 2018).

Bhatla and Leite (2012) described the advantages of using BIM on-site, to provide documentation and information for the work teams about products and process activities, with a 3D/4D components visualization. Harris and Alves (2013) used a pilot site of a hospital construction project in Southern California in order to study and analyse the field operational activities that could potentially benefit from 4D BIM integration and the factors that could foster or hinder successful 4D application in the field. They showed that through 4D BIM, for example, transparency within information exchanges and on-site collaboration increased. This improved the scheduling for subcontractors, assisted with delivery of resources (like operators, equipment and materials), and reduced variability.

Clemente and Cachadinha (2013) studied the implementation of an integrated project management approach to achieve the alignment of interests of all stakeholders towards a common project's schedule. Their results show how a combined BIM-Lean approach improved workflow in HVAC maintenance projects. More in detail, it supported an early change detection of objects between the design and the installation phase on-site in a daily level of detail.

From the literature review emerged that BIM has been investigated mostly as a support for quality control, to identify the discrepancy in design, and to program the activities sequence. Up to now, BIM is not viewed as a central database to collect important information needed and collected on-site as well as a tool used to visualize and share information about the status of a construction project. BIM is not yet used as a repository that can be systematically updated (and graphically detected) with information coming directly from the sites every day or week (e.g. verification of correct installations, reason for non-completion or non-conformity reports).

APPROACH

The approach of normalizing workloads for uniform scheduling and measurement of different construction activities requires the definition of the so-called pitch for every task. The concept of pitching is derived from lean production in the automotive industry and describes the relation of quantities (expressed in the respective measuring unit [MU]) of the task j (e.g. 20 m² of parquet) that the corresponding crew (with crew size k) is able to install in the CA i (e.g. floor 1) to the scheduled time interval (e.g. one working day).

$$Pitch_{CA_i,Task_j,Crewsize_k} = \frac{Quantity_{ij}\ [MU_j]}{time\ interval} \tag{1}$$

The pitch serves to define collaboratively a consistent process model of the entire construction project, whose dependencies and constraints are used to generate accurate schedules. In terms of monitoring the construction progress on-site, the pitch allows for indicating whether and to which extent a daily or weekly goal of value-adding activities had been fulfilled. Figure 1 depicts schematically the proposed approach.

Figure 1: Description of the approach – BIM as supporting tool for construction management

Task-related quantities are derived from the BIM model for accurate estimation of the respective pitch during the modelling phase of the overall execution process. During scheduling, the amount of pitches is used to calculate the task durations and serve as orientation for the progress monitoring. For instance, a task that needs 100 pieces to install, having a defined pitch of 20 pieces per day with 2 workers results in a duration of 5 working days. In monitoring, the pitch provides orientation about the daily goal to be achieved in terms of quantities. The amount of actual installed pieces is fed back into the BIM model in order to visualize the reached construction progress.
Considering non-repetitive works like HVAC, the pitch can vary within one task according to the considered component to be installed. As a practical example, if we consider the task "installation of ventilation ducts", the installation of "straight channels" is different from the installation of "flow regulators" in terms of assembly mode. As such, the installation duration as well as the appropriate measuring unit needed to understand its completion degree could vary. The installation of "straight channels" might be measured in the installed surface (sqm) per crew per day and the installation of "flow regulators" might be measured in number of pieces per crew per day. As a result, to a specific task like "installation of ventilation ducts" different pitches can be assigned according to a specific class of components. To standardize the transfer of construction process related information between BIM models and construction management tools, the Industry Foundation Classes (IFC) file format can be used. IFC, which is prospectively considered to be a standard format for data exchange in an Open-BIM working environment (Dimyadi et al. 2008; Preidel et al. 2016), offers the possibility to describe process-related properties of all objects that comprise a BIM-model. This information is supposed to be stored in instances of the class *IFCProcess* and its subclasses (such as *IFCTask*) as part of the IFC data model (Borrmann et al. 2018). Consistent use of this provided storage space by all software systems involved in the BIM process, such as BIM authoring, coordination or scheduling software, would drastically streamline a BIM-based construction execution management and the exchange of process related information. According to the authors'

experience, the various software solutions still rarely offer the possibility to access directly the *IFCProcess* classes of IFC files without the manual creation of new *PropertySets*. As a result, up to now, execution process related information as an immanent part of BIM-models must be extracted manually and conditioned for the use on-site.
The integration of monitoring data with BIM is not only useful for quantity extraction, but also to intuitively visualize the construction progress. This may provide a twofold advantage for collaboration. On the one hand, it simplifies the input of the daily work performed based on the chosen pitch-measuring unit. On the other hand, it enables all actors, both from the same or other companies, to quickly understand progress issues. By consistently following the loop shown in Figure 1, the approach is aimed at a progressive refinement of the pitch value and, subsequently, at a higher reliability of the short-term scheduling. Therefore, a continuous application of the approach may improve transparency and planning, with the result of improving the overall installation workflow.

RESEARCH METHOD

This study follows an action research (AR) approach based on the application of the pitching methodology presented above. AR stands for the practical application of already developed approaches in order to solve a problem from practice for validating the applicability of the approach to this problem (Khan and Tzortzopoulos 2018). Based on findings of these applications it is foreseen to derive recommendations for future applications (Iivari and Venable 2009). According to AR's pioneer Lewin (1946), AR should follow multiple learning cycles, which consist of planning, acting and evaluating which is in line with the procedure of this research project. More in detail, this paper describes the application of the pitching methodology to a case study from the field of HVAC in one single learning cycle. In terms of monitoring, as one part of the pitching methodology, the progress data on site was collected through regular inspections on site by the authors. The monitoring data was analysed by means of a Microsoft Excel worksheet in terms of pitch deviation and fed back to the BIM model for visualizing the site status. This intermediate step of using Microsoft Excel will help to derive requirements for a direct application of BIM on site, which will be elaborated in the further course of this research project.

CASE STUDY

CONTEXT

The case study selected to validate the approach is a private healthcare facility specialised in rehabilitation and located in Northern Italy. It has a footprint of about 3500 sqm and it is composed of four levels aboveground and one level underground. The interior division of the building is rather complex, as it consists of living spaces and facilities with different purposes, such as medical rooms, generally hosting advanced technological equipment. This complexity is reflected on the HVAC system with little repetition of installation tasks. According to the project schedule, HVAC installation has an overall duration of 9 months, starting from October 2018 up to June 2019.

The case study company subcontracted the HVAC installation task to an external company, while still managing the work, as well as providing HVAC shop drawings and components on-site.

The current process can be summarized as follows. First, the HVAC planner develops fabrication drawings, based on the execution plans. They consist of a 2D plan of the building floors, with a different code for each HVAC component, and 2D fabrication drawings to further detail the ducts. Ducts are produced off-site and delivered to the site with the needed accessories. Each piece has its code written upon it to easily recognize its position. The subcontracted company provides the billing in a monthly frequency according to the reached progress. More in detail, the billing is performed by the subcontracted company according to the surface of pipes (measured in square meters (sqm)) installed. As such, a difficult but important task of the project manager is to understand whether the progress reported corresponds to the real reached progress on-site.

Therefore, the HVAC company agreed upon a collaboration with the research institutes to analyse if BIM could be used to support in a quantitative way the measurement (in terms of surface in sqm) of the construction progress.

APPLICATION OF THE APPROACH

First, the Location Breakdown Structure was defined (Figure 2). It considers a horizontal view of the ventilation ducts as well as a vertical one for the risers. Considering the horizontal view, every level (from -1-5) was subdivided in 5 Construction Areas (CAs) according to their technology content. The CAs consist mainly of bedrooms, rehabilitation gym, swimming pool, offices and room with medical equipment. Moreover, CAs were defined in a way that each CA closes with an outward and return air duct as a closed system. Considering the vertical view, within every CA the risers were indicated with the acronym S.

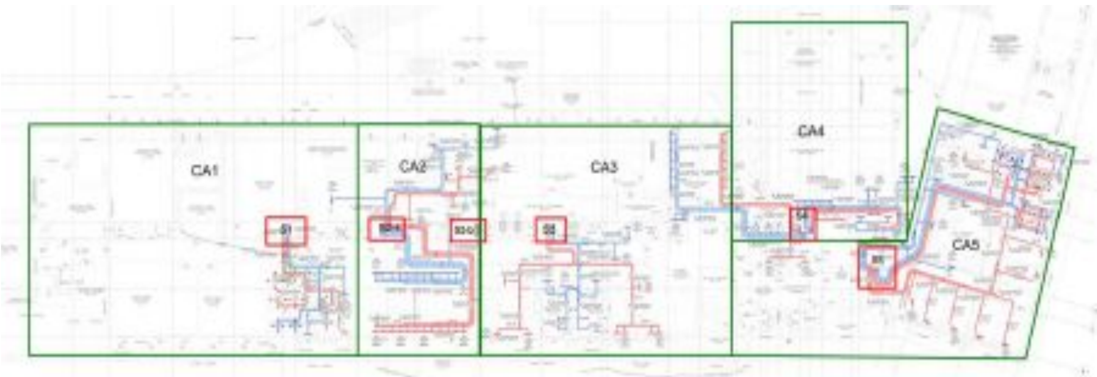

Figure 2: Development of the Location Breakdown Structure (LBS)

Together with the case study company, a meaningful frequency to monitor the installation progress in a weekly frequency was decided. Daily monitoring would provide data that is too fluctuating, and monthly monitoring data would not allow to react to deviations and recover from delays. Visits were performed on Fridays late afternoon, in order to map comprehensively the weekly progress.

The number of workers and the working hours, both necessary to calculate the deviation from the pitch, were retrieved from the daily construction diaries.
Figure 3 shows the model in BIM of level 3 CA 5 developed with the software ArchiCAD version 22 as well as the weekly progress measurement on-site. The model was structured to extract the quantities and to visualize the construction progress. Air duct components were subdivided in two classes: 1) straight and curved sections of the pipes, where the unit of measurement is the total lateral surface, and 2) accessory elements such as flow regulators, nozzles, dampers, etc., for which the number of pieces is used as the measurement unit.

Figure 3: BIM model of level 3 and CA5 (progress reached until 15.02.2019)

To visualize the construction progress in an intuitive way in the BIM model a colour-coding consisting of five scales was applied. This was automatically done in the BIM software by using the functionality of "graphic overwriting" with specific rules and proprieties directly connected to the object tables.
To indicate the *complete* and correct positioning of pipes the colour *green* is used. To visualize any *non-conformities* (quality problems) components are marked in *red*. Components affected by a *delayed* installation are marked with *orange* and *work in progress* is visualized in *yellow*. Components that have *not* been *installed* are visualized in the colour *grey*.
The BIM model has been used to compare the weekly reached progress with the pitch calculated according to budget. Table 1 shows the calculation of the pitch for class 1 pipes.

Table 1: Calculation of pitch for straight and curved channels

Class	Description	Total lateral surface [m²]	Duration [d]	Pitch [m²/2workers/day]

1	Straight and curved channels (pipes)	9,680	280	34.57

The daily pitch was calculated by using the total lateral surface in sqm of straight and curved channels to be installed and the required duration according to the project schedule (9,680 m^2 / 280 days = 34.57 m^2 / day). According to the foreman, a crew composed of two workers is usually performing this task.

The monitoring sheet was configured in ArchiCAD and connected to the BIM model. Duct sections and accessories have been associated with a unique ID, based on the shop drawings provided by the case study company. Five columns have been dedicated to the weekly tracking: 1) Installation status, 2) non-conformity report (NCR), 3) time delay, 4) reasons for non-completion (RNC) and 5) tracking date. The monitoring sheet has been used to track the weekly progress and by importing it into the BIM software, it shows the tracked condition of the different components (reached construction progress).

As mentioned previously, the pitch has been computed in sqm for pipes and pieces for accessories (Figure 4). Therefore, to evaluate the first, a column with the lateral surface has been added to the monitoring sheet.

Figure 3 shows the example of the monitoring of CA5 in L3 in date February 15 2019. Progress has been registered on three Fridays: 11/01/2019 (week 1), 18/01/2019 (week 2), and 15/02/2019 (week 3). Since there has been no major delay or quality issue, it shows only two colours: green for the installed pieces and grey for the ones left.

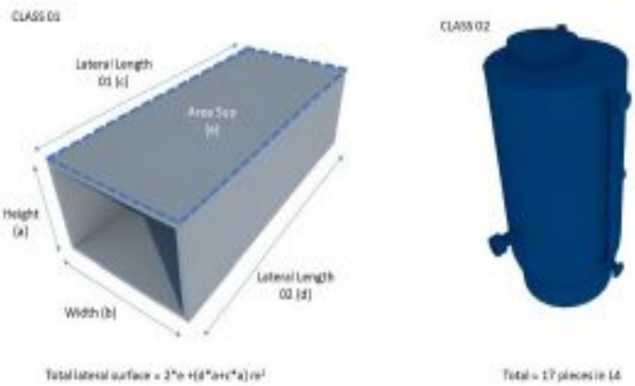

Figure 4: Class 01 pipes and class 02 accessories

Deviation from the pitch was calculated for the ducts of the first class (Table 2). The pitch of the component of the second class was used to reduce the overall number of working hours, to extract the effective used amount of work for just installing pipes. In particular, the overall time spent on class 1 elements in L3 CA5 was, respectively to the three monitoring weeks, 4.5 man-hours, 7.98 man-hours and 0.49 man-hours. Table 2 shows the calculation of the deviation from the pitch for the three monitoring weeks.

Table 2: Calculation of deviation from pitch for task "Installation of pipes" level 3 CA5

	Pitch budget [m²/man-hour]	**Time worked [man-hour]**	**Quantity budget [m²]**	**Quantity built [m²]**	**Deviation [m²]**	**Deviation [man-hour]**
week1	2.1875	4.42	9.67	8.056	-1.61	-0.74
week2	2.1875	7.98	17.45	43.298	25.85	11.82
week3	2.1875	0.49	1.07	15.666	14.60	6.67

According to the calculation, the installation of pipes in level 3 CA5 was a little bit over budget the first week and much under budget the second and third week. However, because the subcontracted installation company did not work exclusively on level 3 CA5 the man-hours spent in week 3 were not sufficient to reach a reliable calculation of the deviation to the pitch. According to a first feedback from the project manager of the case study company, the great potential of the approach is that it provides early warning signals to identify delays and deviations in time and as such, it increases budget security throughout the construction project execution.

Compared to the traditional use of a BIM model for the "quantity take-off" (to obtain information on size, number of pieces and so on) the proposed approach allows also to update information about the correct installation, achievable quality problems, delays with respect to the expected timing directly from the building site surveys.

CONCLUSIONS AND OUTLOOK

The paper shows how information extracted from BIM can be used to schedule and monitor non-repetitive construction tasks by the example of a HVAC case study company and the installation of air ducts in a private healthcare facility construction project. The fact that the installation of air ducts is a highly non-repetitive task makes the construction progress monitoring a challenging activity.

BIM showed to give support in the quantitative measurement of the construction progress. This was achieved by extracting the lateral surface (in square meters) of pipes installed, which allows to timely understand whether execution proceeds according to budget. It is important to note that, with the aim of optimizing the entire construction process, a unique BIM model has been created and used in the design phase, for the extraction of quantities, and, finally, to graphically show the progress of construction activities.

Preliminary results showed that the approach allows a weekly measurement of the reached progress and an evaluation if the project is over or under budget. Thanks to the graphical visualization of the reached progress in the BIM model, it allows an immediate and intuitive understanding of the status of a construction project, which may help easing planning, rescheduling and collaboration among the actors involved in the HVAC operations.

Future research consists of extending the validation of the approach to cover also accessories like valves or flow regulators. Moreover, other non-repetitive parts from HVAC, like water pipelines, will be considered that increase the difficulty for a visual recognition of installed parts on-site. Considering the last aspect, the research team started to investigate the potential for the development of a cognitive support by using BIM in combination with Mixed Reality (MR). Here, the interaction of MR with BIM in a way to record the progress of the installed objects and the indoor navigation to allow the overlapping of BIM with the real building will be investigated.

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INDOOR TRACKING OF CONSTRUCTION WORKERS USING BLE: MOBILE BEACONS AND FIXED GATEWAYS VS. FIXED BEACONS AND MOBILE GATEWAYS

Erez Dror [1], Jianyu Zhao[2], Rafael Sacks[3] and Olli Seppänen [4]

ABSTRACT

Automatic resource location monitoring in construction projects empowers managers to make data driven decisions that improve project workflow. Monitoring data can be processed to measure workflow quality and thus for better understanding of effectiveness and efficiency. We compare two methods for deployment of Bluetooth Low Energy (BLE) beacons for indoor resource monitoring - mobile beacons and fixed gateways (MB) vs. fixed beacons and mobile gateways (FB). BLE beacons can be fixed to walls or carried by workers, and can be fixed to material containers and equipment. Using gateways, such as raspberry pi computers or smartphones, one can easily and automatically monitor resource locations. Several field experiments were conducted, both in the laboratory and in construction sites in Finland, Israel, Peru, Netherlands and China. Technical aspects such as setup, direct cost, feasibility and accuracy were compared for two methods - mobile beacons and fixed gateways vs. fixed beacons and mobile gateways - and the performance of each method in providing the data needed for lean construction workflow assessment was assessed. Both methods are effective in monitoring resource locations but differ in their feasibility of implementation in construction sites and in the utility of the data they provide in terms of identifying value adding activities.

KEYWORDS

Gateways, beacons, bluetooth low energy (BLE), lean construction, waste, situational awareness, indoor positioning

INTRODUCTION

The real-time location of labour, material and equipment is important information for site managers and safety managers and enables efficient production planning and work

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efficiency assessment. However, given the complexity of construction sites and the expense of gathering information, construction managers often make decisions with very limited certainty. Lean construction tools and methods such as the Last Planner System, visual management, Plan-Do-Check-Act, waste identification and workflow assessment are already widespread in construction sites, but their full potential remains unrealized due to limited ability to assess the real status and performance on construction sites. Collecting data manually is time consuming and inefficient (Navon and Sacks 2007) and therefore construction managers are forced to make their decisions based on gut feeling or past experience instead of real-time data (Sacks et al. 2013).

IoT and other technologies enable real-time tracking of labour, material and equipment and might be suitable for the complex environment of construction sites. There are several solutions for indoor resource monitoring, including Bluetooth Low Energy (BLE), radio frequency identification (RFID), Ultra-wideband (UWB), laser scanning, videogrammetry and more. The solution must be easy to deploy, provide efficient and accurate location monitoring and be cost effective. The IoT technology chosen for examination in this paper is BLE beacons. A BLE monitoring system includes four components: BLE beacons, a gateway, a web service and cloud-based storage. The authors examined two methods of deployment of such beacons and gateways - mobile beacons and fixed gateways (MB) vs. fixed beacons and mobile gateways (FB) in the field on construction sites in Finland, Israel, Peru, the Netherlands and China. The research questions we sought to answer were:

- Do the MB or FB methods enable effective and efficient tracking the locations of resources, such as labour, material and equipment?
- What are the advantages and disadvantages of each of the methods?

LITERATURE REVIEW

Production control has been developed over years within the scope of lean construction (Koskela, 1992). For example, the Last Planner System (Ballard, 2000) and Location-Based Management System (Kenley & Seppänen 2010), together with their integration (e.g. Seppänen et al., 2010), have led to positive progress in operations management in construction. Their success has been successfully recorded in many case studies around the world (Seppänen et al., 2015). These methods have been tested to improve resource efficiency through onsite waste elimination (Ballard, 2000) and to shorten project durations thanks to production control and forecasting (Seppänen et al, 2014).

In order to coordinate the complex flows of labour, materials, space, equipment and products (Sacks, 2016, Golovina, 2016), the construction industry needs innovative management processes and software that exploit automated information collection and intelligent data processing (Sacks et al. 2010, Nath et al., 2015). Production control methods in construction used to rely heavily on social processes and manual input (Pradhananga, 2013), but this resulted in human errors and inaccuracy (Costin et al., 2012), which prevent fulfilment of the prospects of lean construction philosophy (Vieira, 2016). There is a need to develop an intelligent real-time platform where all resources can be tracked and analysed to support labour management (Lin et al., 2013), and automate the data recording process (Costin et al., 2012).

Many technologies have been applied for resource tracking in construction, such as passive RFID (Costin et al., 2012), ZigBee (Liu et al., 2007), BLE (Zhao et al., 2017), (Dror, 2018), magnetic field (Park et al., 2016), and Global Positioning System (GPS) (Alarifi et al., 2016). GPS is a mature technology for tracking, but it is not suitable for indoor positioning (Liu et al., 2007). For indoor positioning, among all the technologies, Bluetooth Low Energy (BLE) has proved to be cost-effective because of its high degree of implementation simplicity with minimal infrastructure and ease of calibration (Park et al, 2016), and sufficiently accurate, thus making it, from the implementation perspective, the preferred technology. However, different solutions applying BLE technology have neither been thoroughly discussed nor compared for application to the scope of production control in lean construction. This paper provides a comparative analysis of two BLE indoor positioning solutions serving the purpose of operations management in construction, outlining the potential use cases suitable for the respective methods.

METHODS

We examined two different methods for indoor positioning in construction sites using BLE technology. The two methods used the same principles: a combination of BLE beacons and gateways. In general, location monitoring systems using BLE sensors comprise four main components: BLE beacons, gateways, a web application and cloud storage. Each BLE beacon continuously transmits a universally unique identifier (UUID) that is detected by a compatible app or operating system running on the gateway. The gateway in turn transmits the UUID signals and the timestamp to the server via mobile network or Wi-Fi, and the data is stored in cloud-based storage. The minimum requirements for the gateway are that it can detect BLE signals and transmit data to the cloud using either mobile networks or Wi-Fi.

FIXED BEACONS - MOBILE GATEWAYS (FB)

In this method, the beacons are fixed in place on walls or ceilings in the building under construction, while apps installed on workers' mobile smartphones serve as gateways. The beacons transmit the UUIDs, which are detected by the workers' smartphones, which in turn send packets of UUIDs, timestamps and signal strengths to the data analysis engine in the cloud (Figure 1). Additional fixed beacons in site elevators and site offices can be used to track workers more extensively.

The method requires one-time installation of the beacons in each location. Figure 2 shows a typical distribution of beacons on a typical floor of a residential building in Israel (beacons are marked in green). The beacons require neither infrastructure nor external power source and are fixed in place manually. In the process of positioning the beacons, the location of each beacon is registered using a designated smartphone app interface, matching each physical location to a specific UUID.

Most smartphones available on the market today can receive Bluetooth signals and are connected to cellular networks and are therefore suitable to serve as gateways (Dror, 2018). In order to use smartphones as gateways, a designated app is needed. In the experimental setup, an Android app was implemented for this purpose.

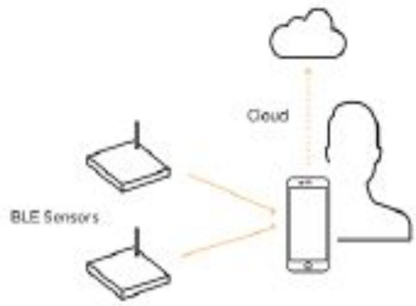

Figure 3 BLE tracking system components

Figure 4 Typical beacon placement in a residential building

MOBILE BEACONS - FIXED GATEWAYS (MB)

In the MB method, mobile BLE beacons attached to equipment or material containers and carried by workers send signals to gateways that are fixed in place. The proposed prototype contains four main parts (see Figure 3): beacons, gateways, cloud storage and a web-based application. Gateways receive signals from the beacons and transmit them to the cloud service via Wifi or cellular networks (using dongles) (link 4). The cloud software compares the signal strength from beacons and determines the location information based on the strongest signal strength received. The software saves the data in the server and displays the results on a web-based application through an application programming interface (API) (link 5). The application aims to provide situational awareness on site from the perspective of operations management and to update production status based on information from the cloud (link 3 and 5). The prototype enables tracking of labor, materials and tools simultaneously (link 1).

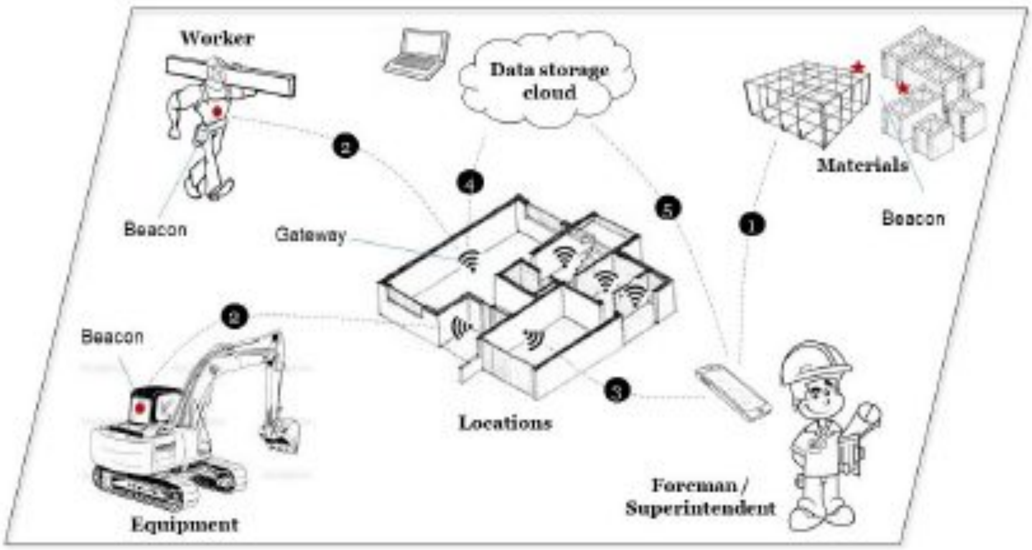

Figure 5 MB indoor positioning solution scheme

COMPARISON

Each method has its own characteristic advantages and disadvantages. In this section, we compare the two methods in detail from technical, system and lean construction implementation perspectives, considering and proposing possible use cases. Both methods were tested on active construction sites. The MB method was implemented and tested in construction projects in Finland, China, Peru, and the Netherlands, including low rise residential buildings and office buildings. The FB method was implemented and tested in several high-rise residential buildings in Israel.

TECHNICAL AND SYSTEM COMPARISON

Setup & maintenance. Both methods require physical setup onsite. The MB solution requires setting up the gateways in their fixed positions. The FB solution requires setting up the beacons in their fixed positions. In both methods the setup process needs around half a day. Additional maintenance work for the system is anticipated to be as much as 1-2 hours per week.

Cost. When examining the costs, we consider only the hardware costs of the system and not the costs related to developing the software or labour for setup & maintenance. The costs are split mainly between two components: beacons, gateways.

The MB solution requires a beacon for each item that is to be monitored, gateways, and a power outlet for each of the gateways (in the case studies examined, the gateways were positioned in proximity to existing temporary power outlets at no extra cost). The FB solution requires 4-5 beacons for each apartment, no infrastructure, and no gateway purchase - worker`s personal smartphones are used as gateways. In both solutions, additional beacons are needed for material and equipment location monitoring. Each element is tagged with a beacon and the number of beacons is the same for both solutions.

As an example, Table 1 details the actual costs for a residential building of three floors with 16 apartments and an entrance floor. The costs assume 15 tracked workers in the building, working with 20 pieces of equipment and up to 30 material containers at a time (beacons are reused).

Table 1: Comparison of example project costs

	Fixed beacons - mobile gateways prototype (FB)	**Mobile beacons - fixed gateways prototype (MB)**
Hardware requirements- labor tracking	65 Beacons	23 Gateways 15 Beacons
Hardware requirements- equipment/ material tracking	50 Beacons	50 Beacons
Total cost	460 €	1,675 €

Feasibility in construction sites. Construction sites are complex environments, with extensive movement of people and vehicles, use of heavy equipment, frequent change of labor and lack of infrastructure such as Wi-Fi signal or electricity. The MB solutions require a stable power supply, which is the biggest obstacle for feasibility testing on site. Therefore, in the tests of MB solutions, the gateways were placed wherever temporary power was available. Data was then analyzed to propose a more rigorous gateway placement strategy for this solution.

The FB solution requires no infrastructure such as Wi-Fi or electricity at all, which makes it highly feasible for construction sites and enables wide spread monitoring. On the other hand, it requires collaboration of the construction workers to allow use of their smartphones. In the case studies, 90% of workers were carrying a smartphones and were using 3G network that is widely available in the construction site, however some 20% of the workers objected, expressing discomfort with the idea of using their personal smartphones to share their locations in the building and on the site.

Coverage & Accuracy. The coverage and accuracy of the system is related to the ability to position the fixed components: beacons or gateways. The rule of thumb is that the more fixed components placed, the higher the possible location accuracy will be.

In the prototype MB method, positioning of the gateway requires access to temporary power. This restricted the positioning to specific locations in the construction site. As the coverage depends on the placement of gateways, location accuracy might be low in buildings with open layout, such as office buildings.

The FB method enables wide spread of beacons in the construction site because it requires no physical infrastructure. It thus enables accurate positioning with unlimited coverage.

Table 2: Technical comparison of the methods

	Fixed beacons - mobile gateways prototype (FB)	**Mobile beacons - fixed gateways prototype (MB)**
Setup & Maintenance	+ Short setup time + Minimal maintenance - Application required for the installation	+ Short setup time + Minimal maintenance + Easy set-up, no mobile application required - Gateways are exposed onsite so they are in risks of damage or movement
Cost	+ Low hardware costs	- Higher hardware costs
Feasibility in construction sites	+ Minimum physical requirements - High friction with workers	- Requires access to power
Accuracy & Coverage	+ Unlimited coverage + High accuracy in closed areas	+ Coverage and accuracy can be improved based on data analysis heuristics - Temporary power requirements decrease coverage in most cases - Internet is required for gateways (from onsite WIFI or mobile network dongles)
Reliability	+ 98% accuracy in apartment scale positioning	+ Accuracy is high and detection in real time - Signal coverage is not perfect due to the

		limitation from gateway placement
Data transmission rate	- Every 5 minutes	+ Continuous

Data transmission rate. In both methods the BLE beacons transmit their UUID continuously and the data is transferred through the gateway to the cloud storage.

In the MB method, gateways receive signals from the beacons at a frequency of one per second. Because gateways are supplied with power all the time, they can provide a continuous signal scan window, thus making the tracking results very detailed.

In the FB method, because the workers phones serve as gateways, battery drainage aspects must be considered. Therefore, a decision was made to monitor the workers' locations every five minutes, resulting in data gaps of 5 minutes. It is possible to minimize the gap to one minute with little adverse impact on the battery life, but continuous monitoring is not possible.

USE CASE COMPARISON

Just as different BLE solutions were employed in these two indoor positioning schemes, the requirements and the functionality of each approach can also be different in practical use cases. We have considered three use cases (labor monitoring, material and equipment monitoring, and movement analysis) in Table 3, highlighting the key features of the two approaches.

Table 3. Use case comparison of FB and MB approaches

	Fixed beacons - mobile gateways prototype (FB)	**Mobile beacons - fixed gateways prototype (MB)**
Labor monitoring	+ High accuracy monitoring - Requires smartphone compatibility and application installation + Workers likely to consistently carry smartphones	+ Workers need carry only beacons that have been registered. - Workers might leave beacons on site, which can cause invalid data - Limited tracking precision due to lack of coordinates of floor plan
Material & Equipment monitoring	+ Beacons can be used as material and equipment tags. Attaching beacons to material packaging at time of delivery is straightforward, and they can be reused.	

Movement data analysis	+ A movement tendency index can reflect the workers' efficiency + Gaps in data flow can lead to gaps in information accuracy	+Time-location analysis can indicate the uninterrupted presence level at work locations for workers

CONCLUSION

The wide-ranging series of experiments has shown that both methods are feasible for resource location monitoring in construction sites. Both provide a robust solution for monitoring labor, material and equipment.The FB method has lower cost and greater coverage than the MB method. The degree of resolution of location reporting can be greater with the FB method than for the MB method, since the cost of beacons is significantly lower than that of gateways. The MB method has lower latency of reporting because the fixed gateways can communicate in real-time as they do not have the battery life limitations that apply to smartphones.

Both methods appear to provide sufficiently accurate and complete data for deducing which tasks are underway at any given moment and thus for updating project and process status automatically. The location data itself can be communicated visually to construction managers as an aid to improve their decision making. When it comes to movement data analysis, both methods provide data that can be processed to yield insights about workers' movement patterns and the wastes related to movement and waiting. However, the greater location precision of the FB method is an advantage in this respect, because knowledge of workers' presence or absence from the work face location - often defined as a single room or a single apartment - is necessary to distinguish value adding from non-value adding activity.

LIMITATIONS AND FUTURE RESEARCH

Both methods share a few implementation limitations. They both require the assent and cooperation of the workers, they both require setup and some maintenance work, and both are subject to vandalism or intentional sabotage. Full scale implementation will require contract terms that ensure cooperation. It is worth mentioning that implementation processes may vary in some countries. The MB method was tested in China, Peru and Finland. Users in China and Peru were more willing to invest resources to ensure the functionality and proper placement of gateways (for example, using power banks instead of temporary power to keep gateways working). They were also more willing to invest in the infrastructure to ensure dense placement of gateways and theft protection. Unlike in China and in Peru, the gateway implementation in Finland was dependent on the availability of power and there was less motivation to invest time or resources. Implementation strategies seem to be dependent on the availability of resources and willingness to invest time and money on new solutions that do not yet have a proven record of positive return on investment.

Future research should focus on examining the features of the two solutions of BLE technologies and apply them in suitable real use cases serving the purpose of production control in construction. Given the success of the experiments with the BLE tracking technology, numerous specific modes of operation can be contemplated. For example: (1) attaching BLE beacons to primary equipment, such as cutting saws, ladders, etc., to provide additional indicators about workers' operations through the day; (2) attaching BLE beacons to palettes of materials to understand actual material flows delivered from warehouse to jobsites; (3) attaching BLE beacons to site managers and providing them a real-time interactive monitoring experience for onsite acitivities of workers. All of these can improve the detail and the reliability of the information provided to the work planning process, which can then better improve planning and hence productivity. Futhermore, productivity at work locations could be analyzed in terms of value-adding level and waste spent onsite calculated from the tracking system. In addition, research should also focus on data analysis and visualization of the information to define what information site management teams would like to accuqire to enhance the construction process flow in practice.

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DIGITIZING LEAN CONSTRUCTION WITH BUILDING INFORMATION MODELING

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ABSTRACT

Construction projects are becoming more complex due to tighter project schedules, increasing cost and quality pressures and associated continuous change during the execution phase. Technical requirements are also increasing, and division of work between the various technical experts involved is highly fragmented. This results in construction projects with unreliable schedules, cost overruns and defects resulting from the lack of coordination on site. Lean Construction Management (LCM) and Building Information Modelling (BIM) are possible solutions to these challenges. In the past, these two methodological approaches have normally been used independently of each other. The combined implementation of the two methodologies requires the highly systematic setup of project structures, processes and data. This results in huge demand for computing and automation solutions to facilitate and support this synthesis. This paper reports on the implementation of a digital LCM approach. The use of QR codes, Kanban cards and daily meetings demonstrates a new platform to add value to the BIM model and to construction site collaboration. Case study data from five pilot projects – as well as images and workshop findings – are presented and discussed, and the successes achieved and the challenges remaining are examined.

KEYWORDS

Lean Construction Management (LCM), Building Information Modelling (BIM), LCM Digital

INTRODUCTION

Achieving project cost, time and quality targets is extremely difficult. This is the result of increasing complexity, e.g. the demand for safety and (environmental) sustainability, and the increased number of project participants. As a result, construction projects are exposed to a vast range of challenges and feature top-down communication and a silo-oriented, linear mechanistic mindset. Conventional management systems are rather static and rigid, neglecting the fact that construction processes are stochastic with many unknown variables. They are often overwhelmed by unexpected events, and are thus often not accepted by the workforce. The underlying assumptions of conventional management approaches are that:

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- Activities, tasks and dependencies can be defined in isolation
- Site workers and subcontractors share the same understanding of what needs to be done
- Required information is provided
- The desired outcome can be achieved on time if the plan / schedule is followed

However, this does not happen in practice. According to Demir and Theis (2018), projects that do not use any form of LCM approach show a Percent Plan Complete (PPC) of between 40% to 60%. This means that many activities are not executed on time. Given this background, LCM and BIM have been accepted by the industry as the most promising methodological approaches to improving project reliability and performance (Sacks et al., 2009; Mollasalehi et al., 2018).

AIM AND OBJECTIVES

In the past, the two methodological approaches were normally used independently of each other (Sacks et al., 2010). BIM has been used for LCM to enable a better understanding of the object and the related interfaces. LCM, in turn, has been used for BIM as a simpler way of communicating product information to project participants. LCM and BIM do not depend on each other, i.e. LCM works with and without BIM, and the other way round (Sacks, 2009). However, a synthesises of the two methodologies allows the full potential to be realized, i.e. to achieve improved project productivity, resource utilization and delivery times (Singhal et al., 2018; Fosse et al., 2017; Tillmann & Sargent, 2016). The combined use of LCM and modern technology has been the subject of several scientific studies and practical tests. It has been shown that the two approaches are mutually supportive (Fosse et al., 2017; Toledo et al., 2014; Dave et al., 2011). Sacks et al. (2009) and Koskela et al. (2010) as well as Sacks et al. (2010) explored 56 possible interactions between LCM and BIM. Based on this work, Mollasalehi et al. (2018) started the development of the LCM and BIM Maturity Model. So far, the solutions for possible interactions have been more theoretical. Recent studies, however, also analysed the possible interactions between LCM and BIM at trade contractor level (Tillmann & Sargent, 2016; Murphy et al., 2018; Singhal et al., 2018). A study by Fosse et al. (2017) showed the results of the practical implementation of LCM and BIM by a Swedish contractor. The common feature of these studies is that – even though LCM and BIM are linked in a certain way to each other – there is still no true interaction. The focus is more on using synergies, deriving meaning, and visualisation. Given this background, there is still demand for an integrative platform to improve ongoing exchange of project, product and resource information. The aim of this research is to close this gap within the existing body of knowledge. In order to do so, this contribution presents the current development status of a platform called 'LCM Digital', the objectives of which are to:

- Improve collaborative work across trades, technologies and locations

- Harmonize analogue and digital work processes
- Systematic compiling, preparation, analysis and assessment of product, project and process information (big data and machine learning)
- Ongoing evaluation of live data, forecasting
- Automatic project support through the provision of solution proposals using artificial intelligence

THEORETICAL CONCEPT FOR INTERACTION BETWEEN LCM AND BIM

The linking and integration of LCM, BIM and other tracking technologies (e.g. via Bluetooth low-energy sensors, QR codes and mobile devices) is very promising (von Heyl and Teizer, 2017; Cheng et al., 2010; Sacks et al., 2010). To date, BIM construction projects have usually only been modelled down to the level of detail of a master or phase schedule (Dave et al., 2011). The reason for this is that linking tasks, durations, dates and dependencies down to the lowest level is not part of the normal planning process, nor can automated linking currently be guaranteed (Dave et al., 2011). Furthermore, manual linking is very time-consuming. A great deal of research and development into suitable methods and software solutions to improve BIM- and LCM-based planning and scheduling processes is still required (Harris and Alves, 2013). Early alignment of LCM and BIM ensures stable interaction throughout the entire course of the project.

The interaction between LCM and BIM mainly involves the exchange of construction-related information. According to the ISO 12006-3, basic information about construction work can be categorized into products, processes and resources. The object-oriented product information is provided by the BIM model. Process information is the result of LCM planning and scheduling activities. Resource information can be retrieved from the systems that store supply chain information such as properties, capacities and availability of certain resources.

If BIM and LCM are successfully aligned, permanent interaction, exchange and adjustment of this information takes place during planning and execution to reduce variability and optimize workflow. The information, particularly in the central field of interaction, has to be combined and evaluated in such a way that relevant preconditions are considered (Ballard and Howell 2003). Koskela (2000) explores seven preconditions that avoid waste in site processes:

- Construction design (information)
- Components and materials
- Workers
- Equipment
- Space

- Connecting works – previous work
- External conditions – such as weather, government regulations, licenses

The preconditions are named 'seven flows' (Koskela, 2000). If the seven flows are in place, an activity can start and finish without interruption or delay. This means that the seven flows can be permanently addressed if interaction between LCM and BIM is functioning well. This results in reliable and accepted data, which in turn leads to improvements in productivity, durations, and resource consumption and utilisation.

PROPOSED FRAMEWORK

The interaction between LCM and BIM during production planning and execution combines a top-down planning approach with a collaborative bottom-up evaluation of constructability. This engages the workforce in both approaches at the same time: A solution-oriented hands-on collaborative approach as well as a digitally planned and controlled production management approach. The outcomes are more realistic schedules based on 'hands-on' experience. The proposed framework – which basically consists of three LCM and BIM interactions – facilitates this.

First, production planning takes place. This is done in a range of workshops. The schedules are based on the geometric ground plans of the construction project as accessed via the BIM model. The platform also provides process templates for highly repetitive processes, and an activity list for the planning and assignment of tasks related to the planning and execution process. All information is stored centrally and exchanged as needed, getting as close to the vision of a single data source as possible.

Secondly, the data records generated during the planning process are brought to the construction site as work instructions, e.g. in the form of Kanban cards (digital or analogue – as required).

Thirdly, the platform facilitates the active management and control of process execution. The status of current processes and activities is updated semiautomatically using mobile apps and QR codes, enabling reliable determination of key performance indicators to support the early detection of problems, conflicts and constraints. This makes it possible to view and investigate basic system behaviour in a more targeted way, facilitating fundamental and cross-project improvements. The proposed framework for the integration of LCM and BIM is summarized in the Figure 2.

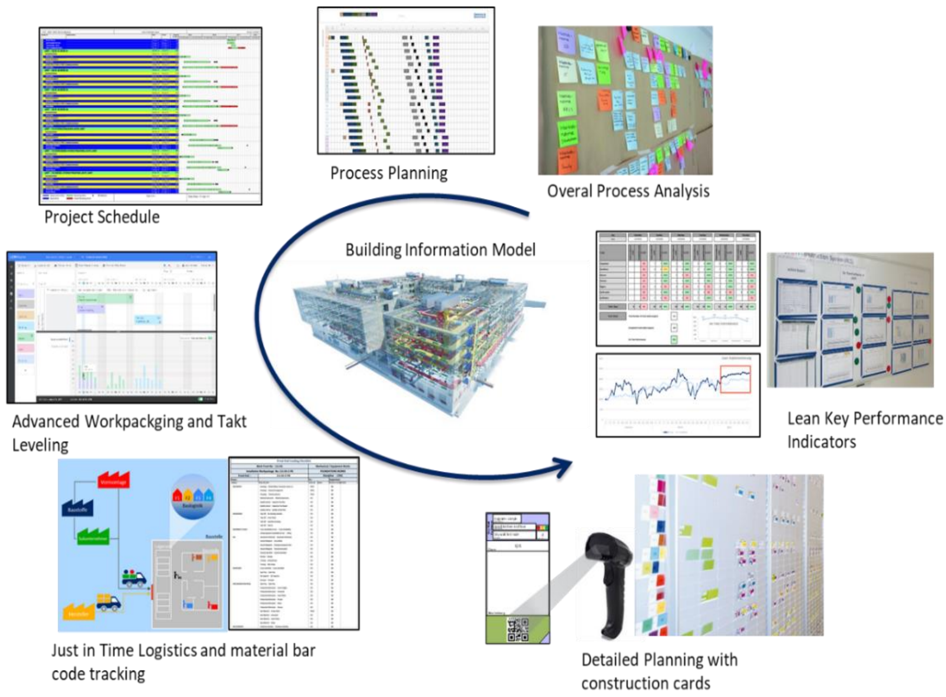

Figure 1: The proposed framework for Lean / BIM interaction

Figure 1 illustrates the proposed framework for the interaction between LCM and BIM, i.e. LCM Digital. The BIM model and the associated information is used to define the execution strategy and implement overall process analysis. This was undertaken in a pull planning workshop. The project schedule was further detailed through process planning. The seven flows (Koskela, 2000) are tracked in cyclical meetings during process planning workshops. The lookahead plan for process planning is between three to six months. The continuous review of preconditions according to the seven flows (Koskela, 2000) enables detection of problems so that they can be solved or alternative process sequences can be determined. Takt planning and line balancing allow resource usage to be optimized to improve performance on site, harmonizing the project heartbeat and creating laminar workflow. To translate this information and strategy to the construction site, daily Kanban cards (work instructions for each trade) are exported and printed out by the online platform. Each Kanban card is a daily target for a crew on site. The start and end of a task are identified with a QR code on the associated Kanban card. These are scanned with a smartphone application by the site team to track the status of the task. The moment the card is scanned, the task progress information is updated on the online platform. The BIM model is also updated, allowing visualization of tasks that have been started, are in progress and have been completed. This facilitates the daily detection of deviations and corresponding problems, which forms the basis for systematic improvement. Overall, this results in a transparent visual management system that is updated in real time and that increases site performance by promoting proactive behaviour. The following sections describe the main elements of the proposed framework in detail.

PRODUCTION PLANNING WITH THE OVERALL PROCESS ANALYSIS, PROCESS PLANNING AND 4D BIM

The central goal of BIM is to manage all project-related data in a virtual building. When the objects are linked to a schedule, the system is called 4D BIM. One common approach is to import the existing schedule into the BIM system. Even if scheduling is undertaken directly in the BIM software schedule application, there is no real change in the way the scheduling is approached. The underlying assumptions of the traditional conversation model remain the same:

- Top-down approach to manage major milestones
- Activities are prioritised by project and construction management
- Schedule content will be understood by the contractors
- Activities can be scheduled precisely
- Activities will start and finish on schedule

Unfortunately, most of these assumptions do not usually apply. 4D BIM can provide many benefits, such as a better understanding through visualization of structural conditions and object-oriented simulation of the schedule. However, if the social management system remains inadequate, an improved technical management system – even a BIM-supported one – cannot truly benefit the project. The conventional conversation model and the related social system can be improved through the integration of hands-on and collaborative workshops. In the ideal case, overall process analysis is undertaken prior to the start of the project. The 3D BIM model supports the workshop through proper visualisation of the project. The workshop is conducted with all available parties. The overall process analysis optimises the entire project process for repetitive and non-repetitive areas. The process steps are sequenced using pull planning, from the back to the front. This is done on brown paper with sticky notes. Remaining design activities are also integrated into the overall process analysis workshops. Bottleneck activities and trades are identified as part of an overall process analysis workshop. Problems, risks and action points are assessed and documented. The results are digitized and then form the basis for the identification of the takt areas. Once the takt time and takt area are clear, the takt train is defined. Metaphorically, the takt train travels through the different takt areas of the building sequencing the various activities accordingly. The number of takt trains running at the same time needs to be clarified based on project circumstances, i.e. resources and requirements.

Process planning integrates the taktable and non-taktable areas. This is done in hands-on workshops. This is undertaken for the entire project duration prior to the start of the project. Lookahead planning is then undertaken in cyclical workshops. The goal of these process planning workshops is to update the activities for the upcoming three to six months. The seven flows (Koskela 2000) are also tracked to enable an activity to start and finish. The results of the workshop are digitized and uploaded to the 4D BIM. This means that – depending on the size and complexity of the project – process planning workshops can be purely digital.

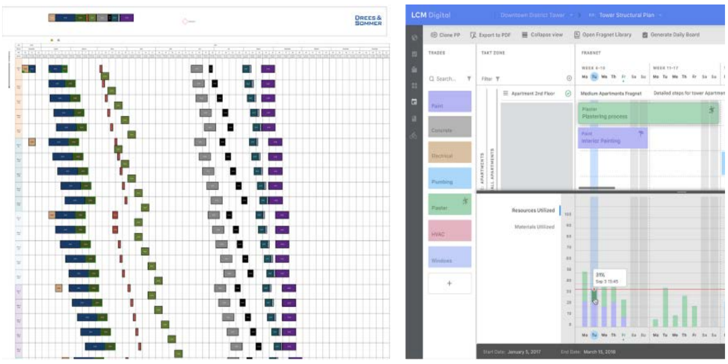

Figure 2: Print view of lookahead planning (left) and platform's data entry field

Figure 2 shows the input and output of LCM Digital. All relevant information regarding duration, quantity, sequence, availability, reliability was tracked through the cyclical interaction between 4D BIM and process planning workshops. The outcome was a more accurate and reliable production planning system.

PRODUCTION CONTROL AND CONTINUOUS PROCESS IMPROVEMENT WITH THE LAST PLANNER AT THE CONSTRUCTION SITE AND BIM

A planning board for the Kanban-Cards was prepared and adapted to the requirements of the construction site. Each row represents one repetitive or non-repetitive work or takt area. Each column represents one day. For the first three to four weeks, each trade details their activities at the planning board daily. Each activity – comprising several predefined operations or daily tasks – is linked to the BIM model by an activity ID. Figure 3 shows how the selected element within the BIM model is related to an activity by an activity ID. Activities that need to be executed are selected in the BIM model. The selection results in a colour coding. Figure 3 shows how the elements selected within the BIM model are shown red. Project participants make selections manually based on process planning.

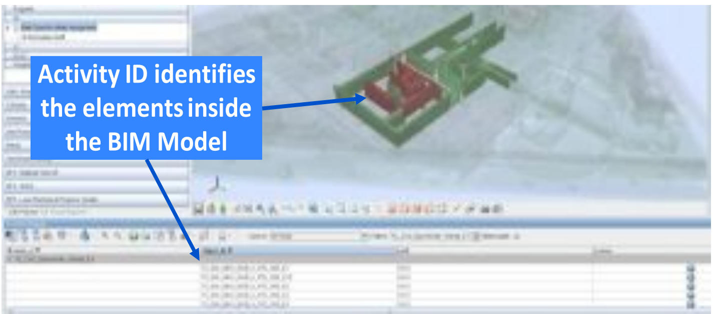

Figure 3: Linking activities and BIM-objects

The information stored in the model also supports prioritisation, e.g. the duration, sequence, and the seven flows (Koskela 2010). Kanban cards are printed by the BIM-linked online platform based on this prioritisation.

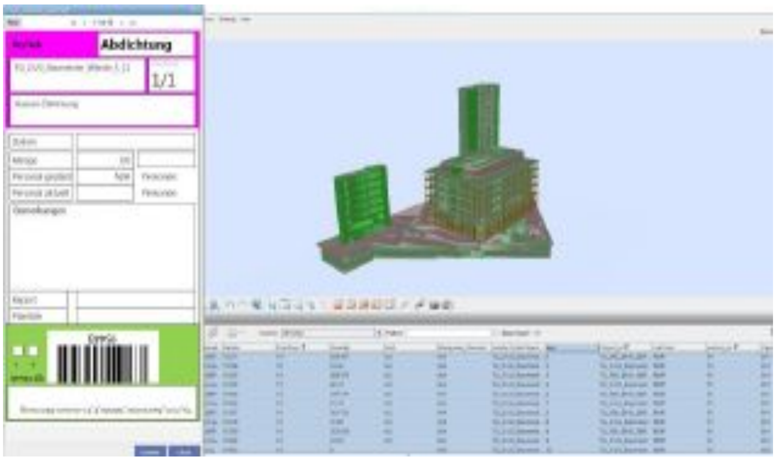

Figure 4: Generating Kanban cards for the last planner at the construction site

Figure 4 shows the printed Kanban cards, which include a QR code to link the virtual and real worlds. Progress is updated and monitored during daily lean leader standard work or lean routines at the construction site, such as daily meetings. The Kanban cards represent the targets for the day. Target deviations are tracked daily. Reasons for deviations are identified and analysed, allowing improvements to be made. Kanban cards relating to started or finished processes are scanned daily and the systems updated. The result is a live status and progress update. Completed cards can be double-checked during daily lean waste walks to ensure that data sets are current and correct prior to any further action.

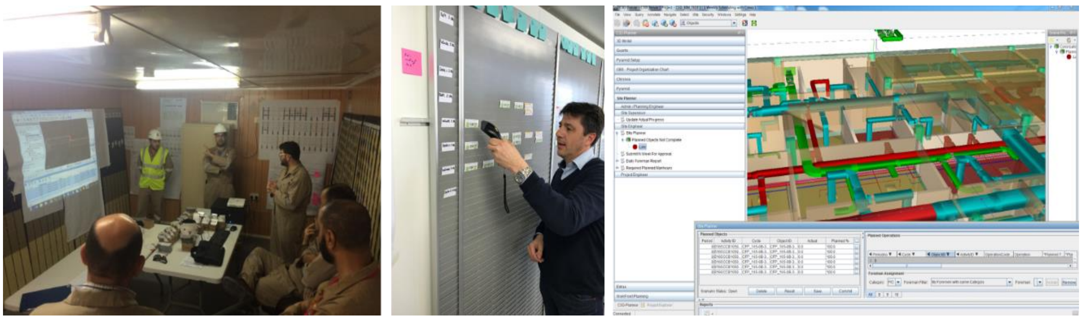
Figure 5: Impressions of the interaction between LCM and BIM at the construction site

Figure 5 shows the interaction between the virtual BIM model and the real construction site. This interaction is primarily enabled through the Kanban cards, tagged with a QR code and printed from the platform. This interaction allows the relevant individuals to gather more accurate information in a timely manner to improve performance. The conventional conversation model is replaced by a new collaborative conversation and interaction model. The project can benefit from knowledge and experience at all levels. Buffers, contingencies, delays and idle time are visualized in real time, supporting the continuous improvement of the construction processes.

CONCLUSION

It has been demonstrated that a platform that facilitates the exchange of information related to products, processes and resources is a key success factor for the integration of LCM and BIM into projects. A successful alignment of LCM and BIM, as well as systematic evaluation of collected data, contributes decisively to an improvement of the general project management as well as to the success of a specific project. So far, several technological concepts have been developed and tested. These include:

- Automated printing of construction assignments (Kanban cards)
- Digital pull planning workshops
- Use of BIM-based quantity take-offs for accurate resource planning and reliable assessment of project performance based on live data (mobile app and QR coding technologies)

One of the main current challenges is the uniform structuring and automated linking of execution-related data sets down to individual elements of a BIM model to facilitate collaborative project execution. Only the acceptance and systematic use of the platform by the workforce will allow meaningful data to be generated. So far, user feedback has been quite positive, stating that it is hands-on, easy and flexible. In conclusion, it can be stated that systematic linking of BIM and LCM via a central platform, as outlined in this paper, validates information and makes it available in a timley and targeted manner. It promotes the cooperation and communication between the individual project participants, and thus makes a positive contribution to social management.

The findings were processed and incorporated into the programming of a web-based software solution called LCM Digital. Further research and development activities will focus on exploring the integration of artificial intelligence, big data and user-experience concepts.

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PREDICTING PERFORMANCE INDICATORS USING BIM AND SIMULATION FOR A WALL ASSEMBLY LINE

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ABSTRACT

Off-site home construction allows for the construction of building components to be completed in an off-site facility. The floors, walls, and roof are constructed on separate production lines, then shipped together to site for installation. This type of home construction presents a good opportunity to utilize lean manufacturing principles allied with simulation methods to better industrialize the home building process. This paper presents a case study of a well-known panelized residential home manufacturer, where the focus is the wall assembly line. Multiple key performance indicators (KPIs) are calculated in order to forecast production for each project and key result indicators (KRIs) are used to predict the outcomes of multiple projects. The predicted performance indicators are found through a simulation model of the production line using quantity take-offs extracted from BIM models. The analysis of these performance indicators will be used to evaluate project feasibility when the project is built in an off-site construction facility.

KEYWORDS

Lean construction, off-site construction, performance indicators, computer simulation, variability.

INTRODUCTION

The construction industry suffers from poor productivity and high levels of waste. The industrializing of construction has long been thought of as a solution to this (Koskela, 1992). Bjornfot and Stehn (2004) define industrialization as a streamlined process promoting efficiency and economic profit. By modelling construction after manufacturing, lean can be applied to construction to solve the shortcomings of traditional stick-built methods. Bjornfot and Stehn (2004) go on to define lean construction as a methodology aiming at streaming the whole construction process while product requirements are realized during design, development and assembly.

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Therefore, the concept of industrialization and the philosophy of lean tie into one another seamlessly. Off-site construction derives its root from the manufacturing industry: entire stick-built construction projects are broken down into components that are easy to manufacture on factory production lines (Zhang et al, 2016).

Ritter et al. (2016) performed a study of the floor area of an off-site construction company (the same company used for the present case study) that focused on the analysis of directly and indirectly productive tasks to determine possible process improvements of the floor production line. By simulating the facility's current state operations, then applying multiple lean improvements to the model, productivity gains were quantified. The results of the future state simulation showed productivity increases and aided management in decision making.

Moghadam (2014) did a similar study of another modular home manufacturing facility. This study focused on the application of lean tools to the manufacturing process, and included studies of the floor, wall, and roof station timings to assist in production levelling. The use of multi-skilled labour was identified as a solution to balancing of the production lines since labourers could move between stations to maintain equal production rates.

Each of these studies provides valuable input on how to make a process more efficient, but does not provide an overall view of the whole manufacturing process. Performance indicators give a clearer representation of the benefits of lean since utilizing traditional accounting methodology is not always obvious (Bhasin, 2008). Performance indicators are used to measure the success of the manufacturing process. Key performance indicators (KPIs) are those indicators that focus on the aspects of organizational performance that are most critical for current and future success of the organization. Key result indicators (KRIs) summarize the activity of more than one team; it is a more overall look at the results of the activities that have taken place (Parmenter, 2010). Both of these performance measures are imperative for evaluating current and past production trends, as well as capturing the outcomes of the variability of project sizes. Through the use of performance indicators, lean improvements to the off-site manufacturing facility can be analysed.

The tools used to calculate these indicators are building information modelling (BIM) and computer simulation. BIM is a technology used to integrate the architectural and structural design, modularity concepts, and framing best practices into one model that helps the end-user during the decision-making process (Alwisy et al., 2012). Sacks et al. (2009, 2010) provided a conceptual framework for assessing the interconnections between lean and BIM and they identified 56 interactions through their developed matrix. Using the BIM model, it is possible to extract quantity take-offs that can be used in the simulation model.

Simphony.NET is an integrated environment for simulating construction activities that was developed by AbouRizk and Mohamed (2000). Simulation models are used to replicate complex operations and give valuable output regarding productivity, resource utilization, and material usage. Based on the output of the simulation model, it is possible to calculate these performance indicators and forecast manufacturing operations.

MOTIVATION

The objective of this paper is to use performance indicators to predict the outcomes of building the walls of a construction project in an off-site construction facility. Based on material quantities extracted from BIM models and the results generated from computer simulation, many performance indicators are evaluated. The predicted key performance indictors give insight into project specific production (cost and productivity): these indicators aid management in determining if a project is feasible. The predicted key result indictors are used to evaluate production outcomes over multiple projects (material usage, time and cost). By comparing actual production measures to the predicted performance indicators, management can determine material, budget, and schedule deviances.

METHODOLOGY

This research combines BIM modelling and discrete event simulation to predict the performance indicators of a wall production line for potential projects. Figure 6 shows the overall process used to extract information from BIM models, organize the information into a database, and feed this information to a simulation model to get data for calculating KPIs and KRIs. The information is extracted from each BIM model through a Dynamo script and parsed through a developed add-on in two stages: (1) sequencing and combining of all panels in the project into panels of maximum length of 40 feet, and (2) addressing each panel's attributes relevant to the simulation model as per Barkokebas et al. (2017). All information is stored in Microsoft Access and imported in the simulation model for the development of KPIs of each project.

Figure 6: Process Diagram of Information Flow

The first step is to construct a current state simulation model of the wall production assembly line as shown in *Figure 7*. The simulation model was developed through discrete event simulation in Simphony.NET, a program developed by AbouRizk and Mohamed (2000). The current production process consists of ten stations as outlined in Table 3. To build the current state simulation model, each of the ten stations are broken down into multiple tasks with deterministic and heuristic durations dependent upon each panel's attribute such as number of openings, area, and use (exterior or interior). Each station also includes a probabilistic chance of delay that has a distributed duration. The tasks' durations are constant because of the high level of automation and standardization used in the manufacturing process. Simphony.NET is used to find the best fitting distribution for the delay durations based on the time study data gathered. Resource constraints for the number of labourers and equipment are also represented in the model. Altaf (2016) verifies and validates this simulation model in his doctoral dissertation. The inputs required for the simulation model are the number of window and door openings, studs, OSB sheets, corners and intersection and beam pockets. From this information, the total wall area, number of multi-panel walls, and number of single panel walls are determined.

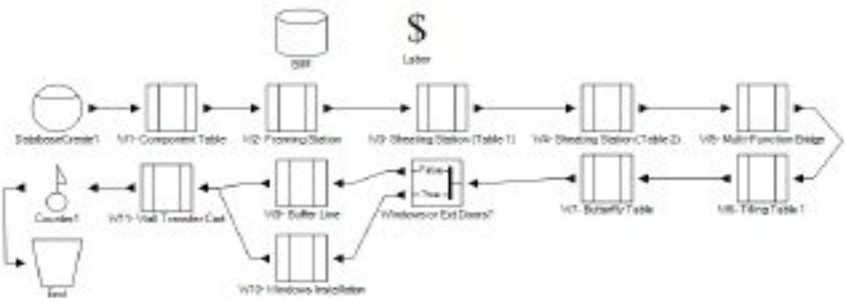

Figure 7: Wall Production Line Simulation Model

Table 3: Wall Production Stations

Order	Station	Description	Crew Size (persons)
1	Component table	Opening rough-ins are assembled prior to framing	3
2	Framing station	Studs, plates, and pre-assembled components are nailed together	2
3	Sheathing Station 1	Label walls, and place hooks	3
4	Sheathing Station 2	Place blocks, OBS sheathing and vapour barrier	3
5	Multi-function bridge	Nail sheathing	1
6	Tilting table	Sheathing quality control	2
7	Butterfly table	Place rods, and cut exterior walls	2
9	Buffer Line	Backing and plastic wrap	3
10	Window/door installation	Installing windows and doors where it applies	5
11	Wall transfer	Flip wall	1

The next step is to gather all the take-off information from the BIM models. This is done by data parsing to gather the necessary information for every wall (single panel information). In order to efficiently construct the walls, the single panel walls must be arranged into multi-panel walls; this is done through the use of a greedy algorithm. This algorithm arranges single panel walls of the same size (2”x4”, 2”x6” or 2”x8”) to be as close as possible to the machine limit of 40’ in length. Data parsing is used again to gather the single and multi-panel data; this data is then exported to a Microsoft Access database that feeds the information into the simulation model. In this study, the BIM models of 5 commercial projects and 1 residential house are used. The information extracted from the BIM models and used in the simulation model is shown in Table 4.

Table 4: Project Information

Project ID	**Project**	**Number of Multi-Panel Walls**	**Number of Single Panel Walls**	**Total Wall Area (SF)**
1	BC Residential Housing	5	20	1785.33
2	Kamsack Liquor Store	18	25	5113.37
4	ATCO Site Office/Washroom	8	28	2006.18
5	ATCO Small Office/Washroom	3	8	559.07
6	ATCO Office Building	22	72	10587.35
7	Car Wash	4	8	607.73

Each project is put through the simulation model separately and for one thousand runs. All multi-walls of each project are released to station 1 at time zero. The simulation model outputs are: directly productive time (min) and waiting time (min) for each station. The hourly rate for crew workers is assumed to be \$25/hr and the overhead rate for the facility is assumed to be \$4500/hr. From the simulation results, the predicted KPIs are calculated as shown in Table 5. The predicted KRI values are calculated through the formulas shown in Table 6.

Table 5: Key Performance Indicators Formulas

KPI	**Formula**
Total Project Cost (\$)	$= \left[Directly\ Producitve\ Time\ (min) * Crew\ Size * 0.42\left(\frac{\$}{min}\right)\right] + [75\left(\frac{\$}{min}\right) * Lead\ Time(hr)]$

$$\text{Productivity (SF/min)} = \frac{Total\ Wall\ Area\ (SF)}{Project\ Lead\ Time\ (min)}$$

$$\text{Project Cost (\$/SF)} = \frac{Total\ Project\ Cost\ (\$)}{Total\ Wall\ Area\ (min)}$$

Table 6: Key Result Indicators Formulas

KRI	Formula
Total Material Usage	$\sum_{i=1}^{n}(\text{total wall area}_\text{i})$
Total Lead Time	$\sum_{i=1}^{n}(\text{project project time}_\text{i})$
Total Cost	$\sum_{i=1}^{n}(\text{project cost}_\text{i})$

RESULTS

The simulation output for the productive and waiting times for each project are shown in Table 7 and *Table 8*. Figure 8 shows the total time per station for each project found by totalling the simulation results. The first spike in total time is due to significant waiting times found at stations 1 and 2 (component table and framing station, respectively). Wait times are highest here because all multi-walls are released at time zero to station 1, meaning there is a backlog of walls to begin with before they make their way down the assembly line. The second spike in total times occurs because of the long productive times of stations 9 and 10 (buffer line and window/door installation, respectively). Station 9 has a high productive time for the projects that need beam pockets, and is zero for projects that do not require them. The variability in the number of openings (windows and doors) strongly influences the productive time of station 10: if the multi-wall contains many openings, the productive time greatly increased. The simulation results identify stations that could be targeted for lean improvements to reduce project lead time. In this analysis, the stations with the highest wait times and productive times should be the focus of lean improvements. It is also important to note that the productive and wait times are highly variable due to the range of project sizes.

Table 7: Simulation Results - Productive Time

	Productive Time (min)									
Project ID	**@W1**	**@W2**	**@W3**	**@W4**	**@W5**	**@W6**	**@W7**	**@W9**	**@W10**	**@W11**
1	7.70	12.21	6.50	8.48	3.44	1.70	2.83	0.00	32.34	2.70
2	5.57	9.64	3.14	6.55	3.12	1.70	2.83	77.56	49.84	2.70

4	11.55	13.21	6.72	5.23	3.14	1.70	2.83	152.97	51.74	2.70
5	14.73	11.92	6.43	4.49	2.96	1.70	2.83	0.00	55.84	2.70
6	9.98	15.53	6.78	3.47	3.75	1.70	2.83	205.04	72.45	2.70
7	12.59	10.68	4.95	4.52	2.81	1.70	2.83	0.00	46.38	2.70
Average	10.35	12.20	5.75	5.46	3.20	1.70	2.83	72.60	51.43	2.70

Table 8: Simulation Results - Waiting Time

	Waiting Time (min)									
Project ID	**@W1**	**@W2**	**@W3**	**@W4**	**@W5**	**@W6**	**@W7**	**@W9**	**@W10**	**@W11**
1	17.46	12.29	0.00	0.00	0.03	0.00	0.01	0.00	0.00	0.00
2	69.61	67.63	0.00	0.00	0.25	0.00	0.09	0.00	0.00	0.24
4	55.98	12.39	0.00	0.00	0.27	0.01	0.09	0.00	0.09	0.14
5	14.90	0.38	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.08
6	109.35	82.59	0.00	0.00	0.23	0.00	0.01	0.00	0.00	0.12
7	23.59	7.39	0.00	0.00	0.35	0.02	0.15	0.00	0.00	0.00
Average	48.48	30.45	0.00	0.00	0.19	0.01	0.06	0.00	0.02	0.10

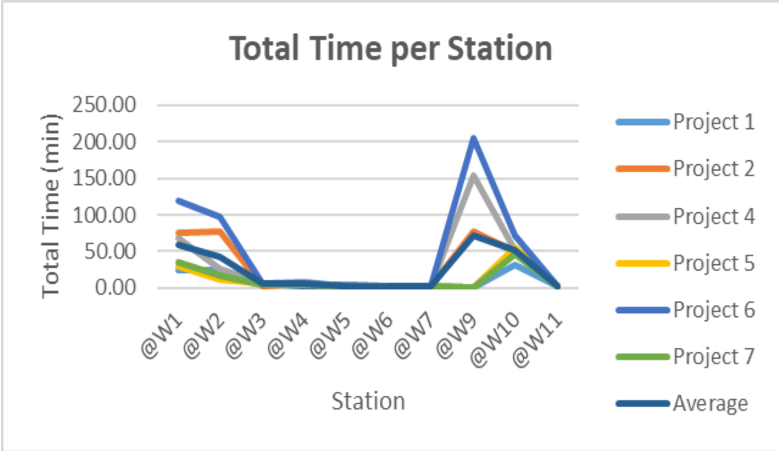

Figure 8: Total Time for Each Project

The predicted KPIs for the wall assembly line are shown in Table 9. These predicted values can be compared on a per project basis with actual KPIs once a project has been completed to determine material, schedule, and budget deviations. It was found that as project size increases, productivity increases and cost per square foot decreases, along with the obvious total project cost and time increase. This productivity increase and cost per square foot decrease occurs because wait times do not significantly increase when a larger project is being worked on. This is due to resource utilization of each station not being maximized. Once resource usage is maximized, wait times will increase, causing productivity to decrease and cost per square foot to increase. Therefore, productivity and cost savings can be gained by constructing projects with higher square footages of wall area, until resource utilization is exhausted. Figure 9 plots project size vs productivity with a linear trend line, which has $R^2 = 0.6453$. Figure 10 plots project size vs cost with a linear trend line, which has $R^2 = 0.5216$. These R-squared values are seemingly low but do still provide proof of a correlation, given the small sample size. Furthermore, total project cost and project time vs project size (not shown graphically) were found to have $R^2 = 0.8245$ and $R^2 = 0.8260$, respectively. This reinforces results from the simulation model for the time and cost increases when constructing larger projects.

Table 9: Predicted Key Performance Indicators

Project	Project Size (SF)	Productivity (SF/min)	Direct Cost ($)	Indirect Cost ($)	Project Cost ($)	Cost ($/SF)
1	1785.33	16.58	61.07	8076.57	8137.63	4.56
2	5113.37	17.02	154.50	22534.71	22689.21	4.44
4	2006.18	6.25	263.72	24057.65	24321.37	12.12
5	559.07	4.70	74.24	8924.97	8999.21	16.10
6	10587.35	20.50	336.08	38738.45	39074.54	3.69

7	607.73	5.04	64.63	9048.40	9113.03	15.00

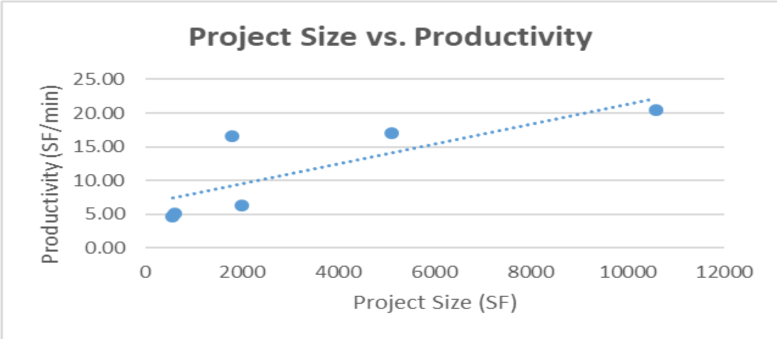

Figure 9: Productivity of Each Project

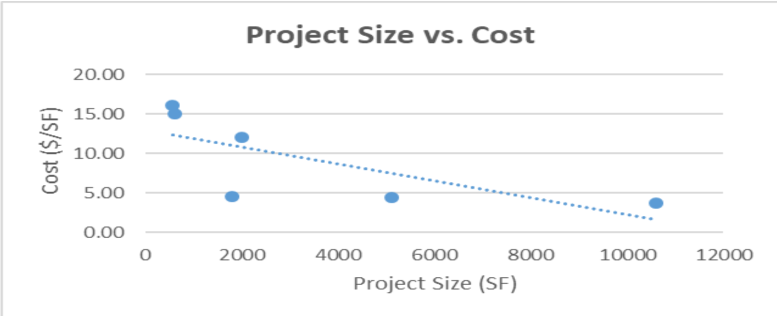

Figure 10: Cost of Each Project

Since each project produces a high variability of results further analysis into production over a specified time period is necessary. The predicted KRI values are shown in *Table 10*. These values are a summation of material, time, and cost requirements for completing all six projects. By comparing the predicted KRI values to actual material, time, and cost outcomes, production can be evaluated in terms of material, schedule, and budget deviations over the entire production period. Table 11 defines how to interpret the deviations of predicted vs actual KRI values. Evaluating production over numerous projects gives an overall analysis of facility performance rather than focusing on project-specific production.

Table 10: Predicted Key Result Indicators

Total Material Usage (SF)	20659.03
Total Project Time (min)	1485.08
Total Cost ($)	112335.00

Table 11: Key Result Indicator Interpretation

KRI	**$\Delta = KRI_{actual} - KRI_{predicted}$**

Total Material Usage	+ Δ = material waste - Δ = material saving
Total Production Time	+ Δ = schedule delay - Δ = ahead of schedule
Total Cost	+ Δ = over budget - Δ = under budget

LIMITATIONS AND FUTURE WORK

This research is limited by the separate simulation of each project. This method does not completely reflect actual production methods of releasing a new project to the floor once there is resource availability at the first station. The method of simulating production over multiple projects is preferable to simulating projects one at a time because rarely will a single project have the entirety of the factory floor. If only one project is simulated, the waiting time will only be accumulated due to the backlog of multi-walls of one project and not due to the wait time of projects catching up to one another. Calculating performance indicators based on only a single project will lead to a slight overestimate of production and underestimated costs. In the future, it would be useful to simulate production continuously over all projects in order to determine the additional wait time that would be accumulated. Furthermore, it would be ideal to simulate a larger number of BIM models in order to prove a stronger correlation between productivity and cost vs project size. If enough projects have been simulated, predictive data analysis techniques such as regression, clustering, or time series analysis can be used to predict the KPIs of possible projects without having to construct a BIM model to be used in the computer simulation model. Through the data analysis of performance indicators, it will be possible to efficiently evaluate the feasibility of potential projects in an off-site construction facility. Another limitation of this research is the focus on only the wall production line. In the future the same analysis should be done for the floor and roof production lines in order to determine the performance indicators of the whole projects, rather than just those for the wall production line.

CONCLUSION

Through BIM modelling and computer simulation the productive and waiting times for the wall assembly line was determined for six different projects. Using these times and information from the BIM model, numerous key performance indicators were predicted. Upon analysis of these KPIs it was found that as project size increased, productivity (SF/min) and cost ($/SF) decreased. Additionally, the predicted key result indicators for construction of all six projects was calculated. Based on these results, the feasibility and outcomes of producing walls through off-site construction can be measured. On a per project basis the predicted KPI values can be used to determine the schedule, budget, and material implications. While the predicted KRI values give an overview of the total material, schedule, and budget requirements of production over several projects.

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SITE LAYOUT PLANNING THROUGH BIM VISUALISATION – A CASE STUDY

Paramjit Singh Lota[1], and Jyoti Trivedi[2]

ABSTRACT

Site layout planning is a critical factor for the successful execution of any construction project. As cities develop, site logistics becomes an essential planning aspect for any construction project. Project sites in tight neighbourhoods lead to not just space constraints but also challenges to approach, material handling, and pollution control. Site layout planning has been in practice in the industry, however, limited to a traditional approach of a pre-construction assignment, rather than a dynamic system to analyse construction sites in terms of both space and time. Material handling and delays related to waiting for materials add to a considerable amount of waste during the execution of projects. The paper here explores minimisation of wastes on construction sites, as defined by Lean Construction, using a BIM model highlighting the construction site layout planning to visualise the various aspects of space constraints, access routes, safety considerations, and a visual approach to progress monitoring and reporting. The research follows a case study analysis to develop an understanding of the present scenario, based on which a proposed scenario has been developed to elaborate on the improvements. The paper concludes with a summary of wastes observed and minimised, along with benefits observed through BIM implementation.

KEYWORDS

Lean construction, site layout planning, site logistics, building information modeling (BIM), and BIM visualisation.

INTRODUCTION

Site layout planning is traditionally done to highlight the various areas of logistics required for the construction works to be executed on site, with an idealistic approach of only space constraints. Further, a 2D representation of the site limits the understanding of the project team to the complications arising with the development of the project on site. Improper planning can lead to tremendous wastes in terms of unnecessary transport of materials and other resources around the site (Singh & Delhi, 2018). Material logistics planning is

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essential for efficient project delivery, supporting lean construction by reducing unnecessary transportation and material handling, which are regarded as wastes (Cheng & Kumar, 2015).

Lean Construction conceptualises “wastes” as hidden in construction processes. Rework due to design or construction errors, and non-value adding activities in the material and workflows, such as waiting, moving, inspecting, duplicated activities, and accidents are highlighted as the factors creating inherent waste on construction site (Koskela, 1992). Waste minimisation, enabled by Lean Construction, is driven by the primary goal to reduce non value-added time in construction processes. Further, it is also essential to make the wastes visible to the project team. This is where visualisation through BIM is proposed to enable all stakeholders to commonly develop an understanding of the site constraints and the supporting processes.

Construction projects in cities, as part of rapidly growing urban centres, have critical space constraints, with several projects coming up in densely packed residential areas, thereby adding to constraints of working hours, pollution and approachability. A number of these projects are now depending on supplied RMC through Transit Mixers for concrete, instead of providing for on-site concrete batching plants due to space limitations on site. Thus, the activity of concreting, a primary activity of typical construction projects, becomes extremely critical for such sites. Such project sites require extensive planning to factor in the lead time for concrete delivery based on the vendor's location, vis-à-vis the scheduled activity of concreting on site. Numerous projects plan activities such that multiple elements of concreting are sequenced to be carried in one go, in accordance with the amount of concrete being supplied by the Transit Mixture.

Singh and Delhi (2018) proposed an AR-BIM model tool for site layout planning, expecting to minimise construction wastes on site. However, the tool was in the development phase and hence, not implemented yet. Though a similar approach has been applied here, the authors, in this case, have developed a BIM model of the existing site layout of a project currently under execution. Based on the visualisation provided by this BIM model, the authors have developed a proposed site layout BIM model to enable minimisation of wastes on the site. Further, the various aspects of the construction activities on site have been analysed for highlighting the various observed. The BIM enabled visualisation of the project site layout is proposed as an essential planning factor prior to the execution of the project.

LITERATURE REVIEW

Pikas et al. (2011) highlight the importance of visualisation in enabling project teams to develop a shared understanding of the project. This is further backed by Dave et al. (2013) stating the benefits of visualisation to scheduling. Such mutual understanding, when developed for site layout planning prior to execution works commencing on site, can enable the generation of flow through minimised wastes during construction activities. Guerriero et al. (2017) suggest how virtual 4D planning, through an IPD approach by gaining constructability information from the Contractor, can enable modeling of temporary structures and management of tight site conditions. This makes the early involvement of stakeholders essential for pre-construction activities, enabling better planning for the execution on site.

The fact that Lean Construction and BIM have positive synergies has been well established by Sacks et al. (2010). This is further reinforced by Fosse et al. (2017) by stating the benefits observed by several contractors by integrating both Lean and BIM in construction projects. Multiple authors have highlighted the similarities in working principles and the importance of BIM and Lean integration for projects to reap Lean efficiency gains and reduce wastes in their processes (Gerber et al. 2010; Guerriero et. al. 2017). Sacks et al. (2010) elaborate on the fact that though cycle time is reduced by BIM, the comprehensive benefits can only be achieved when its meaning is perceived clearly, thereby supporting the integration of Lean and BIM.

BIM-based constructability analysis contributes to Lean and green outcomes, as highlighted by Ahuja et al. (2016) in their case study of green Indian projects. The factors enabling this have been identified as reduction of rework, minimisation of errors, and improved productivity and performance.

However, despite the benefits of BIM and Lean Construction and their integration on projects, BIM implementation has been limited to the design phase of the project (Jin et al. 2017), and to some extent to the construction phase (Pikas et al. 2011). An exploration into BIM use for site layout planning is generally overlooked. The literature review highlights a limited exploration into the development of a BIM model for site layout planning.

Bortolini et al., 2015 explores the planning and controlling of logistics processes with the use of 4D BIM modeling. The paper studies the use of BIM to simulate both value-adding and non-value-adding activities, such as waiting, inventory and moving materials, as well as site layout. However, the case explored was in context of engineer-to-order prefabricated building system, devoid of several site constraints related to space, access, and safety.

The paper here aims to address this gap by understanding the site layout constraints of a typical construction project in India and reducing wastes observed by the visualisation enabled through the BIM model developed.

RESEARCH METHODOLOGY

The research aims to understand the importance of site layout planning to minimise wastes observed on construction site and add value to the project through collaborative planning, by visualisation through BIM models developed for the site layout of the project.

The paper adopts a case study approach of commercial development in an urban city in India. The project was studied over a period of three months, during which the BIM model of the existing site layout was developed based on extensive documentation and site visit by the authors. The proposed site layout BIM model was developed based on the understanding of the processes of construction activities documented over these visits.

The work is supported by direct observation and interaction with the project teams. The interactions were essential to understanding the processes linked to the construction activities being executed on site, and the challenges and limitations faced. Observations over the various site visits enabled a real-time understanding of the nuances of these constraints, that were generally overlooked during the interactions with the project team.

SITE LAYOUT PLANNING CASE STUDY

The project under study is a G+13 commercial development project with 3 Basement levels, currently under execution at the 8th-floor roof slab level. Located in a rapidly developing city in India, the project is proposed to house retail stores and office spaces. The BIM model was developed during the execution phase, providing an understanding of the limitations of the current site layout vis-à-vis the activities being executed on site, based on which a proposed layout was developed to overcome the observed limitations.

EXISTING SITE LAYOUT BIM MODEL

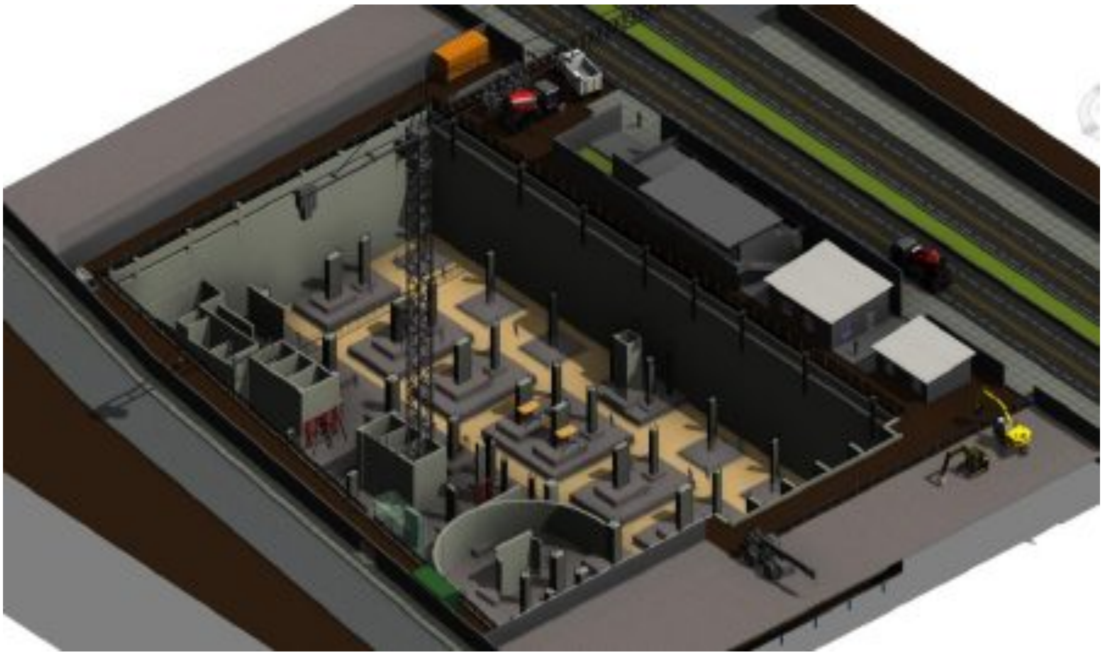

Figure 11: Existing site layout BIM model

The BIM model was developed using the drawings provided by the Project team, along with multiple site visits to understand the existing layout in terms of space, material and equipment logistics. A detailed model was developed based on a thorough understanding of the on-going activities on site, and the processes enabling them. Figure 11 shows the existing site layout BIM model. The image shown here is of the model progressively developed along with active participation with the project team. The model tracked the activities from excavation to now showing the foundation work that was being executed on site. The dynamic development of the model enabled the team to further pull BIM for various discussions concerning the planning of activities being executed on site.

The existing site layout model shows the location of the various components on site, including the sales office, site offices, stores, material un-loading points and the various equipment being used on the project site. The same has been highlighted in Figure 12.

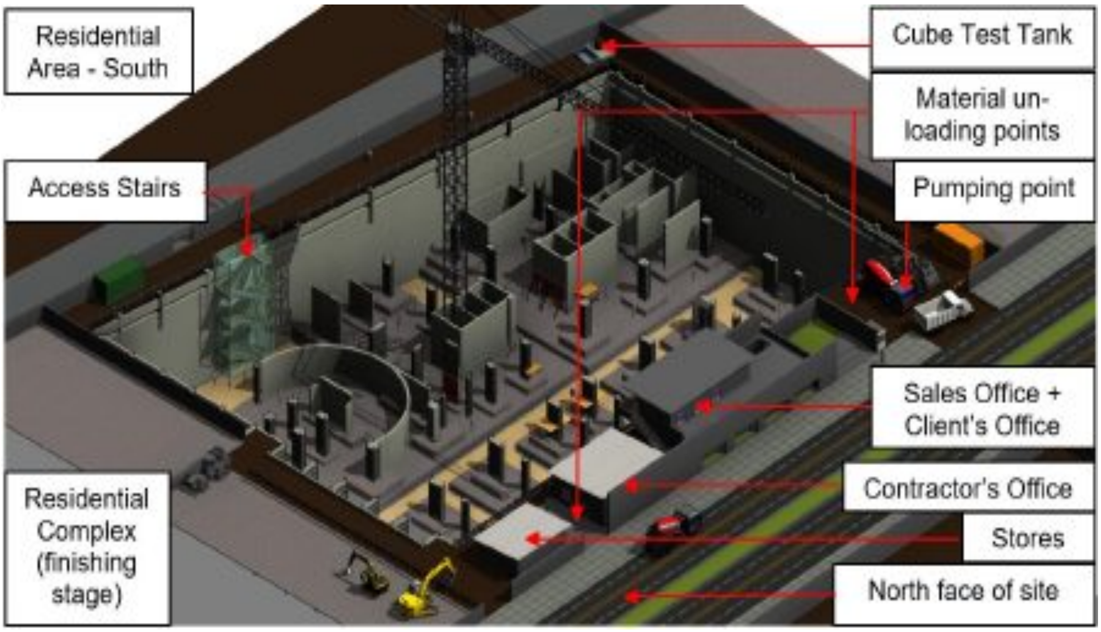

Figure 12: Exiting site layout BIM model highlighting the various site components

Figure 13: Primary material un-loading and concrete pumping point

SITE LAYOUT ANALYSIS

The site is located on the main road. To the west of the site, there is a storage depot while to the east is a residential complex under construction (finishing stage). To the south is a by-lane leading to the dense residential neighbourhood (Figure 12).

The project site is adjoining built plots on either side. The direct and most accessible side is to the North of the site, i.e. the main road. This side becomes the most crucial for all construction operations on site. The sales office, site offices, stores, material un-loading points as well as concrete pumping points are all housed on this side (Figure 13).

Key limitations of the existing site layout

Based on various site visits, several limitations have been critically observed on site. The primary limitation is of space constraint, due to which storage of material and equipment is very poorly managed on site. A lot of material is observed lying around at various locations on site, making the access unsafe. The barricade to ensure fall-protection is damaged at various parts on site. At various parts, the site-team is expected to walk over temporarily store rebars on site, making the access further unsafe.

The second key limitation is the access constraint to site. The limited frontage available at the north face towards the main road for receiving material and RMC leads to excessive crowding of transporters on site; trucks and Transit Mixers. This leads to excessive waiting at times, due to the limited organisation of space to house the transporters. Further, transporters occupy parts of the footpath for waiting, thereby increasing the responsibility of cleanliness and maintenance of the same by the project team, adding to extra work.

The cube testing curing tank present on site is located at the far southwest end. Samples prepared at the unloading area to the north are taken all the way for curing of the Cube - test samples. Presently there is no dedicated quality testing lab on site.

Unloading of materials, deployment of equipment by mobile crane, preparation of cube-test samples, pumping of concrete, etc. are some activities which raise critical safety and quality concerns in practice.

PROPOSED SITE LAYOUT BIM MODEL

Figure 14: Proposed site layout BIM model

Construction Site layout planning is done by identifying, sizing, and placing all the facilities, safely and efficiently, within the boundaries of the construction site. The issues identified with the existing site layout have been addressed here.

The proposed site layout model has been developed (Figure 14) considering how the planning could have been done for locating the Sales & Site offices, Quality Lab & Material Store, and the labour provisions. The sales office has been moved to the N-E corner of the site, thereby clearing out maximum space for the concrete pumping and material unloading points. The provision of two points will ensure complete coverage of concreting works for the site. Further, the centrally located Store & Material testing lab ensures minimum movement of material around the site (Figure 15).

Safety barricading has been proposed on the main-road facing side of the site, with dedicated access gates for parking the transporters and other heavy equipment, thereby creating a safer environment on site. Labour provisions have been provided next to the access staircase with appropriate sheltering and toilets for the convenience of the labour workforce operating on site. Clear area has been demarcated for material stacking at the south side, creating a sense of organisation and order in the site layout.

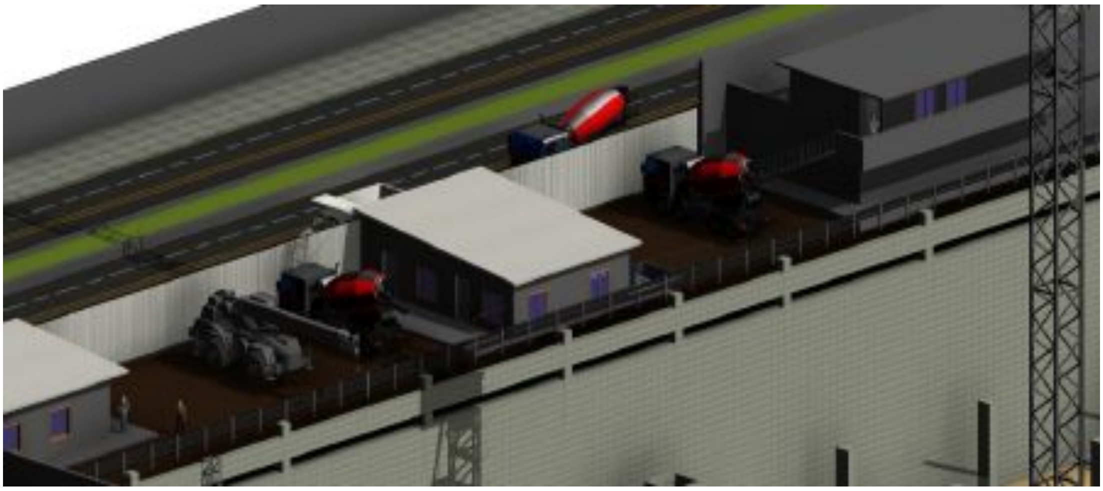

Figure 15: Proposed central store and quality testing lab

As discussed repeatedly, the site location is such that site boundary is extremely close to the building perimeter. The storage area is limited, and concrete can be pumped from only one side of the site. Due to space constraints on site, judicious use of access points for construction activities is a must, based on which the proposed layout has been developed. By proposing two unloading points, an attempt has been made to minimise wastes by reduction of waiting time, increase flow by mobility of equipment and labour, and generation of value by providing a safer and organised environment for activities on site. The simultaneous use of two points for pumping of concrete would enable minimum waiting and allow for concreting activities to complete sooner. Though the logistics requirement would also increase to enable the same (more manpower, two concrete pumps, etc.), the potential of such a scenario is possible and critically important for such sites, wherein space constraints are a major hindrance to the execution of the project.

To illustrate a more practical scenario, the team could enable the two points by using one for concreting of slab pours using a single concrete pump, while the other unloading point could be simultaneously used for the casting of vertical members using a concrete bucket and the tower crane on site. This would considerably reduce the waiting time of activities.

Importance of early involvement of stakeholders

The exploration through BIM visualisation done for this research is brought about by the essential requirement of early involvement of stakeholders, driven by the principles of Integrated Project Delivery (IPD). BIM enables IPD, and the fact that such site layout modeling is possible stands to show the need for involving contractors at the right stage of project planning to enable efficient execution of construction activities. The case study here highlights the crucial requirement of providing frontage to the side at the access from the main road, wherein the sales office was developed by the Client before the Contractor was mobilised on site. This location has proved to be of inconvenience for the Contractor to set up the required infrastructure and execute the activities on site. With early involvement, such collaboration would enable discussion through visualisation provided by BIM models, that can help teams to be better prepared for the execution stage.

Summary of wastes observed and minimized in the site layout planning

The table below (Table 12) highlights the summary of wastes, as defined by Lean, observed and minimised through appropriate planning of the proposed site layout. The visualisation offered by BIM was observed to enable discussion on these between the project team.

Table 12: Summary of wastes observed and minimized through the proposed site layout

S. No.	Waste Identified	Existing Site Layout	Proposed Site Layout
1.	Waiting, Overproduction, Transportation	Inappropriate location of sales office leading to space constraints for loading & unloading of material and pumping of concrete.	Relocated to the corner of the site, in order to clear out maximum usable space in the centre for construction activity.
2.	Motion, Defects, Transportation	Currently, there is no provision of Quality Lab on site. The Curing Pond is located at the S-W corner of the site, making it difficult to bring samples all the way.	A dedicated Quality Lab is proposed along with the Central Store, at the unloading points. The Curing Pond too has been moved adjacent to proposed lab
3.	Transportation, Motion	The newly made Store on site is adjacent to the Contractor's Site Office, with very narrow access, making unloading and movement of material extremely tedious.	In the proposed layout, the Store has been proposed in the centre of the access face, making it accessible from both sides of the unloading zones.
4.	Motion	Labor provisions of Toilets and Canteen are placed in the middle of the access route to the South, leading to crowding.	Labour provisions have been moved to the S-E corner, after the access route to the excavated site, minimizing any crowding and making access more convenient
5.	Inventory, Overproduction	Excessive material stacking is observed at multiple locations. TMs are ordered in excess leading to temporary inventory	Organized layout with dedicated space for storage and parking enables dedicated scheduling of materials to be brought on site
6.	Defects, Transportation	Currently, the access face of the site is devoid of any safety barricading, spilling most of the activities on the main road.	To avoid such a safety hazard, the proposed site barricading of 4m ht. is proposed to ensure the safety of passers-by.

BENEFITS OF BIM FOR SITE LAYOUT PLANNING

The development of the proposed site layout enabled various discussions with the project team. The visualisation offered by the model was also helpful in enabling other stakeholders and fellow colleagues to better understand the project conditions and progress, without having to visit the site. This stands to show that efficient reporting to the Client, as well as the higher management at the Contractor organisation can be enabled through model development.

Further uses of BIM were explored during this process. The intent was to understand the potential of BIM in the execution phase, for enabling a lean approach to construction activities on site. Some of these explorations have been highlighted in the following sections.

DETAILING OF CONSTRUCTION ACTIVITIES

Certain construction activities could be detailed to highlight cases of rework or failure analysis. For this purpose, a portion of the retaining wall that collapsed on site was highlighted in this model to clearly illustrate the rework strategy undertaken (Figure 16).

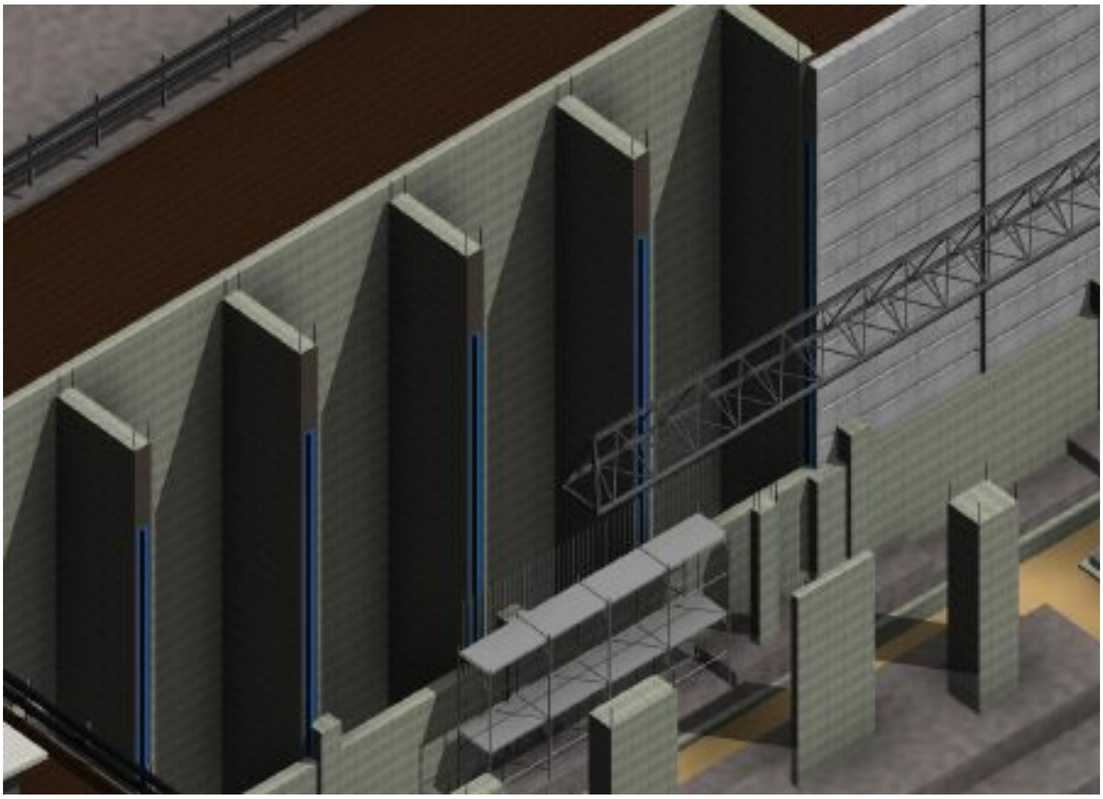

Figure 16: Detailing of construction activities

EXPLORATION OF FORMWORK BEING USED ON SITE

The model was developed to also highlight the formwork being used for columns and shear walls on site. It was realised that plug-ins are now available for use with BIM platforms to enable prior planning of formwork for the execution stage of the project (Figure 17).

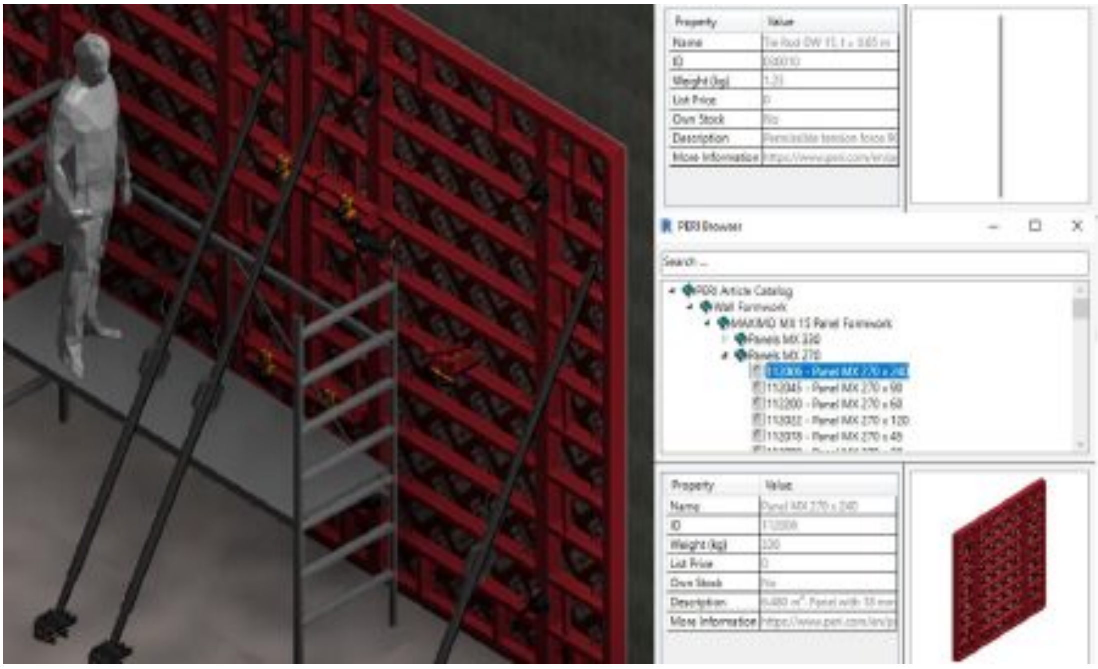

Figure 17: Formwork detailing enabled through a plug-in for BIM platform

Such involvement of formwork planning during the pre-construction stage of the project through BIM implementation can enable accurate estimation of requirement and on-time delivery of appropriate material to the site during the execution stage of the project.

CONCLUSION

The research stands to show the potential of BIM in site layout planning and monitoring of construction activities on projects. It strives to highlight that lean principles of waste minimisation and value generation can be obtained through appropriate site layout planning, leading to time and cost savings for the stakeholders of the project. The essential factor for enabling this is to have early involvement of stakeholders, driven by an IPD approach.

BIM visualisation enables collaboration between stakeholders, as has been observed by the authors through active participation with the project teams. The authors conclude that a deeper understanding of construction activities and constraints on site develops through the visualisation offered by BIM. To reinforce this, the authors further explored the potential uses of BIM in terms of detailing and rework cases observed on site. This was observed to be a critical factor for enabling discussions between project participants that are essential to the successful realisation of projects with minimum wastes. Hence, BIM can play a crucial role to enable lean delivery of projects during both pre-construction, as well as the execution phase.

BIM enables site layout planning at an early stage, through collaborative working with the Contractor and project team. Their crucial inputs for the execution activities of the project can greatly determine the timeline of activities on site. It stands to show that Target Cost (Budgets) can be achieved not just through project design changes and reviews, but also by planning the site layout appropriately for the execution of the project on site.

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PLENARY PAPERS (4)

Schimanski, C.P., Monizza, G.P, Marcher, C., Matt, D.T. (2019). "Conceptual foundations for a New Lean BIM-Based Production System in Construction." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire, C, Hamzeh, F. (ed.)*, Dublin, Ireland, pp. 877–888. DOI: https://doi.org/10.24928/2019/0106 Available at: <www.iglc.net>.

CONCEPTUAL FOUNDATIONS FOR A NEW LEAN BIM-BASED PRODUCTION SYSTEM IN CONSTRUCTION

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ABSTRACT

This paper presents a new lean BIM-based production system to face productivity deficiencies in construction. To prove whether the current situation can be improved, the aforesaid production system is designed to assess the hypothesis that a true integration of BIM functionalities with the Last Planner System will contribute to a more efficient project delivery. Although beneficial synergies of BIM and Lean have been widely described and acknowledged in research, previous work has not fully addressed the stated hypothesis, since it has only provided frameworks on how to use BIM and the Last Planner System in parallel. The core of the here-proposed lean BIM-based production system is the linkage of BIM objects at data processing level with the Last Planner System routines making use of digital Kanban boards. The production system will also be extended by cost control aspects of the Earned Value Management approach and thus represents the basis for a complete construction management system with respect to quality, schedule and costs. This paper discusses the first concepts of the new lean BIM-based production system and introduces an information system integration model as a starting point for future software development activities.

KEYWORDS

Production System Design, Industry 4.0, Lean and BIM, Last Planner System, Digital Kanban

INTRODUCTION

The digitization, which is often referred to as Industry 4.0 in industrial production, is seen as one of the keys to increase productivity in construction (Dallesega et al. 2015). Building Information Modeling (BIM), as a method for digital representation of physical and functional characteristics of buildings and the data provided in this way, can be considered

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as the starting point for Industry 4.0 in construction. While Industry 4.0 in stationary manufacturing aims at reaching the highest possible flexibility whilst maintaining productivity rates of the mass production era, the construction sector wants to industrialize the de facto existing one-of-a-kind production and thereby increase productivity (Pasetti Monizza et al. 2018).

To this end, the challenge of making BIM data systematically available for the execution process needs to be addressed. One possibility for the standardization and systematic use of BIM models in execution is seen in the combined use with Lean Construction methods (LCM) (Sacks et al. 2010a). In fact, synergies resulting from BIM functionalities and Lean principles are described in numerous scientific publications (Dave et al. 2013; Khan and Tzortzopoulos 2014; Sacks et al. 2010b; a). More in detail, the Last Planner System (LPS) was identified as the most suitable lean method for construction execution processes to exploit these synergies (Sacks et al. 2010a). The LPS developed by Ballard (2000a) supports production planning and control by providing systematic routines to increase workflow reliability and process stability. The most important pillars for achieving that are collaboration, transparency, continuous improvement and commitment from task leaders responsible to actually fulfil the work on site, the *Last Planners*. However, Uusitalo et al. (2018) bewail that the LPS does not offer indications for its application in BIM-based processes.

Nonetheless, several attempts have been made to combine LPS and BIM in practice and scientific contexts. This paper briefly describes these attempts and will discuss their limitations of constituting solely frameworks for co-application, rather than true integrations. Given that, we propose an integration model on data processing level which lays the foundation for a new BIM-based production system, making use of the Industry Foundation Classes (IFC) as a non-proprietary data exchange format for BIM models. For convenience wording and as a symbol for the fusion of **BiM** and *Lean*, we will name this production system: **B***ea***M!**

RESEARCH METHODOLOGY

This paper follows a combined research approach which is composed of systematic literature review addressing the co-applications of BIM and LPS in previous studies and a Design Science Research (DSR) approach to develop new artefacts for system integration of BIM and LPS allowing for a joint application. The starting point of the DSR approach is a specific problem, which is followed by elaborating hypotheses for a possible solution of that problem based on previous knowledge and the literature review. Subsequently, in the development phase we will create concrete artefacts, in this case the BIM-LPS integration model and a description of the new process. The evaluation foreseen in DSR is not part of this study and will be dealt with in future studies. The development of the integration model itself follows Highsmith (2002) proposal for method development and considers not only the methodology and process perspective but also other environmental impacts, so that a holistic ecosystem is presented embedding **B***ea***M!** as a new production system.

STATE OF THE ART: BIM-LPS CO-APPLICATIONS

Literature reveals still problems at integrating BIM with LPS. Amongst these, Toledo et al. (2016) criticize that recent LCM and BIM research is limited to theoretical synergy possibilities of both approaches and that little focus is placed on the development of practically applicable methods and tools. Therefore, they propose a Lean-BIM planning framework, in which they include an Autodesk Revit® BIM model in the LPS process and explain how it can be used most efficiently in the various LPS phases.

With the *Smart Construction Planner*, Guerriero et al. (2017) developed a Lean IT-tool which supports for collaborative planning according to the LPS. Additionally, they mapped the LPS steps to BIM 4D scheduling and argue that a framework for joint application should follow their research activities.

Gerber et al. (2010) investigate the co-application of selected BIM functionalities with certain Lean principles from Sacks et al. (2010a) in case studies. One of these case studies interprets BIM as a starting point for process planning and lookahead planning, not considering the LPS methodologically to its full extent though. However, in their opinion, both approaches Lean and BIM are inextricably linked, but further research would be needed to support their hypothesis.

Bhatla and Leite (2012) also attempt to combine LPS and BIM application for evaluating the hypothesis that LCM and BIM are not independent of each other and most benefits can only be obtained when both approaches are used together. However, they implemented only look-ahead and weekly work planning (WWP) of LPS which were included in regular BIM coordination meetings. In addition to only partial LPS implementation, it can be criticized that the make-ready activities were limited to clash-free MEP ducts which were checked by using BIM models.

Garrido et al. (2015) use an integration framework of BIM and LPS developed by Mendes Júnior et al. (2014) in two case studies in Brazil. They conclude that BIM models support decision making processes during LPS phases due to their ability to provide right information at the right time. However, in these contributions, BIM and LPS are not used in an integrated information system, but one system supports the other in a detached way.

Moreover, Lagos et al. (2017) emphasize that the IT-supported use of LPS correlates positively with Percent Planned Complete (PPC) values. In their opinion, especially during the planning of the execution process, the systematic make-ready process of tasks as well as progress monitoring can benefit from IT-support. However, the authors claim that standardization in this sense can only be achieved by improved communication and a frame-giving Knowledge Management System (KMS). BIM can be interpreted as an approach for an effective KMS (Deshpande et al. 2014), which is taken up by Hasan and Akbas (2017) by claiming that BIM has the power to improve and streamline look-ahead planning. Nonetheless they see big challenges in structuring data and making it available for managing the execution process on site. Addressing this challenge, they propose a generic information management approach by aggregating the BIM data and other information required for look-ahead planning such as crews, equipment and basic workflows on an online platform. This platform is a prototype simulation platform which automatically generates a simulation model for construction processes for a given input. However, the collaboration aspect of the cooperative phase planning of the LPS is neglected and the focus is placed on computer-assisted optimization of master schedules rather than establishing a production system according to Lean thinking.

In the field of BIM and Lean supporting IT systems, *VisiLean*, developed by Dave et al. (2013, 2011), has to be mentioned. It is a cloud-based construction management tool that supports LPS principles and pairing with BIM. Tasks can be linked directly to BIM objects and thus the progress can be visualized by means of the model. However, for these tasks, quantities and other BIM information must be entered manually. The BIM model does not deliver them automatically. Furthermore, within the system a *phase* is solely interpreted as a far-reaching look-ahead window (e.g. 3 months). Nevertheless, elements such as deep collaboration and hand-offs discussion amongst the Last Planners, characterizing the cooperative phase planning, are not considered.

In addition, and with regard to information systems, Sacks et al. (2010c) describe a list of six requirements as decisive for an integral BIM-based lean production management system for construction, most of which relate to visualization capabilities, the establishment of pull systems, workflow stability and continuous improvement. These requirements have been implemented in the IT system *KanBIM* (Sacks et al. 2010b; c) which is based on the hypothesis that IT systems can significantly enrich the LPS by enabling access to 3D building representations. Being a non-BIM approach, in our opinion, pure geometric 3D representations are not sufficient for a complete construction production system with regard to the three target variables quality, schedule and costs. We consider it as extremely important for an effective production system to have an exact knowledge of the quantities to be built on and the associated costs in order to be able to pursue the road towards industrialised construction processes. Therefore, we propose the addition of point (7) *Automatic and precise quantity-take off for process management* to the list of Sacks et al. (2010c) requirements. To further complete this list, we also suggest introducing (8) *Clear roles within the processes*. The latter point is taken up again and explained in the design of the new lean BIM-based productions system described below. We take these requirements and the described current absence of a linking of BIM and LPS to a new information system as an opportunity to propose a concept for a new lean BIM-based production system in construction.

THE NEW PRODUCTION SYSTEM

Production goals in construction usually direct to the optimization of the interrelated target variables quality, schedule and costs (Borrmann et al. 2018), for which planning reliability and process stability in execution plays a crucial role (Kim and Ballard 2010). Consequently, methods directed to these objectives, such as for example the LPS, become anchors for production systems in construction (Hamzeh et al. 2012).

DESIGN OF THE NEW PRODUCTION SYSTEM

Hence, assuming the LPS as foundation for our new production system and being set to truly integrate it with BIM, the design of the **B***ea***M!** system technically represents a system integration on data processing level of the two sub-systems BIM and LPS to deliver new functionalities and exploit synergies. Eventually, both sub-systems should work together, where their conjunction will be expressed through an integration model. Regarding new functionalities and in addition to already mentioned individual BIM and LPS strengths, we have identified three major aspects for potential improvement, which consequently will be added into the integration model. These three aspects are (1) elements of the Scrum method, as a representative for agile project management (APM) techniques, the (2) implementation of a digital Kanban board to make use of both the Kanban method itself and enhanced visualization capabilities of digital whiteboards and (3) adding features of the Earned Value Management (EVM) project control system since LPS lacks in controlling cost performance (Novinsky et al. 2018).

Adding aspects of Scrum: After investigating the applicability of agile project management ideas in construction execution, Owen and Koskela (2006) suggest beneficial applications in process planning of execution but not for the site-management itself. Contradictorily Fernandes and Ribeiro (2010) state that agile techniques were suitable for steering all project phases in the context of medium and small sized enterprises (SMEs). Based on these prospects, we want to discover the potential of APM aspects for the **B*ea*M!** system. Particularly, we see value in adopting Scrum's clearly defined roles to our proposal. Since literature showed that main barriers of successful LPS implementation amongst others are comprised of poor methodological correctness and partial implementation, we think that precisely formulated roles with distinct responsibilities in the single process steps will improve the production system. Whilst LPS routines of iteratively checking commitments and learning cycles intrinsically cover some agile ideas already, we want to extend the **B*ea*M!** system by introducing new roles analogously to the Scrum framework. For establishing a parallelism to the game of chess, we call these roles the **B*ea*M!**-King and the **B*ea*M!**-Knight, which will be described in detail later on.

Adding aspects of (Digital) Kanban: A Kanban system provides information in terms of pull signals along value-adding-chains in manufacturing settings by means of cards or boards. Applied to the LPS, it can support the pull planning requisite of task-completion releasing new work (Ballard 2000b). Thanks to the information provided by the Kanban, task specifications and sequencing are clearly visible to workers or respectively to Last Planners (Matt and Rauch 2014). In addition, Mossman (2015) emphasizes the success factor of visualization when implementing the LPS. Therefore, today sticky-notes are standard for a visual representation of the LPS. Beyond that, Modrich and Cousins (2017) hypothesize that the joint use of LPS with Kanban techniques in design is better suited than conventional project management approaches. Based on their study, they conclude that the interaction of LPS metrics and Kanban-board metrics leads to better information flow. We take up this hypothesis and extend it to the execution phase by making our system applicable on digital whiteboards (**B*ea*M!**-Board) and enabling Kanban control.

Adding aspects of Earned Value Management: Cost control will be addressed by introducing EVM elements to the **B*ea*M!** system. More in detail, **B*ea*M!** will compare the EVM metrics Planned Value (PV) which represents the budgeted cost of work scheduled (BCWS) and the Earned Value (EV) which corresponds to the budgeted cost of work performed (BCWP). For applying earned value analysis in **B*ea*M!**, the LPS will define the work that needs to be accomplished and at the same time determine the "earning-rules" for deciding whether work has been actually accomplished or not. Finally, monitoring the actual costs (AC) and comparing it to EV will provide for insights regarding overall cost status. Here it is important to remark that in any case, the site-management remains governed by a "managing by means" (MBM) thinking approach, which has been defined in Kim and Ballard (2010). This means that cost parameters solely represent informative attributes of LPS operations. However, stabilizing the workflow stays decisive for sequencing these operations.

Complementary applications of LPS and EVM have been recently investigated in Novinsky et al. (2018); Zhang et al. (2018) and disclosed their mutual fit. Since positive findings in Novinsky et al. (2018) were only related to the design phase, we want to extend the joint application also to the execution phase.

FORMULATION OF THE NEW PRODUCTION SYSTEM

The guidelines for designing an agile methodology according to Highsmith (2002) are applied in an adapted form to design the **B***ea***M!** system. As **B***ea***M!** being embedded in a holistic ecosystem, the latter is characterized by providing not only the new process itself, but defining also emerging roles, scoping the domain of its application and formulating underlying ideals and principles. The comprising parts of this ecosystem are depicted in Table 13.

Table 13: Formulation of the new production system: BeaM!

Design Science Research			
Problem statement	Parallel co-application of BIM and LPS does not exploit synergy potentials to the maximum extent		
Suggestion for solving he problem	True integration of BIM and LPS on data processing level and deriving a new production system		
Development of solution	BIM-LPS integration model as basis for a new production system (**B***ea* **M!**) within a defined ecosystem, where:		
Methodology development	**Ideals**		Collaboration, communication, data orientation, visual perception, commitment, agility, feedback & learning
	Principles		▪ Adherence to all goals of the project management triangle of quality, schedule and costs ▪ Seamlessly BIM-based ▪ Schedule and cost tracking with great frequency
		List of requirements by Sacks et al., (2010c)	▪ *"Visualization of the construction process and its status"* ▪ *"Visualization of the construction product and work methods"* ▪ *"Support for planning, negotiation, commitment and status feedback"* ▪ *"Implementation of pull flow control"* ▪ *"Maintenance of work flow and plan stability"* ▪ *"Formalization of production experiments for continuous process improvement"*
			▪ Automatic and precise quantity-take off for process management ▪ Definition of precise roles
	Domain of application		▪ General contractor + multi-trade environment ▪ Repetitive and non-repetitive processes ▪ Applicable for any project size ▪ Local cooperation (project members need to be regularly present in meetings)
	Components	***Roles***	i. **B***ea* **M!**-King → GC representative in liaison with customer ii. Project team = Last Planners iii. **B***ea* **M!**-Knight → Process responsible
		Artefacts	i. Process description ii. Integration model iii. Tools: **B***ea* **M!**-Board + **B***ea* **M!**-App
Evaluation	Subject of future studies where software prototypes will be tested on pilot projects		

PROCESS DESCRIPTION

In line with the LPS, the starting point for phase planning is a master schedule with milestone representations. The master schedule, together with contractual documents, bills of quantities as well as the coordinated BIM model in the IFC file format, are assumed as given input. Generally, the **B***ea***M!** process follows the five-step logic of the LPS but is consistently digitally supported and linked to associated BIM objects except for non-digital master schedules. In addition, the LPS will be methodologically extended in a way, that process-describing sticky-notes - the Digital Process Kanban (DPK) - can be created individually by the Last Planners during phase-planning on their cell phone via the **B***ea***M!**-App. Then, DPK can be literally "beamed" to the **B***ea***M!**-Board and will serve as pool for the cooperative phase planning (Figure 18).

Before or during planning the phases, roughly calculated costs will be associated to each DPK which will represent the PV with respect to EVM. Differently to as proposed in Novinsky et al. (2018) and Zhang et al. (2018), underlying quantities do not have to be estimated, but constitute given information as an inherent part of the linked BIM objects.

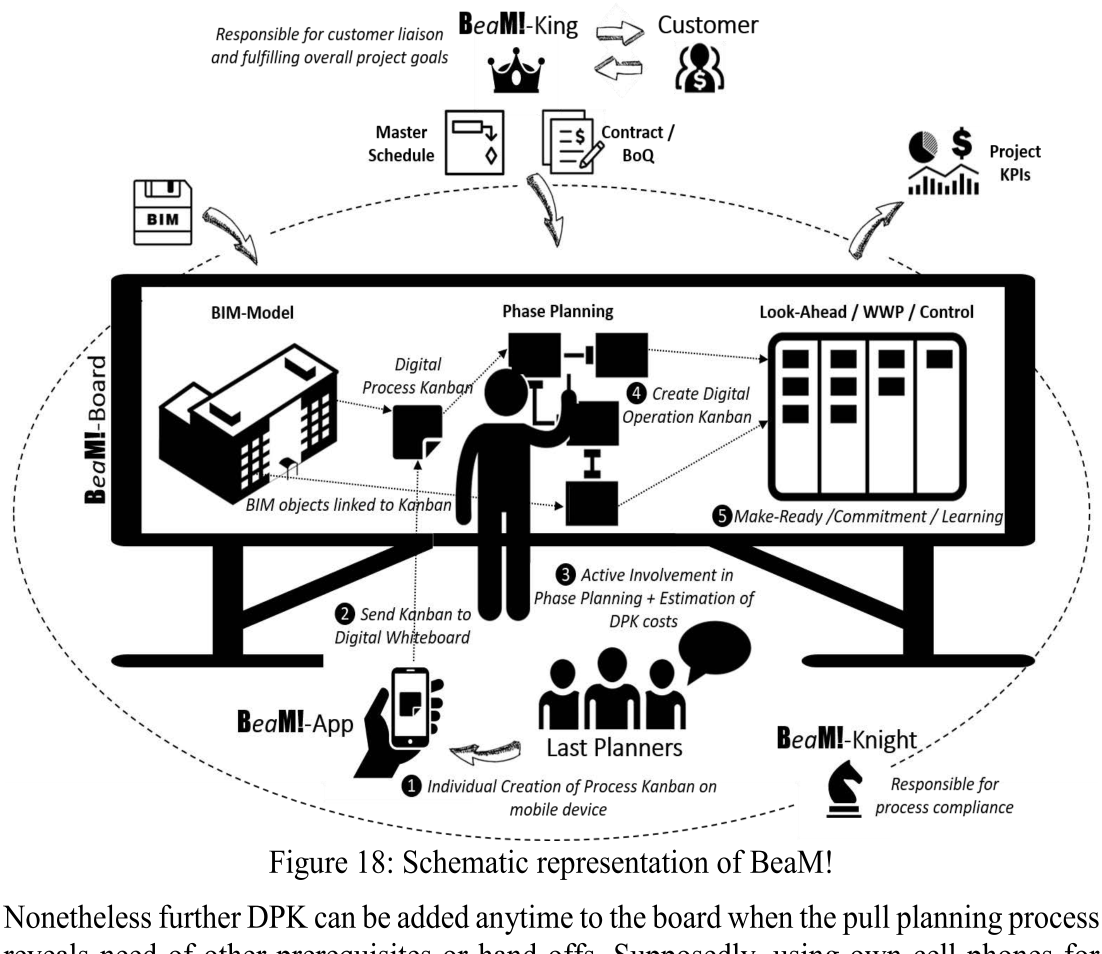

Figure 18: Schematic representation of BeaM!

Nonetheless further DPK can be added anytime to the board when the pull planning process reveals need of other prerequisites or hand-offs. Supposedly, using own cell phones for creating the Kanban will reduce resistance to standing up, labeling and attaching sticky-notes to the board. The corresponding BIM objects can be selected in the BIM viewer and thereby linked to the DPK. A second possibility is to first select the BIM objects in the viewer via touch control and then to create a linked DPK. In both cases, the BIM-linked DPK are available for phase planning according to LPS, in which the Last Planners are supposed to be actively involved. We experienced in non-digital pull planning sessions that arranging sticky-notes on a board generates significantly less resistance than creating them, so that a lively collaboration can be assumed here, once the DPK are present on the board.

In the next steps which foresee look-ahead and WWP and according to the nomenclature of task granularity provided in Hamzeh et al. (2012), DPK are the starting point to transform *processes* into assignable *operations*. These will be represented by new digital sticky-notes, the so-called Digital Operation Kanban (DOK) maintaining the link to the respective BIM objects and quantity information though. An example could be the DPK of *producing concrete slab* being transformed to multiple DOK such as *formwork construction*, *reinforcement placement* and *concrete pouring*, which still point all to the same BIM objects. In respect of quantities of operations, algorithms can be applied to the DOK for approximative calculations. For example, the quantity in terms of steel tons for the operation of *reinforcement placement* could be approximated in many cases as an order of magnitude to 10% of the related concrete volume [m^3]. The definition of such calculation rules is supposed to be subject of discussion amongst Last Planners during make-ready-planning sessions, where their experience from practice will be leveraged purposefully. In terms of costs, Last Planners will have to distribute the PV assigned to DPK to the subordinated DOK on a percentage basis.

Regarding the introduced roles, the **B***ea***M!**-King is responsible for the creation of phase schedules in accordance with the objectives of the milestone plan and the customer, but has limited action possibilities to intervene in the **BeaM!-**process itself in line with the established chess parallelism. It is proposed that his role will be filled out by the site manager of the General Contractor (GC). The role of the **B***ea***M!**-Knight, on the other hand, can be filled out by either a GC representative or an external project manager. The main task of the **B***ea***M!**-Knight is to ensure process compliance and thus also to control the methodological correctness of the individual LPS steps. Analogous to the name-giving chessman, the **B***ea***M!**-Knight has the possibility to jump back and forth on the "playing field" and intervene where necessary. Content definition for DPK and DOK does explicitly not fall within his remit. Furthermore, he/she is responsible for moderation and operation of the **B***ea***M!**-Board during make-ready and commitment planning as well as control sessions and communication of Key Performance Indicators (KPIs). Speaking of LPS's control stage at the end of each week, besides the usual check of commitments and root cause analysis, as an extension of the regular LPS, EV's of each completed DOK will be summed up and used for evaluating the current project performance.

INTEGRATION MODEL

The integration model is presented according to the steps of the LPS and the link to the BIM model is shown by association on data processing level with respect to the IFC format.

Master schedule: The master schedule with milestone representation is assumed to be a given input. It can be provided in either way, digital or as a not-digital print-out.

Phase scheduling: In Table 14 phase planning steps 1-6 defined in Ballard (2000b) will be associated to manipulations of an IFC-file as the representative of a BIM model on data level. Besides that, it will be presented how these manipulations are conducted with the **B***ea***M!**-Board as a digital whiteboard.

Table 14: Mapping phase planning according to Ballard (2000b) to the IFC data structure

Step	**Phase scheduling steps 1-6 by *Ballard (2000b)***	**Digital Kanban-Board functionality**	**BIM: IFC manipulation**
0	Have master schedule as starting point and identify milestones	Select BIM-Objects in IFC Viewer and press "create Milestone" button	Instantiate *IfcTask* object and set boolean *IsMilestone* to true
1	*"Define the work to be included in the phase; e.g., foundations, building skin, etc."*	Select BIM objects in IFC Viewer and press "create *Digital Process Kanban* Button" **OR** create corresponding Digital Process Kanban on mobile device and send it to **B***ea* **M!**-Board and then link to BIM objects	Kanban trigger instantiation of *IfcTask* objects which are linked to selected BIM objects (*IfcElements*) through *IfcRelAssignsToProduct* objects
2	*"Determine the completion date for the phase, plus any major interim releases from prior phases or to subsequent phases."*	Click on respective milestone and set finish date	Set attribute *LateFinish* of Type *IfcDateTime* in entity *IfcTaskTime* and relate to milestone *IfcTask* objects in step 0
3	*"Using team scheduling and stickies on a wall, develop the network of activities required to complete the phase, working backwards from the completion date, and incorporating any interim milestones."*	Arrangement of Kanban via touch control on **B***ea* **M!**-Board defines dependencies	Manipulate the *IsSuccessorFrom* and *IsPredecessorOf* attributes of *IfcTask* objects defined in step 1
4	*"Apply durations to each activity, with no contingency or float in the duration estimates"*	Click on respective Kanban and set duration	Assign duration through type *IfcDuration* and relate to *IfcTask* objects defined in step 1
5	*"Reexamine logic to try to shorten the duration."*	Collaborative re-arrangement of Kanban via touch control on **B***ea* **M!**-Board	Update of dependencies in *IfcTask* objects defined in step 1 according to re-arrangement
6	*"Determine the earliest practical start date for the phase"*	Click on first *Digital Process Kanban* of the phase and set start date	Set attribute *EarlyStart* of Type *IfcDateTime* in entity *IfcTaskTime* and relate to first arranged *IfcTask* object in step 5

Make-ready planning (Look-ahead-plan): The make-ready process of moving *processes* into the look-ahead-schedule, which comprises six weeks, is characterized by identifying affected DPK for the entire look-ahead-window, analyzing and removing their constraints and eventually transforming those DPK starting within the next three weeks into assignable operations, the DOK. On data processing level, the system filters internally for all DPK with a start date within the look-ahead-window and selects them on the **B***ea***M!**-Board. From the selected DPK, whose start lies within the next three weeks, the associated BIM objects are highlighted in the BIM viewer as a visual support for designing *operations*. The relation between *operations* and *processes* is technically represented by *IfcProcedure* objects being nested in *IfcTask* objects.

Commitment-planning (Weekly work plan): As transforming operations that CAN be done to operations that WILL be done, a *committed-to-be-built*-BIM model (CTBB-

Model) can be generated incorporating the WWP with all committed operations for the next week. By doing so, implicitly an *As-built*-Forecast-BIM-model will be made available for workers on site as a visual indicator for what needs to be done the next week. During the following control and learning phase, components specified by the CTBB-Model can be checked on site whether they are actually built or not. To this end however, a coordinated BIM model with at least a Level of Development (LOD) 300 is required, in order to ensure a controllable minimum information content.

Control & Learning: The LPS metrics PPC, Tasks Made Ready (TMR) and Tasks Anticipated (TA) will be supplemented by both the interplay of EVM's metrics PV, EV and AV and Kanban metrics such as average cycle-times (CT) and lead-times (LT) which will be derived from cumulative flow diagrams (CFD). The integration with the BIM model here is exploited by the fact that the CFDs can display the cumulated consumed materials in addition to the pure amount of operations in a given state (eg. made-ready). This in turn represents a further aid, e.g. for the control of material allowance on site. The metrics represent total project measures but can be broken down to different tiers according to Ratajczak et al. (2018) if, e.g., only the performance of a particular trade is of interest. The process status of the single DOKs will be stored in the *IfcTask* attribute *status* and serves as a query parameter for the construction progress visualization in the BIM viewer.

DISCUSSION & CONCLUSION

This design of the proposed production system aggregated different existing and well-proven techniques: EVM provides methods to determine whether a project is running well or not. LPS offers the instruments to define when and whether value has been earned. Furthermore, it provides a framework for enhanced process stability and workflow reliability which in turn increases the probability of “earning” as much as planned. The missing piece in this puzzle here is BIM, which on the hand provides quantities and information to estimate durations and costs of construction processes. On the other hand, it serves as a better basis for decision-making in phase and look-ahead-planning session as well as a medium for intuitive visualization of the project’s status. These features will be unified in the **B***ea***M!** production system making use of digital Kanban boards.

Therefore, a model for system integration on data processing level is proposed in this paper, which will be used as a starting point in this ongoing research project to develop software prototypes making **B***ea***M!** available for pilot construction projects and thus for evaluation in the sense of the DSR approach. Furthermore, the possible application domain of **B***ea***M!**, as well as underlying ideals, operational principles and new roles in allusion to Scrum were introduced. In this way it has been shown, that **B***ea***M!** represents a production system which fully embodies the Lean philosophy but at the same time functions as a complete project management system harmonizing the target values of quality, schedule and costs with a rigorous adherence to a digital working procedure.

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EVALUATING THE LEAN-ENABLING COMPETENCIES OF CLIENTS

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ABSTRACT

The principles of lean thinking are rapidly gaining the attention of construction companies while client-side organizations are not catching up at the same pace. However, the client plays a crucial role in driving and setting the framework of the process throughout all phases of the project and thus has a critical influence on the successful implementation of lean. This issue has not been given enough attention in literature, especially in the Middle East. Hence, this study aims at identifying the current status of Middle Eastern clients' characteristics, behaviors and practices throughout the different phases of a construction project. The paper investigates the lean-enabling competencies of clients from the perspective of designers and contractors through online data collection surveys. The results revealed that clients were regarded by AECs as being knowledgeable and involved. However, it appears they persist in taking unilateral decisions, especially regarding deadlines, and focusing on short-term financial goals while neglecting the importance of enforcing collaboration measures.

KEYWORDS

Clients, lean construction, middle east, collaboration, value

INTRODUCTION

For years, lean thinking has been successfully applied in the construction industry bringing improvements to both the planning and execution of projects. Womack and Jones (1996) emphasized value as the primary principle of lean thinking and defined it as the first of the five steps of lean implementation. Value is directly correlated with client requirements making the client's role central to the success or failure of any project, particularly a construction project. Clients are responsible for driving and setting the framework of the process throughout all phases of the project, and their needs must be set and accurately understood to maximize value and minimize waste. However, the current literature does not widely discuss the issue of clients and emphasizes instead on implementing lean

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principles and tools within design companies or contracting firms. Therefore, while Lean Construction is becoming more and more popular with construction companies, client-side organizations are not catching up at the same pace (Dlouhy et al. 2017). Additionally, the client is often mistaken to be a single-entity, while in fact this client is usually a representative of different values, interests and time perspectives (Bertelsen and Emmitt 2005). This can be particularly problematic for Architectural and Engineering (AE) firms and General Contractors (GC) since the nature, behaviour, and the level of knowledge of the client can highly impact the flow and success of the project.

CLIENT ROLE, COMPETENCIES AND IMPACT ON THE PROJECT

Tzortzopoulos et al. (2006) summarized the activities that clients should perform to lead a successful project. These activities include: choosing the suitable participants for each project, comprehensive understanding of the construction process in order to set reasonable timescales and milestones, well coordination and cooperation with different stakeholders throughout the project while clearly defining roles and responsibilities, adopting a sound decision-making process, being aware of project constraints, and commitment to the project.

An example of a knowledgeable client who has succeeded in managing and producing successful projects in terms of quality, cost, time, and safety is Sutter Health, a health care provider in California. Their approach to lean implementation is based on “The Five Big ideas” which aim at generating the highest value for all stakeholders. The organization selects the project team based on quality evaluation, promotes a collaborative design environment, makes sure that all key stakeholders are involved early on and during all the phases of the project, and encourages innovation and employee empowerment. This is achieved using lean-enabling tools such as Integrated Project Delivery (IPD), The Last Planner System, Building Information Modeling (BIM), and Target Value Design. Moreover, their contracts distribute both risks and rewards between stakeholders to align interests and unify goals (Lichtig 2005; Sinclair 2012).

Other client organizations are attempting to follow the lean path but still have a long way to go. For example, the status of 8 client organizations implementing lean in Germany was analysed in order to specify their lean maturity. The results show that only one of the 8 companies reaches a maturity level of “Lean Organized” (i.e. accepting lean principles and implementing them regularly) while the others are still at more primitive levels (Dlouhy et al. 2017). Bolpagni et al. (2017) also studied the level of maturity of the integration of lean construction and BIM in a client organization in Massachusetts. The authors concluded that an internal change in client organizations is empirical, where traditional procurement practices as well as traditional contracts should be modified in order to support BIM and lean.

Moreover, reasons for delays and cost overruns in construction projects have been divided in literature to those that are directly related to client actions and characteristics, and those that are related to the actions of other stakeholders. Samarghandi et al. (2016) found that the probability of occurrence of delays due to owner defects ranked before those related to the contractor and the consultant. Similarly, in a study about delay causes in Egyptian construction projects, owner related causes were ranked “Very High” relative to their frequency of occurrence, while those of the contractor ranked “High” and of the consultant ranked “Low” (Marzouk and El-Rasas 2014). However, Sutter Health have proved that wise and knowledgeable owners can mitigate the factors that hinder the project success. Owners can even control factors that are not directly related to them through effective management of the relationship between stakeholders.

MIDDLE EAST STATUS QUO

The Middle East (ME) region, consisting of the Gulf Cooperation Council (GCC), North Africa and a few countries in Asia, is presently witnessing an upsurge in the construction industry (Fahy 2017). According to a report by Harris (2013), 117 major construction projects with a total cost of 1 trillion US dollars are currently ongoing in the region and planned for completion by 2030. However, this growth is accompanied with various cultural and technical barriers that can hinder successful project completion and ultimately lean implementation in the region. These barriers are observed at both AEC and client organizations and they include: cultural aspects, governing project delivery methods as well as knowledge and implementation of latest industry technologies.

To begin with, the ME region exhibits several cultural traits that can largely impact any construction project. In a study on global leadership, the ME cluster was one of the cultural clusters that scored low in terms of pertinent attributes such as team orientation, uncertainty avoidance and future orientation (Javidan et al. 2006). Another relevant cultural aspect is that of inertia where the Middle Eastern society, similar to other comparable societies, is found to be hesitant of change (Littrell and Bertsch 2013). Moreover, corruption was observed in the Lebanese construction industry, a representative part of the ME industry (Rizk et al. 2018).

As for governing delivery methods, the majority of projects in the region still adopt the traditional project delivery method instead of IPD (Rached et al. 2014). The latter encourages driving value and eliminating waste through collaboration and mutual trust of the different stakeholders (AIA 2007). Thus, opting for a traditional delivery method can highly impact time, cost and efficiency of the project.

In terms of latest industry knowhow, an investigation conducted on the implementation of BIM in the ME showed that only 20% of the AEC firms in the region are currently using or in the process of adopting BIM technology (Gerges et al. 2017). Moreover, people only perceive it as an “advanced AutoCAD tool” and are thus not fully utilizing the capabilities of this tool in increasing efficiency and promoting collaboration in early project phases.

OBJECTIVES AND PAPER ORGANIZATION

Since the key to the success on any project lies in the hands of clients, their role remains crucial in both initiating and promoting lean construction throughout the life cycle of the project. The literature, however, lacks studies related to client organizations in the construction industry especially in the context of the ME. This study therefore sets out to evaluate the current status of Middle Eastern clients’ characteristics, practices, and activities throughout the phases of a construction project. The aim is to assess how close the client competencies are to facilitating the implementation of lean construction in the ME with respect to different project participants, namely designers and contactors. This paper begins with the research methodology adopted in this study followed by the key findings and the corresponding analysis. Finally, study limitations, conclusions and future work recommendations are presented.

METHODOLOGY

In order to gain further insight into the issue of lean-enabling client competencies, an online survey was conducted among AE consulting firms as well as contracting companies operating in the ME region. The aim was to assess how clients performed on specific projects and how their behavior affected the overall project performance in light of lean values. Since questioning clients about their own conduct would lead to a natural positive bias, it was decided to carry out this assessment from the more objective perspective of the expert engineers (over 10 years of experience) who worked at length with them on behalf of their respective AE or contracting firms. Furthermore, as the role of the client is most critical in large, complex and multidisciplinary projects, the firms selected were chosen with a relatively large volume of work to ensure their projects are medium to large-scale.

To achieve the objectives of this study, a thorough literature review was first conducted in order to identify the possible lean competencies of clients. Based on the findings and the authors' own experience in the field, the most relevant factors related to client role and impact were divided into 2 separate groups. The first group contains 4 categories of aspects that are directly related to clients (their own characteristics and traits). These categories are: Knowledge & Involvement, Requirements & Transparency, Decision Making, and Value. The second group is related to the actions and characteristics of other stakeholders but that the client can impact and successfully manage: Collaboration & Relationships. Table 1 shows a detailed description of the categorisation.

Next, specific questions related to each aspect in the table were prepared followed by the formulation of the survey which consists of two main sections. The first part of the questionnaire includes demographic as well as general questions to gain more background information about the projects, the Architecture Engineering Construction (AEC) firms and the client organizations. General questions are related to the organizational structure of the AEC firms, the client type, the project size as well as project award and delivery method and the like. As for the second part of the questionnaire, it includes the prepared questions related to the expert engineers' perceptions of the client competencies and their impact on the project performance. The respondents were asked to select a specific recent project (less than five years) they worked on and to answer a number of questions related to the way the client approached and dealt with various aspects of the project. Based on their replies, it was ascertained how closely the client practices were aligned with lean principles. In total, the survey was comprised of 28 questions of which 26 were closed and 2 were open-ended. The closed questions included 6 matrix questions and were all recorded in the five-point Likert scale to ensure accurate mapping.

An online structured cross-sectional survey was adopted to enable easy access to respondents. To select the respondents, purposive non-probability critical sampling was adopted based on the researchers' "knowledge of the population and the objectives of the research" (Wilson 2014). Moreover, to facilitate the search for qualified participants, snowball sampling was used whereby the survey was initiated with a few people who were then asked to recommend others with similar profiles (Wilson 2014). The final sample size of this study was 47 respondents. It is also noteworthy that the questionnaire was developed to suit the Middle Eastern construction industry. For instance, general terminology was used to prevent possible confusion among respondents unfamiliar with lean related jargon. In a final note, the protection and confidentiality of respondents was ensured through an informed consent form and by keeping their identities anonymous.

Table 1: Client-Related & Stakeholders-Related Aspects Tackled in the Survey

	Key Aspects	Description	Lean Principles/Lean Tools/Related References
Client-Related	Knowledge & Involvement	• Level of knowledge and experience of clients • Level and kind of involvement in the project These questions will give insight on the client's wisdom, know-how, commitment and responsibility towards the project.	• Lean Principle 12: "Go and see for yourself to thorough understand the situation" (Liker 2005). • Study on owner characteristics that affect project delivery by Liu et. al (2014): among the 14 factors in literature, the top 3 are responsibility, owner's experience with similar projects, and owner's willingness to be involved.
	Requirements & Transparency	• Clarity of the scope of work as provided by the client • Reasonability of deadlines and requirements • Openness to suggestions and consistence with required standards These questions will give insight on how clients perceive the complexity of projects and whether they are willing to collaboratively shape their requirements.	Some of the most important causes of delays related owners in construction projects are the unrealistic duratio provided by the owner as well as the insufficient time provid in order to study whether his requirements are feasib (Marzouk and El-Rasas 2014).
	Decision Making	• Responsiveness in issuing approvals and making critical decisions • Promoting involvement of key stakeholders in making these decisions	Lean Principle 13: "Make decisions slowly by consensu thoroughly considering all options; implement decisio rapidly" (Liker 2005).
	Value	• Importance of certain factors with respect to the client including: short-term incurred cost, quality of the project, end user satisfaction, sustainability and LEED, the impact of the project on society, and considering innovative approaches • Learning from unsuccessful decisions and continuous improvement These questions will give insight on what owners perceive to be valuable in a project.	• Lean construction revolves around maximizing the value f the client (Koskela et al. 2002). • Integrated Project Delivery method shifts the bulk of th effort towards the design phase as opposed to being in th construction phase in traditional delivery methods, whic implies additional cost to the client in earlier stages of th project (AIA 2007). • Lean Principle 1: "Base your management decisions on long-term philosophy, even at the expense of short-ter financial goals" (Liker 2005). • Lean Principle 14: "Become a learning organization throug relentless reflection and continuous improvement" (Lik 2005).
Stakeholders-Related	Collaboration & Relationships	• Promoting/Encouraging collaborative meetings between stakeholders, the integration of design and the consideration of alternatives through involving different stakeholders, especially contractors, in early phases of the project. • Level of control exercised by the owner in handling and managing the relationships between stakeholders	• Sutter Health approach to Lean Project Delivery is based the Five Big Ideas, including "Collaborate, really collaborat (Lichtig 2005). Collaboration should take place between key stakeholders and through all phases including desi and planning, not just execution, to achieve "constructib maintainable, and affordable design" (Lichtig 2005). • Lean Principle 11: "Respect your extended network partners and suppliers by challenging them and helpi them improve" (Liker 2005).

RESULTS AND DISCUSSIONS

RESPONDENTS, THEIR FIRMS AND SELECTED PROJECTS

In total, approximately 250 surveys were sent out and 47 valid replies were received which corresponds to an approximate return rate of 19% where 68% of the respondents belong to AE design firms while the rest worked for GC firms. The expert engineers and architects surveyed were all active in the field for more than 10 years with 41% having 15 to 20 years of experience and 28% having more than 20 years.

As for the organizational structure of the AEC firms, 72% were department-based while only 19% had a project-based structure and the rest were hybrids. It is noted that the most common structure observed, the department-based, is the type that least promotes an effective implementation of lean since the foremost loyalty of the teams remains to their departments rather than to the project as a whole.

The projects chosen by the respondents were all located in the ME and belonged to various construction sectors including commercial, institutional, residential, heavy civil, infrastructure and industrial. They were medium to large-scale jobs with total costs exceeding 4 million USD, of which 55% had a budget 50 to 500 million USD while 13% had a cost exceeding 500 million USD.

Figure 19 shows the delivery method of the chosen projects chosen while Figure 20 assesses knowledge and experience in lean and IPD.

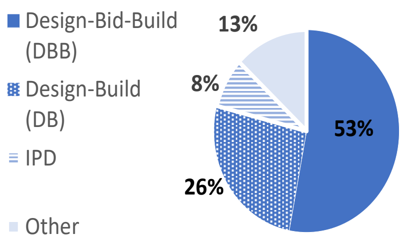

Figure 19: Project Delivery Method of Selected Project

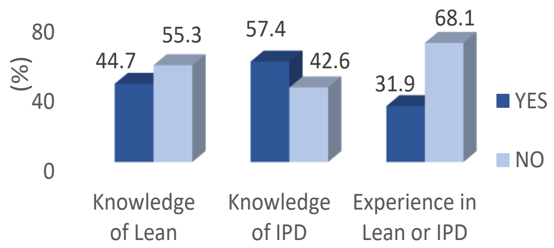

Figure 20: Respondents Knowledge & Experience in Lean and IPD in ME

The illustrated results show that the traditional delivery methods such as the Design-Bid-Build (DBB) and the Design-Build (DB) remain the most widely adopted. This validates previous studies conducted on the governing project delivery methods in the ME, which are mentioned in the Middle East Status Quo section of this paper. Moreover, more people declared having knowledge of IPD than knowledge of lean. This indicates that some of the respondents are not aware that IPD is based on lean principles or have confused IPD with Integrated Design Projects (IDP).

OWNERS AND THEIR REPRESENTATIVES

The clients selected by the participants were either from the private sector as developers (68%) or contractors (17%), or from the public sector (15%). The client representatives were mostly from the client organization (55%), e.g. an engineer or the owner himself, or from a PM firm appointed by the client (45%).

OWNER RELATED FACTORS

Knowledge and Involvement

The respondents were asked to rank the various factors related to the knowledge and involvement of the client in the project on a five-point Likert scale, ranging from Strongly Agree (S.A.) to Strongly Disagree (S.D.).

Results in Figure 21 show that the respondents mostly agreed that the client was informed and knowledgeable. A natural outcome is the ability of the client/client representative to provide a clear scope of work to stakeholders and be actively involved in his project which is confirmed in the same figure where the three metrics followed a similar trend. When the results are divided between those of AEs and GCs, it can be observed from figures 22, 23 and 6 that the client was generally viewed as more informed and involved by the GCs than by the AEs especially for the case of the scope of work where 94% of GCs agreed it was clear as compared to a 75% agreement by AEs.

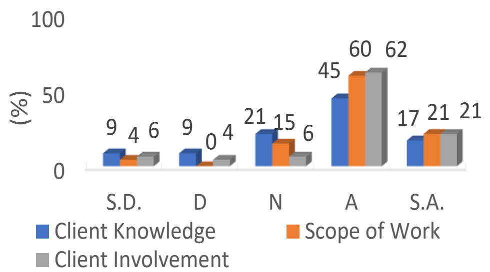

Figure 21: Summary of the Three Client Metrics Shown in Figures 4, 5 & 6

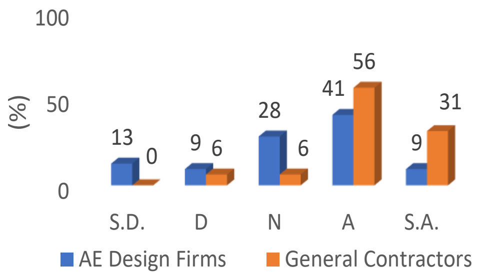

Figure 22: Client was Informed & Knowledgeable about Similar Projects

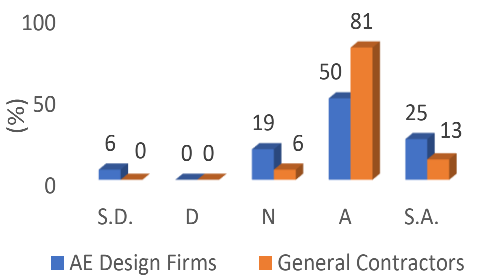

Figure 23: Scope of Work Required from AEC as Specified by Client was Clear

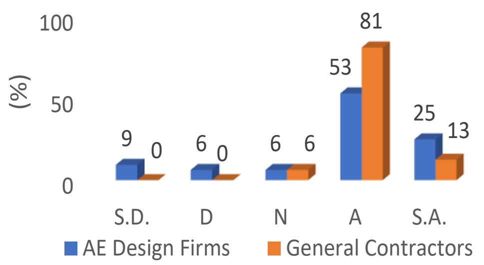

Figure 24: The Client/Client Rep. was Actively Involved in All Project Phases

One of the most crucial roles required from AE firms is assisting the client to learn and develop his requirements and to translate his purposes into values and then into clearly defined specifications. This process is necessary to ensure that the client gets what he wants but it is highly iterative. This would explain why more GCs than AEs saw that the scope of work provided by the client was clear since by the time a project reaches the construction phase it would have relatively matured.

Requirements and Transparency

As a natural result of being knowledgeable and involved, clients are found to be consistent with their standards and open to suggestions, as shown in Figure 25. However, only 47% of the respondents viewed client requirements, although clear, as being reasonable and a lower 35% saw the deadlines set by the clients as achievable. This is in line with previous findings that important causes of owner delays are the unrealistic durations they set for their projects as well as the insufficient time provided for AECs to study the feasibility of owner requirements (Marzouk and El-Rasas 2014). It is rather contradicting, nevertheless, that the client is knowledgeable and open to suggestions but still imposes unrealistic requirements and timelines on the project team. A client who understands the design and construction process and is willing to accept the opinions of the professionals working on the project should be able to set realistic requirements collaboratively with the remaining stakeholders.

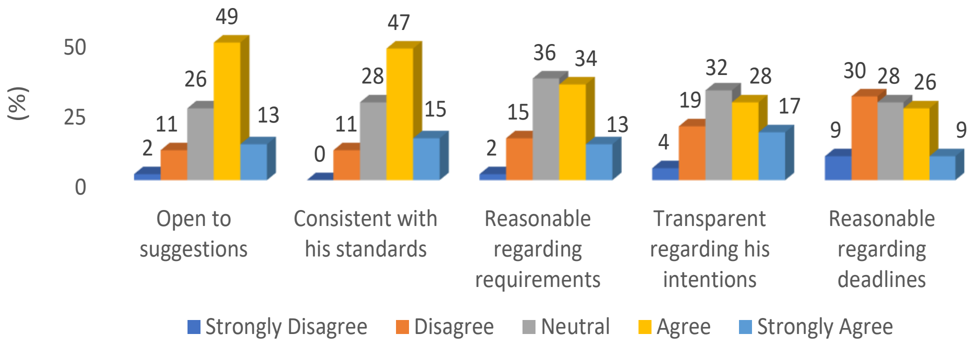

Figure 25: The Clients Attitude and Behavior as Seen by AEC Firms

Furthermore, only few respondents viewed clients as being transparent regarding their intentions, a cornerstone in building long term relationships based on mutual trust and respect.

Decision making

In total, 51% of respondents viewed the client as being responsive while 34% believed he was prone to issue frequent and unreasonable variation orders. Whether the client issues approvals and takes critical decisions in a timely manner bares a direct impact on the project schedule. Given that the client is the party most affected by unwarranted delays, it is surprising to see such numbers. However, a closer look at the results reveals that among the 29 respondents who said the client was well informed, 62% indicated the latter was responsive in taking decisions. Thus, informed clients are more comfortable and better equipped to take timely decisions probably since they understand well the implications on the progress of the project.

Moreover, even though involving stakeholders in major decisions related to them would benefit the project as a whole, only 46% of participants agreed that the client actually does that.

Value

Results listed in Table 2 show that clients consider the project quality and end user satisfaction to be important which is in line with lean principles. However, the remaining factors reveal that some values of ME clients are not aligned with those of lean. Giving high importance to short term costs does not comply with lean principles. Similarly, neglecting the importance of innovative approaches and actively learning from errors are contrary to lean principle 14 relating to relentless reflection and continuous improvement (Liker 2005).

Table 2: Value as seen by AEC firms

Factors ranked according to their importance to the Client	Mean rate (/5)
Quality of the project	4.26
End user satisfaction	4.09
Short-term incurred costs	4.02
Building long-term relationships with stakeholders based	3.36
Considering innovative approaches	3.30
Learning from design/construction errors and unsuccessful decisions for continuous improvement	3.28
Impact of the project on society	3.15
Sustainability and LEED design	3.02

STAKEHOLDERS RELATED FACTORS MANAGED BY THE CLIENT

Collaboration & Relationships

Few respondents agreed that clients were clear advocates of collaboration measures, as shown in Figure 26.

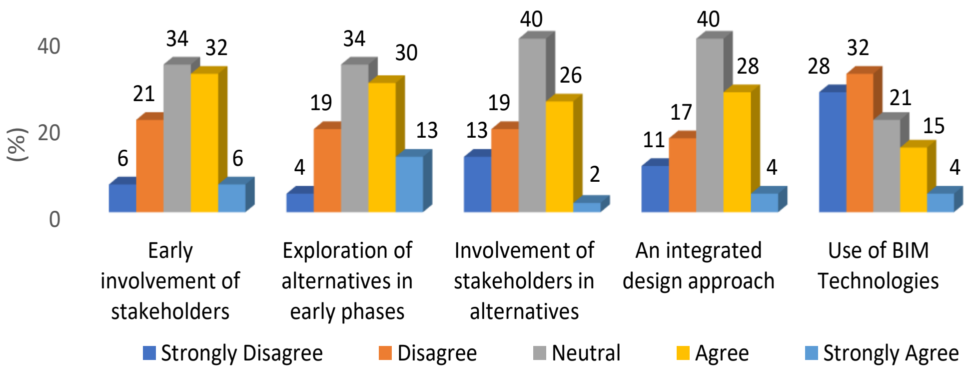

Figure 26: The Clients Promotion of Collaboration

Moreover, when asked if and when collaboration meetings were called for by the client, 66% of respondents acknowledged having participated in some kind of collaborative meetings during construction. While 42% were involved in such meetings in the Design Development and Final Design phases, only 28% were implicated in the Project Definition stage and 13% said no collaborative meetings were held. This confirms that collaboration meetings, if held, were usually at later stages of the project, which is common in traditional delivery methods. This is in line with (Dettman and Bayer 2012), who state that "Traditional contractual and project management systems establish vertical silos of parties and management structures… Their [the people] communication and decision making tend to be vertical—up and down each silo's chain of command, and then over and up/down to another organizational silo". Therefore, although collaboration attempts were made, they cannot reach their full potential since the loyalty of parties remains to their own firms rather than to the project as a whole.

It is encouraging to see though that some of the ME clients, as shown in Figure 27, seem to endorse, at least to some extent lean principle 11 of respecting and challenging your partners. Still, clients need to take a step further to achieve the desired results of long-term relationships away from the adversarial and claim/dispute-oriented relations that now govern traditional project delivery approaches widely adopted in the ME.

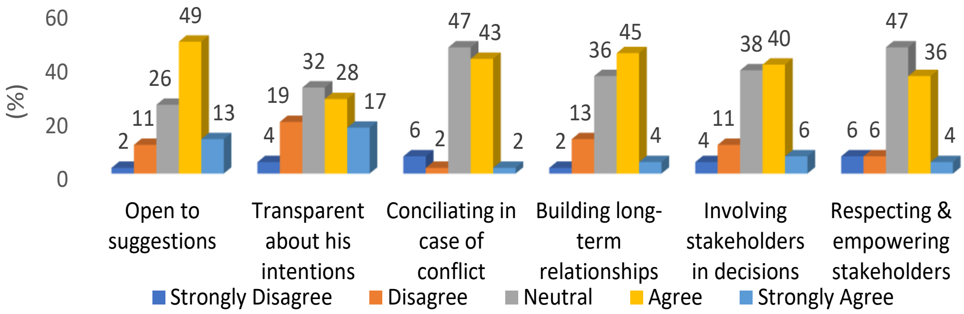

Figure 27: Client and Stakeholders Relationships

LIMITATIONS

The bidding practices and appointment criteria commonly used by the client are key factors that provide insight on client ethics and perception of value. However, since AEs and contractors theoretically cannot know these issues about the client organizations, these questions were not addressed. Moreover, like any study involving assessment of human behavior, there is always bias in the results obtained.

CONCLUSIONS AND RECOMMENDATIONS

Overall, the results revealed that clients in the ME were regarded positively by AECs as being knowledgeable, well informed and actively involved in their projects. However, it appears most owners persist on taking unilateral decisions instead of involving stakeholders and enforcing a team decision making process. Moreover, a number of current client practices were not in line with lean principles such as focusing on short-term financial goals instead of a long-term philosophy. Innovation, set-based design and continuous learning did not score high on their value scale. Also, clients were often not seen as actively enforcing collaboration measures such as early involvement of stakeholders, adoption of an integrated design and use of BIM.

From the findings of this study, it may be concluded that, in general, clients are either unaware of lean construction or do not have a deep understanding of its underlying principles. Some of the undeniable benefits of adopting lean in the ME construction industry include gaining better control over projects, maximizing value, reducing waste and successfully completing the project both on time and below target cost. Claims, disputes and adversarial relationships can be replaced by long-term relationships with stakeholders based on mutual respect and trust. However, clients and AECs must undertake radical changes to their way of thinking, traditional methods and organizational structures to achieve that. Before embarking on this journey, both the owners and AECs should be educated about lean concepts, tools and language. This training should further help parties to overcome cultural barriers such as resistance to change, in-group collectivism and a focus on short-term goals.

The authors hope that this assessment of the client lean-enabling competencies provides a basis for future research into this critical area which has not been documented to the extent it merits. An interesting point to consider is the standards to which the AECs evaluated their clients. It would be only natural for them to rank the selected client with respect to others they previously worked with. So, had the AECs been familiar with clients who fully embrace and practice lean principles, such as Sutter Health, would they have rated their clients differently?

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THE INTRODUCTION OF AI IN THE CONSTRUCTION INDUSTRY AND ITS IMPACT ON HUMAN BEHAVIOR

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ABSTRACT

The digital shift has arrived in the construction industry, with the aim of increasing the efficiency. However, how should the industry implement digital tools? And how should a human-technology relationship work? The purpose of this paper is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of implementation of AI. This paper presents research based on a comprehensive literature review, a case study of a construction project in Norway, and three external interviews. The case study consists of a document study and seventeen semi-structured interviews.

The experiences established through this research indicate that it is possible to gain experience from the implementation of basic digital tools when implementing advanced technology, such as artificial intelligence (AI). When come at AI, the human-AI trust will be the most decisive factor for a successful implementation. This paper constitutes a piece of pioneer work, as it investigates the implementation of AI, and how humans and technology should work together.

This research is limited down to one case study as well as three digital tools. To extend the research it is recommended to discuss the adaption of AI on premise of the users, collect more empirical data and look into experiences done by other industries.

KEYWORDS

Collaboration, Commitment, Trust, Digitization, Artificial Intelligence

INTRODUCTION

The construction industry is currently experiencing transformation from traditional, hierarchically organized construction sites to digital and more autonomous ones. A digital

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shift is taking place, and the development of the digital is advancing so fast that the industry struggles to keep up (Harty et al. 2015). This paper constitutes to a piece of pioneer work, as it investigates the implementation of AI. Implementation of AI is a relatively unexplored topic, especially within the construction industry. AI can automate several operations and increase the efficiency of the building process (Salehi and Burgueño 2018). This is aligned with the lean-mindset, where minimizing waste and maximizing value is central (Ballard and Howell 2003).

Based on the above mentioned, the purpose of this paper is to illuminate how the construction industry can close the gap between the potential benefits and the harvested benefits of implementation of AI. In order to find a way of closing the gap, the following two research questions has been developed.

- What are the potential benefits of implementing AI in the construction industry?
- How does the construction industry harvest the benefits of AI implementation today?

This research is limited to a case study of a building project located in Oslo, Norway, in addition to three external interviews. The case study is restricted to look at three digital tools. Based on the lack of published research regarding the implementation of AI, a document study and interviews has been chosen as case specific methods. It has also been necessary for the authors to take advantage of the research regarding implementation of lean, last planner system (LPS), lower levels of digitization and other industries. In the following, the article consists of a method chapter, a theoretical framework, findings and discussion and at the end a conclusion and further research.

METHOD

This study is based on a qualitative research method with the use of triangulation. Triangulation increases the research's validity (Yin 2009). Initially, a literature study has been performed in order to map current research on the topic. The empirical data collection consists of a single case study and three external interviews. Case study was chosen to obtain data from an ongoing project. External interviews were chosen with the aim of taking advantage of the experiences done by other industries. The following section describes the line of action of the methods used.

LITERATURE STUDY

The literature study was carried out using several acknowledged databases, journals, conference articles, articles, books and snowballing, in addition to recommendations from supervisors. A systematic searching strategy was developed, with keywords such as "Lean", "Last Planner System", "Implementation", "Digitization", "Culture", "Change", "Human Behavior", "Artificial Intelligence" in combination with various search functions and limitations such as "construction industry". The reliability-objectivity-accuracy-aptitude principle was used to evaluate the sources (NTNU 2019). Findings from the literature study are presented in the theoretical framework as a current state of research related to the topic of the study.

EMPIRICAL DATA

Case Study

Due to the lack of published research regarding implementation of AI, was case study chosen as a suitable method. The chosen case is Bispevika, a building project in Oslo, Norway. The project consists of approximately 7 years of construction and NOK 4-5 billion (AF Gruppen 2019). Bispevika was chosen based on its non-traditional way of working regarding innovative processes and tools, and the fact that a project of that scale seems a perfect testing ground for implementations due to the possibility of learning and the possibility of having the same people improving it along the way. The Bispevika-mindset is based on a lean approach. To get a grip on the implementation of AI, it is chosen to look closer into the implementation of the three digital tools described in Table 1.

Table 1: Explanation of the chosen digital tools at Bispevika

Tool	Description	Level of digitization	Implementation phase
Touchplan	A web-based construction collaborative tool, which can be seen as a digital version of the tools in the LPS (Sticky notes and physical boards) (Touchplan 2018)	Digitization	Late implementation
Synchro	A 4D digital construction platform. Gives the workers the opportunity to visualize, discuss and collaborate in order to find all possible constraints before executing (Synchro 2019)	Digitalization	Midway implementation
ALICE	An AI planning Software which uses the input from the users to, create and optimize schedules based on the recipes created (ALICE 2017)	Digital Transformation	Early testing

Document study and interviews was chosen as suitable methods to collect data. Two of the authors were also participating on a workshop with, and about ALICE, with the intent of acquire more knowledge about the tool.

Document Study

Mainly, three different project documents were used to support the data from the interviews and increase the authors knowledge regarding the project and ALICE. The document "Lean in Team Bispevika" is considered a guideline of understanding the culture and the way of working at the project. The documents "ALICE overview" and "Construction Information Model" can be considered as necessarily to acquire information about the complexity of ALICE.

Interviews

Seventeen semi-structured in-depth interviews, in addition to one pilot interview was carried out with interviewees from the main contractor and subcontractors. More specifically, 1 interviewee represented the company management, 3 represented the project management, 10 represented the operating department and 3 represented different subcontractors. The interviewees were people with different experiences, knowledge and mindsets regarding digitization.

The intention of the interviews has been to unveil the interviewees' opinions regarding the digital shift and its impact on the human behavior. A semi-structured technique was chosen to allow the interviewer to angle the questions and topics toward the relevance based on answers given by the interviewee (Yin 2009). Interviews was carried out with a prepared interview guide. The guide was developed in collaboration with supervisors/co-writers through a brainstorming of questions related to the research questions. Furthermore, all questions were grouped into categories, and the categories was named: Technology, Process and Culture. All interviews were recorded and completely transcribed. The analysis was conducted with inspiration from a step-wise-deductive inductive method, with the use of coding (Tjora 2017).

External interviews

With the aim of unveiling useful experiences considering implementation of AI in other industries, three external interviews were conducted. The three interviewees represented three different companies, further described in Table 2. All three interviews were conducted and analysed in the same way as the case specific interviews.

Table 2: Description of external companies

Company	Description company	Description interviewee
Norwegian open AI lab	Research center that brings together various research efforts within AI. Current key areas for the research are health, energy, ocean space, digital economy and smart environments (NTNU 2019)	Professor in Computer Science and AI. Long experience within the development and implementation of AI systems within the oil and gas industry and fishing industry
Inmeta	One of the leading consulting companies within machine learning in Norway (Inmeta 2019)	Data scientist with specialization within machine learning. Experience with development and implementation of AI systems in the healthcare industry
Spacemaker	Norwegian start-up company that has developed an AI based technology that calculate and optimize a construction site (Spacemaker 2019)	Chief Operating Officer with experience within implementation of AI in the design phase of construction projects

THEORETICAL FRAMEWORK

The construction industry is claimed to be undigitized and with a low productivity development compared to other industries (Barbosa et al. 2017). However, research indicates that the right implementation of digitization will increase efficiency of the building process (Barbosa et al. 2017). More advanced technology such as AI is now entering the industry. With more or less no research considering the implementation of AI, it will be necessary to take advantage of research regarding the implementation process itself and combine it with the technical knowledge of AI.

IMPLEMENTATION AND THE IMPACT ON HUMAN BEHAVIOUR

Implementation consists of the process of putting into practice an idea, program, or a set of activities and structures new to people attempting or expecting to change (Fullan 2007). Implementation can be considered as a change process, with inputs and a wish about a specific output. Research shows that incomplete implementations are often a result of incomplete preliminary work, where organizations are focusing on “what” instead of “how” (Noonan 2017; Senior and Swailes 2010).

Organizations are about people, and people forms cultures. Senior and Swailes (2010) defines culture as the following: “What is typical for the organization, the habits, the prevailing attitudes, the grown-up pattern of accepted and expected behavior”. An implementation can also be considered as culture work. Culture is deep-seated, and is, therefore, likely to be resistant to change (Senior and Swailes 2010).

Motivation to change is decisive when implementing something new, but how do people get motivated? The goal-setting theory is strongly supported by research (Arnold et al. 2010). Setting performance goals that are specific and challenging (but not impossible), and to which the person feels committed, is likely to improve their work performance, their self-efficacy and their willingness to commit to new challenges (Arnold et al. 2010). However, recent research indicates that clear performance goals is not always beneficial. When working with simple processes, performance goals are considered beneficial, but when the processes are complex the same measures could actually inhibit productivity (Kahneman 2011).

Implementing change can be a long-term process, and commitment to the process can be weakened. The achievement of short-term wins is therefore essential, both as a motivating factor and as a mechanism for tracking the process towards the longer-term goals (Senior and Swailes 2010; Arnold et al. 2010). Another central factor considering motivation is the "implementation drivers". The people which drives the development further. The implementation is likely to fail if only the implementation drivers are motivated, as collaboration is key to innovation. Collaborative attitude, relationships based on trust and responsibility towards each other will facilitate motivation (Senior and Swailes 2010).

Every change will require training (Roland and Westergård 2015; Arnold et al. 2010). A training strategy should be developed and consist of: Training needs analysis, training design and training evaluation. All three are equally vital (Arnold et al. 2010).

As above mentioned, an organization is about people and people that forms cultures. So, what will happen when an organization is formed of people and AI? Will the factors motivation, commitment, collaboration, and trust as the literature are mentioning as decisive for a successful implementation be affected? In order to answer this, it is necessary to look deeper into the possibilities and limitations of the AI.

AI IN CONSTRUCTION

Digitization, digitalization, and digital transformation are often referred to as the same. However, the words represent different levels of the digital. Digitization involves creating a digital version of analog information, such as checklists on your mobile device instead of paper. Digitalization refers to the second level, where machines can perform human-controlled processes, such as continuously updating your Building Information Model (BIM). Digital Transformation is the integration of digital technologies in a way that the organization is fundamentally changing how they operate (Clerck 2016).

AI is defined as the ability of a machine to mimic intelligent human behavior, thus seeking to use human-inspired algorithms for approximating conventionally challenging problems (Salehi and Burgueño 2018). The implementation of AI can be seen as a digital transformation. Bolton (2018) exhibit the leading advantages of AI for organizations to be the following: Improve end-users experience using the data it provides, automate tasks to allow humans to focus on work that will add value and reduce human errors and deliver services more quickly. This can be seen in relation with the lean principles where maximizing value, minimizing waste and increase the efficiency of the working process is central (Ballard and Howell 1998).

As well-known is the adaption of AI relatively low in the construction industry (Blanco et al. 2018). However, today there are some start-ups that offers applications relevant to scheduling and image recognition. Using historical figures in addition to human-inputs, algorithms can consider millions of alternatives for project delivery and continually enhance the schedules. Image recognition can identify unsafe workers and aggregate this data to inform future training and education priorities. However, any AI-algorithm is based on training rather than programmed, which means that algorithms needs a certain amount of data to perform at the level of humans. Obtaining large data sets is today considered as a limitation for many building companies (Chui et al. 2018).

AI may help the construction industry to overcome the industry's greatest challenges, including costs, scheduling and safety (Blanco et al. 2018). However, is the construction industry in the starting phase of the digital transformation, and few projects have actually implemented AI. A central question considering the implementation will be how to get a successful human-AI collaboration?

HUMAN-AI COLLABORATION

The digital shift introduces new ways of working, where humans and technology have to cooperate. Traditional culture classifies humans and technology as separate entities (Carpenter et al. 2018). However, the last years technological development have resulted in advanced automation that can respond better than a human in specific situations (Abbass 2019). Humans can't compete with AI regarding analysis of data, information and knowledge, likewise AI cannot compete with a human's ability of pedagogy, creativity, visions and ethics (Carpenter et al. 2018).

As a successful human-human cooperation requires defined tasks and responsibility, a human-AI cooperation will require the same. Although, the tasks and responsibility are distributed between the human and AI, it can be difficult for the human to trust the AI output. How AI arrives at a particular prediction and recommendation, and further discern whether it is a good solution or not? This is one reason that adoption of some AI tools remains low in application areas where explainability is useful or indeed required (Chui et al. 2018).

Trust blend a complex array of interactions factors including attitude, beliefs, control, emotion, risk and power (Abbass 2019). Stated that AI do not have attitude, beliefs or emotion in addition to the human lack of understanding, may cause it hard for a human to trust the output. The human is in a vulnerable situation. However, if vulnerability is defined as f (capability, opportunity, intent), and one assume that the AI's intent is aligned with the human's intent, humans can through training learn AI's capabilities and opportunities. In other words, it is possible to increase the transparency, and further the trust, by educating humans about what AI can and cannot do, and where disruption might occur (Abbass 2019).

However, what happens if the human and AI disagree? Fluid interaction which allow the human to edit AI, and the AI to guide the human will be necessarily. The aim is to enable a collaborative exploration of the data that leads to common ground where both the AI and the human beliefs have been updated (Chander et al. 2018). An interaction that makes it possible for the AI to answer questions such as "Why do I need to re-plan at this point" will increase the human's ability to find biased data, understand and trust the AI (Fox et al. 2017) .

Another important factor regarding trust is time. If the machine operate reliably and predictable over a long time, humans will start to trust AI to the same degree they trust other humans (International Business Machines 2015). However, while it is possible to trust AI in a calculative, and a knowledge based way, it is difficult to reach a higher level of trust by identification (Lewicki and Bunker 1996) which seems to be reserved for fellow humans.

FINDINGS AND DISCUSSION

This section presents findings and discussion from the collected empirical data. With the aim of mapping where the construction industry is likely to be in the future considering AI and where the industry currently is regarding AI.

THE POTENTIAL BENEFITS OF ARTIFICIAL INTELLIGENCE

The digital shift is taking place, but it can be difficult to predict how the digitization will impact the construction industry. The findings are based on three external interviews, with high AI knowledge, in addition to nine case specific interviewees, with relatively low AI knowledge. The remaining eight case specific interviewees are not included, due to their lack of knowledge considering AI. The interviewees were asked an open question considering AI's future in the construction industry to map people's thoughts about construction's digital future. The question resulted in both examples of applications and possible impacts. During the analysis of the collected data, the applications emerged into three AI categories inspired by Lee (2018) and Blanco (2018), namely: Machine learning, Pattern recognition and Automation.

Machine learning consists of algorithms that can analyse data and develop new solutions based on historical figures in a way a human never would be capable of. **Pattern recognition** is the process of recognizing patterns by using a machine learning algorithm. **Automation** is the process where AI will be able to carry out tasks done initially by humans, or tasks that go beyond human's ability. Table 3 is structured after these three categories, further is the potential benefits of taking them in use discussed.

Table 3: Future application of AI presented by Team Bispevika

Categories of AI	Application	Impact
Machine learning	Scheduling	Analysis of a large amount of data based on historical figures and human input. Makes it possible to evaluate millions of scheduling options that take humans exponentially longer to accomplish
Pattern recognition	Health, Safety and Environment	Predict/early detection of dangerous situations by using machine learning algorithms in combination with pattern recognition
Pattern recognition	Storing space	A digital map that continuously shows the site and where it is possible to store materials or machines. Will increase the predictability and efficiency on site
Pattern recognition	Detection of unregistered people	Using pattern recognition to detect people and find those who are not registered at the construction site. Will increase the safety and possibility of larceny and criminal damage
Automation	Robots executing dangerous work	For example, work in the height, such as fire protection of steel beams. Will improve the safety of humans
Automation	Self-driving construction machinery	The use of robots and self-driving construction machinery will change work flow
Automation	Quality assure work	Robots that drives around the construction site scanning the site situation and compare it with the BIM. This technology may save hundreds of hours spent of quality assuring work, both considering the main- and subcontractors

All applications mentioned in Table 3 will impact the workflow and work tasks. In order to function optimally, the applications will require human-AI trust and human-AI collaboration. The industry is today putting trust in individual expertise over empirics. This is interesting as the human remember feelings more than the actual event as a whole (Kahneman 2011). AI will act on common sense with no underlying intentions. One interviewee says the following: “Some people have bad intentions, that an AI would never have. I would have been equally sceptical to a human being as an AI, owing to people’s intentions”. This makes it easier to trust AI. AI will also have the ability to explore several “What ifs” while humans cannot. This is positive considering the optimization of processes but on the other hand, the reason why there is a need for transparency, as described in the theoretical framework. AI will never have a bad day at work. A result will be increased predictability in workflow and quality.

However, good solutions will require the right amount of data, sufficient data, and the right variables. All nine case specific interviewees are mentioning that knowing that AI is based on the right data set or BIM will be a prerequisite for trusting the AI. Eleven out of twelve interviewees point out that visualization of why and how the output is made will increase their understanding of the causality and further increase the trust. One interviewee says the following: “I would have managed to rely on the AI if it visualized why and how the output was made. Exemplification makes people understand and learn.” The need for explanation corresponds with the research described in the theoretical framework. As stated in the theoretical framework will interaction with AI be necessarily to get a functional collaboration. However, the majority of the interviewees sees it hard to imagine how communication with AI should work, especially if the AI and human disagree. Others can’t imagine how they are supposed to disagree, if the input to the AI are based on human thoughts.

Considering the future, can it be beneficial to investigate the logistics and transportation industry and take advantage of their experiences considering machine learning and route optimization. The healthcare sector can contribute to experiences regarding pattern recognition. Experiences considering robotics can be taken from the manufacturing industry.

HARVESTED BENEFITS OF ARTIFICIAL INTELLIGENCE

This section is based on the seventeen case specific interviewees. To map the harvested benefits of artificial intelligence in Team Bispevika, it was chosen to investigate the implementation of three digital tools: Touchplan, Synchro and ALICE. The tools represent the three levels of digitization (digitization, digitalization and digital transformation), described in the theoretical framework. Table 4 and the following discussion will be structured after these three tools. The categories and sub-categories were developed in co-operation with supervisors as a foundation of the interview guide. A brainstorming and discussion of questions relevant for the research questions were conducted. Further, the different questions were emerged into Technology, Process and Culture and their following sub-categories as shown in Table 4. The three categories Technology, Process and Culture was inspired by Arnold (2010), and Roland and Westergård (2015) opinions regarding important implementation factors. An implementation can be seen as successful when all rows in Table 4 is marked.

Table 4: Today's situation regarding implementation of digital tools at Team Bispevika

Categories	Sub-categories	Touchplan (Digitization)	Synchro (Digitalization)	ALICE (Digital Transformation)
Technology	Knowledge	X	X	
	Training	X		
	Use	X		
	Person Independence	X		
Process	Knowledge	X	X	
	Training			
	Routines			
	Person independence			
Culture	Visibility of the utility	X		
	Willingness to use	X		
	Sense of achievement			
	Ownership			

Touchplan is a web-based construction collaborative tool, which is a digital version of the tools in the LPS (Sticky notes and physical boards). There is currently no training strategy regarding LPS or the use of Touchplan. Most interviewees think that the technical training is enough, although there is no defined training strategy. The interviewees consider themselves as competent users that can operate independent of expert users. This can be seen in the context of Toucplan's easy user interface. It is important for a successful implementation to illuminate the benefits it has for each employee's daily work tasks. Team Bispevika manage this in a good way, which is reflected by the high willingness and motivation to use Touchplan. One interviewee tells the following: "Six month ago, the only thing I was able to do on a computer was opening an e-mail. Today I am using Touchplan to plan and coordinate my work tasks. It's fantastic."

However, it is notable, that the interviewees tell that they are feeling person independent, but at the same time feel no sense of achievement, ownership nor commitment. This underlines how dependent they are on implementation drivers, in combination with the lack of a well-defined strategy and concrete goals. It seems like the implementation drivers have clear thoughts about who needs to learn the different things (training analysis), but that there is a lack of getting it into a clear and tangible structure (training design) in addition to continuously evaluation with the workers involved (training evaluation). As stated in the theoretical framework will all three factors (analysis, design and evaluation) be decisive.

Synchro is a 4D digital construction platform, which gives the workers the opportunity to visualize, discuss and collaborate in order to find all possible constraints before executing. As with Touchplan, there is currently no defined training strategy regarding 4D planning nor training in Synchro. There are today few people that can operate the program, and the interviewees are mentioning lack of time and extra work as main reasons. The lack of time may be a result of prioritizing in connection with the fact that few interviewees see the upsides of learning Synchro. This seems to affect the willingness and motivation to learn, and further the sense of achievement, ownership and commitment. However, those who are using it are pointing out the benefits of using the 4D model to get a common understanding of work tasks. The model is especially helpful in terms of the diversity of languages on a construction site.

Touchplan and Synchro represent transparent technology. Transparent technology is technology where the human control how the input is transformed to an output. As a result of the human controlled process, which makes the process transparent, is the output reliable and easy to trust. However, there is no guarantee that the given output is the most optimized, for example in terms of progression, staffing and cost, as the human brain have limited capacity of seeing different possibilities.

ALICE is based on AI which analyze, optimize and provide an output, such as a schedule. The tool is currently in the testing phase, which is illuminated by the empty rows in Table 4. AI is today a "hot" topic and widely used term. As the understanding of AI is not general knowledge in the industry, it will be difficult for a worker to understand how ALICE arrives at the presented output, and further trust the output. Today's lack of historical figures makes ALICE dependent of human-input. Humans partially controls the output, which makes it easier to trust the output. However, with enough historical figures the human input will no longer be necessary. Trust between humans are a decisive factor for a good collaboration and will likewise be important for a good human-AI collaboration. All interviewees agree that the implementation of AI will require other knowledge and training than the lower degrees of digitization.

CONCLUSION AND FURTHER RESEARCH

This paper has the purpose of illuminating how the construction industry can close the gap between the potential benefits and the harvested benefits of the implementation of AI. The gap has been identified by looking into the construction's possible benefits of implementing AI and today's harvested benefits of AI.

The research has been conducted as a literature study, a case study of Team Bispevika and three external interviewees. It is possible to assume that the results can be generalized to other projects, as the chosen interviewees are persons with different positions, knowledge and attitudes considering the digital shift. Research done in this paper shows that technology, process, and culture are equally important to succeed with an implementation. Figure 3 and 4 illustrates the current implementation situation of Touchplan (digitization) and ALICE (digital transformation). Dark grey illustrates the required level for a successful implementation, and light grey illustrates that some factors are achieved but not everyone, while white illustrates that the required level for a successful implementation is far from reached.

Figure 3: Implementation of Touchplan

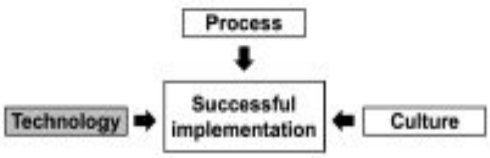

Figure 4: Implementation of ALICE

As shown in Figure 3, **Touchplan** and LPS are not considered implemented. However, Touchplan can be considered as a user-friendly tool, where **Technology** is sufficiently developed in order to succeed with the implementation. The expert users have managed to make engagement and positive attitude among the employees. This has further resulted in the willingness and motivation to learn and use the tool. The employees miss the sense of achievement and ownership, and as a result, is **Culture** marked light grey. The **Process** is marked white as there is no clear training strategy. As illustrated in Figure 4, **ALICE** is not fully implemented, and is currently in the testing phase. The AI-technology itself is present, but the absence of historical figures and transparency makes the **Technology** light grey. **Process** and **Culture** is marked white as there is no defined strategy of implementing ALICE nor a flexible, motivated and knowledgeable working culture. It can be concluded that AI has come to stay, and that there exist several benefits by implementing AI. However, several barriers must be broken in order to take advantage of the proposed benefits. Table 5 presents the factors concluded to be decisive for a successful implementation of AI.

Table 5: Factors considered essential for closing the gap between the current and future use of AI in the construction industry

Experiences	Experiences and thoughts that can contribute to close the gap between the current and future use of AI
Touchplan and Synchro	• A well-defined training strategy • The training should focus on the process it is supposed to support • Concrete goals for each employee, including long-term goals and short-terms goals • Implementation drivers with positive attitude • Cultivate a culture characterized by a positive attitude, commitment, and curiosity • Involvement is important, but equally important is expectations • A Team should consist of people with experience from both production and use of digital tools • The use of 3D models improves the common understanding and communication • Getting a positive reputation will make the implementation process easier
Other factors considered important. Based on literature, empirical data and the authors thoughts	• It should be taken advantage of AI in those cases where the technology can improve the process • Interaction with the AI will be necessarily in order to collaborate and trust the AI • A user interface that normal people can understand • Visualization of the process from input to output will increase causality and further the trust • Increased technological knowledge considering AI will contribute to trust • Good experience considering the use of AI, will increase the trust • Implementation drivers with good understanding of human and AI • Available support is needed in a longer period compared to the lower degrees of digitization • Data with sufficient quality

The combination of human-AI trust and continuously optimizing a process makes it possible to increase the efficiency. Trust between humans and AI can more easily prevail when first established due to a lower possibility of conflict. AI can therefore be a supplement to improve a lean workflow.

AI technology differs from lower degrees of digitization as it has other prerequisites considering trust and collaboration with humans. It is recommended that further research discuss the adaption of AI on the premise of the users, collects more empirical data and investigates experiences done by other industries.

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STREAM 15: LEAN PROJECT DELIVERY

Abou Dargham, S., Bou Hatoum, M., Tohme, M., and Hamzeh, F., (2019). "Implementation of Integrated Project Delivery in Lebanon: Overcoming the Challenges." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 917–926. DOI: https://doi.org/10.24928/2019/0242. Available at: <www.iglc.net>.

IMPLEMENTATION OF INTEGRATED PROJECT DELIVERY IN LEBANON: OVERCOMING THE CHALLENGES

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ABSTRACT

Integrated Project Delivery (IPD) approach is important to deliver value and reduce waste by integrating the stockholders early in a project. Despite its numerous advantages over the traditional delivery systems, IPD's applicability in the Middle East has not yet reached its potential. In Lebanon, the construction market is dominated by delivery practices such as design-bid-build or design-build. The aim of this paper is to examine the Lebanese construction industry experiences in project delivery methods and their attitudes towards shifting to Integrated Project Delivery. Research is conducted through surveys and interviews with industry professionals to investigate the performance of the traditional delivery approaches and the implementation of IPD in Lebanon. The data collected will be used to evaluate and critique the construction industry current project delivery practices, analyze the experts' awareness and attitudes toward IPD delivery method and identify the main barriers that prevents practitioners from implementing IPD.

KEYWORDS

Integrated Project Delivery, Contracts, Lean Construction, Traditional Delivery Approach, Lebanon, FIDIC.

INTRODUCTION

Integrated Project Delivery (IPD) has offered a great deal of improvement by maximizing value and reducing waste through the early collaboration of cross-functional teams to align goals and share risks and rewards through a relational contracting approach (Matthews & Howell, 2005). In the contractual frame work, IPD agreements define new set of rules that limit liability and hierarchical management approach and enhance the flow of information and creativity. Several professional organizations are striving to adopt the IPD approach, and some successful projects have demonstrated its huge potential in delivering projects with high quality and lower costs. However, its application in the Middle East is still marginal because of the required perquisites for its implementation (i.e. technological, legal, and cultural); thus, the number of projects

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adopting IPD remains relatively small (Hamzeh at al 2019; Korb et al., 2016). In Lebanon, it is yet to be adopted.

The construction industry in Lebanon and the Middle East (ME) is governed by traditional delivery approaches: design-bid-build, construction management (agency or at-risk), or design-build. These types of contractual delivery have historically resulted in an enormous amount of claims, high risks and late schedule and over budget projects. Some attempts have been made to avoid such conflicts such as post design constructability reviews, value engineering exercises, partnering and contractual efforts to shift the risk (Lichtig, 2006). However, these approaches merely solved the ongoing issues in construction delivery. The industry is in a crucial need for improvement which can be done by shifting to the integrated approach.

Since IPD remains a concept in Lebanon, few studies about its implementations have been conducted. This paper serves as an attempt to present the current state and practises in the Lebanese construction industry, to analyse the industry's attitudes and notion of the IPD method and to identify the main hurdles that may prevent its implementation.

INTEGRATED PROJECT DELIVERY

IPD is a new approach of delivering construction projects that aims to increase the value in the eyes of the customer, increase profit for all parties through mutual benefits, enhance communication, appropriate technology, and high performance (AIA, 2007). In other words, it is organizing the work and goals of all project teams under one unified goal.

FUNDAMENTAL REQUIREMENTS FOR IMPLEMENTING IPD

Contractual Requirements: IPD contracts are considered to be "relational" contracts because they consider the process and not only the end product (& Gerber, 2011). AIA C195, AIA C191, ConsensusDocs 300, and IFOA are the most common IPD contracts. These contracts secure shared financial risks and rewards, and guarantee collaborative decision-making, liability and integrated design. Unlike the traditional contractual structure that aim at shifting risk from party to party, relational contracts align the commercial terms of participants (Thomsen et al., 2009).

Technological Requirements: A successful IPD process must adopt technologies that integrate information across all stakeholders such as Building Information Modelling (BIM). BIM is a 3D technology that provides integration in design, construction and management; it improves coordination in construction industry and enhances collaboration among teams (Eastman et al., 2011). On the other hand, Lean tools such as Last Planner System (LPS) Value Stream Mapping (VSM), A3 reports, etc. are considered complementary to the technological requirements and necessary for IPD implementation and often used as the IPD operational system (Mesa et al., 2019).

Cultural Requirements: Practices must secure collaboration, trust, and continuous improvement through trust-building activities and IPD training (Ghassemi & Gerber, 2011). It is a part of lean philosophy making open communication an important requirement to deliver a successful IPD project.

Financial Requirements: In selecting compensation and incentive structures, fair distribution of shared savings and profit must be guaranteed (Rached et al., 2014). If selected properly, a concrete incentive structure will secure a professional project delivery.

CURRENT DELIVERY METHODS IN THE REGION

Several types of traditional delivery approaches are used in the MENA Construction Industry, most notably is the design-bid-build (Hamzeh et al., 2019). And since the 1970s, companies in the Middle East use the *Fédération Internationale des Ingénieurs-Conseils* (FIDIC) family of contracts in their traditional project delivery approaches (Rached et al. 2014). The major systematic problems in traditional delivery methods include holding back ideas, limiting cooperation and innovation and promoting local optimization at the expense of the project. As for adopted contracts, they do not necessarily spur innovation at the project level since they limit coordination and collaboration (Wilkinson et al, 2012).

IPD research within the ME construction industry is very limited. Studies on the subject include an investigation of cultivating collaboration within ME industry by adopting IPD contracts done by Hamzeh et al (2019), an evaluation of the cultural acceptance of the ME industry to IPD practises done by Rachad at al. (2014) and finally a reflection on an IPD project done in ME presented by Korb et al. (2016).

METHODOLOGY

In order to fulfil the research purpose, a qualitative assessment was performed using survey questionnaire. The survey questions were developed based on similar studies and literature findings related to integrated project delivery systems. Then they were tested through mock interviews for further screening and fine-tuning. After identifying the survey respondents, the selected professionals were contacted to set interviews. An online version of the survey was drafted, yet it was filled and administered through face to face interviews. This method was utilized because it is not common in Lebanon to fill surveys online and usually the response rate with online surveys is very low. Also, because it yields more reliable results compared to online surveys, ensures that the new concepts of IPD are conveyed properly to the respondents and stimulates further input on the subject.

A cumulative of 23 interview hrs. were recorded with experts from different backgrounds and experience level, most of which are executives and seniors with a collective of 700+ years of experience in the Lebanese AEC industry. A total of 21 construction industry professionals completed the survey over a period of two months. Finally, the results were analysed using analytical tools provided by Excel to guide recommendations.

The originality of the study lies in addressing the IPD framework (standards, industry attitudes and perception, implementation etc.) from a Lebanese market perspective; a market not familiar with IPD systems. Therefore, the survey was tailored to collect facts and describe phenomena through 42 questions mixed between rate and open-ended questions. The survey outcomes were presented through descriptive statistic to present the and the market practises while the discussions aimed to display the respondent's perception and attitudes towards a foreign system based on their local experience.

The survey was divided into three sections. The first section was designed to gather general information about the respondent's profile, practices, and satisfaction with current project delivery practices. The second section reflects upon the participant's knowledge and value perception regarding IPD philosophies and tools. The third section investigates the respondent's opinion on factors that hinder IPD implementation in Lebanon and attitude towards adopting this delivery approach.

SURVEY FINDINGS AND ANALYSIS

The survey reported the findings of 21 construction industry practitioners with diverse professional background ranging from construction management consultants, architects and engineering consultants, owner representatives, general contractors, and sub-contractors. 57% of the respondents were project managers and executives with more than 20 years of industry experience, 14% of respondents were seniors with 10 to 20 years of experience, 10% were mid-level practitioners with 5 to10 years of experience and 19 % of them were juniors with 5 or less years of experience. As for the contractual forms adopted by the practitioners, almost 38% reported to use a modified contract template based on FIDIC family of contracts (1987 and

1999 depending on the project), 10% used FIDIC 1999 template only, 14% use FIDIC 1987 template only and the remaining 38% use their own company's template modified based on previous experiences. The replies also reflect that 90% of the participants were experienced with Design-Bid-Build (DBB) projects, 38% of them had experience in Design-Build (DB) projects, 48% had experience with Construction Management at risk (CM at risk), 20% were experienced with Staged Design-Bid- Build and Multiple prime contractor and finally 5% were involved in partnering projects.

PROJECT DELIVERY PRACTICES IN LEBANESE CONSTRUCTION INDUSTRY

According to the survey, the most common type of project delivery method practised in the Lebanese construction industry is design-bid-build. On the other hand, most of the contracts employed by industry are derived from FIDIC suits of contracts.

Respondents Satisfaction with the Contracts Employed in the Market

FIDIC is considered to pose certain limitations on different levels such as risk allocation, liability and insurance; it is also criticized for being biased towards the contractor more than the owner (Alves & Shah, 2018; Hamzeh et al., 2019). Respondents were asked to rate their satisfaction with their employed contracts' ability to manage important factors using a Likert scale (1- Very dissatisfied to 5- Very Satisfied). The results are presented in Figure 1.

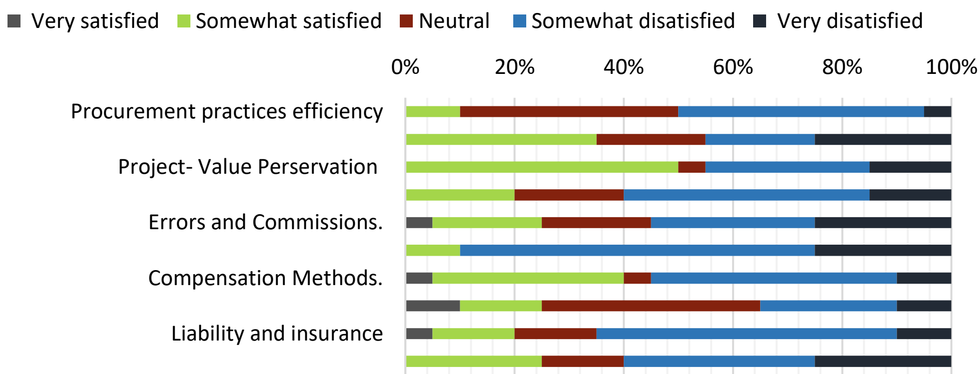

Figure 28: Satisfaction with the Contract Templates Employed in Lebanon.

The average of all means of each factor is 2.55, indicating that practitioners are generally dissatisfied with the employed contracts abilities to manage the factors shown in Figure 1. More than 50% of the respondents were dissatisfied or extremely dissatisfied with factors related to risk allocation, liability and insurances, claim conscious behaviour, errors and commissions, illicit practises and compensation method.

Respondents Satisfaction with the Project Performance

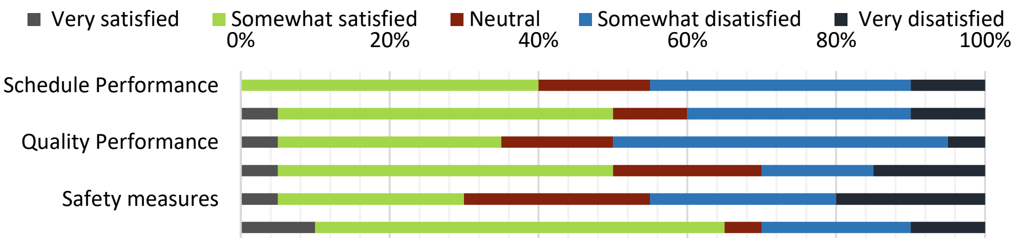

Figure 29: Respondents' Satisfaction with Project Performance.

Using the same Likert scale, participants were asked to rate their satisfaction with project performance based on a list of performance indicators introduced by El Asmar et al. (2015).

The results in Figure 2 indicate for each KPI, nearly half the respondents were satisfied, and the other half were dissatisfied.

Project Performance Criteria	Mean (μ)	Standard Deviation (α)
Schedule Performance	2.85	1.06
Cost Performance	3.05	1.16
Quality Performance	2.85	1.06
Sustainability Performance	3.1	1.18
Safety measures	2.7	1.19
Customer Relationships	3.35	1.19

Table 1: Detailed Respondents' Satisfaction with Project Performance.

As shown in Table 1, respondents were mostly dissatisfied with their safety measures, quality and time performance. A major cause would be the dominating state of construction projects which are mostly behind schedule. The average of the displayed means is 2.98 which indicates that respondents are neutral at best when it comes to their satisfaction with project performances.

Reflection on Current Project Delivery Practices

To further examine the market familiarity with the integrated project delivery practices, respondents were asked to state the frequency of occurrence of the following practices: participating in making and organizing a joint decision, facing communication issues between the various team members, adhering to the owner's specifications without alteration in design or construction, resolving project problems with different project entity outside the contractual obligations, signing a contract that contains comprehensive clauses which promote collaboration. The rating system used for these questions was a five point scale with (1) Never happened to (5) Always occurring. The results are shown in Figure 3.

A considerable number of respondents participated in a joint decision and participated to resolve construction problems outside contractual obligations on a regular basis. However, this phenomenon is limited to the construction phase of the project when most of the participants are on-board. Respondents also saw that help provided to other project entities outside the contractual obligations negatively affected the project and claims were referred to arbitration.

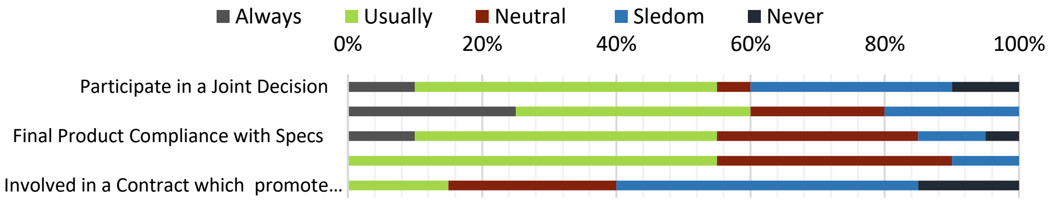

Figure 30: Respondent's Current Project Delivery Practices

Collaboration Level in the Lebanese Construction Industry

To examine whether the cultural prerequisites for integrated project delivery are present in the Lebanese construction projects, respondents were asked to reflect upon the collaboration level among project parties, to state examples of collaborative tools they used and to indicate factors that might hinder collaboration and information sharing based on their experiences.

Figure 31: Level of Collaboration between Parties in a Project

Most of the participants agree that the parties involved in a construction project do not trust each other. This is evident in the responses to the question that address trust and goodwill intention among team members. The rating was done using a five-point scale with (1) indicating Trust is not present and (5) indicating Trust is always present. The results are shown in Figure 4. The computed average rating of trust was 1.85. According to the respondents, the lack of trust is the outcome of fraudulent practices and claim conscious behaviour among participants to gain extra profit. As a result, the contracts were modified to control these occurrences resulting in a stringent contract biased towards the construction entity and an unbalanced risk sharing between the three main construction teams (Architect/Engineer, Owner, and General Contractor).

The respondents were also asked to rate their confidence level in the experiences and capabilities of other team members using a scale of (5) Extremely confident to (1) Not Confident at all. Results show that most of them are either neutral or not very confident with a mean of *2.85*. The distribution of the results however indicates that the percentage of the respondents who are confidant are somewhat similar to those who are not confidant (around 25% each). These groups represent either the contractor's entity or the A/E entities. The latter voiced some concerns due to the presence of incompetent contractors on projects which results in degrading project performance in terms of quality. Consequently, the A/E respondents tend to increase their insurance when confidence is not present, especially in DB projects when they operate as the owner's consultants which negatively affects the Trust attribute.

Moreover, participants were asked to rate the current construction practices in terms of communication and information sharing using a five-point scale with: (5) Open-Communication present at all times and is highly encouraged; to (1) Communication is not present. A similar scale was applied for knowledge sharing. Reflecting upon the results related to these attributes in Figure 4 indicates that the majority of the respondents are somewhat satisfied with their collaborative practices suggesting room for improvement in the area. This is expected considering the trust and confidence related problems that is always present between parties. The interview discussions also indicate that the respondents consider basic coordination activities such as "weekly meeting during construction phase" as the main implemented collaborative tools which explains why this attribute had a higher mean value compared to other attributes

IPD Knowledge AND AWARENESS Level

The survey aims to assess the participant's knowledge and awareness concerning IPD tools and philosophes. Respondents were asked to rate from 1 to 5 their level of knowledge when it comes to IPD delivery approach, Lean Construction tools (Last Planner System, Target Value Design), relational contracts (AIA, ConsusDocs, and IFOA), BIM and other integrated information systems. The results, summarized in the Figure 5, indicate that most of the respondents are not familiar with the IPD system and lean tools. Almost 30% of the respondents have been involved in a project where they used a shared information platform because the project complexities necessitate it. Less than 10% of the respondents are familiar with Lean construction tools.

On the other hand, most of the respondents reflected positively when asked whether they perceive certain project criteria such as early involvement of key team members, open communication and knowledge sharing among project teams, aligning interests of all project teams and contractual incentives: risk-reward sharing are requisites for project success. The results are displayed in Figure 6. These criteria were derived from basic IPD features provided by the American Institute of Architects (AIA) guidelines. The bar graph indicates that more than 80% of the participants agree that risk-reward sharing, and interest alignment are necessary for project success.

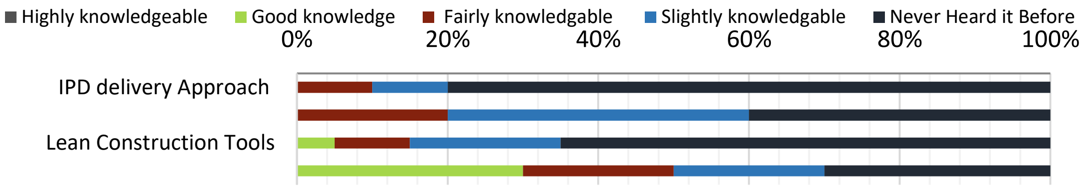

Figure 32: Level of Knowledge Regarding IPD Tools

Based on the open-ended questions, most of the participants valued collaboration and working towards common project goals. And they seem to have tangible evidence based on their experience with projects where they collaborated with other parties.

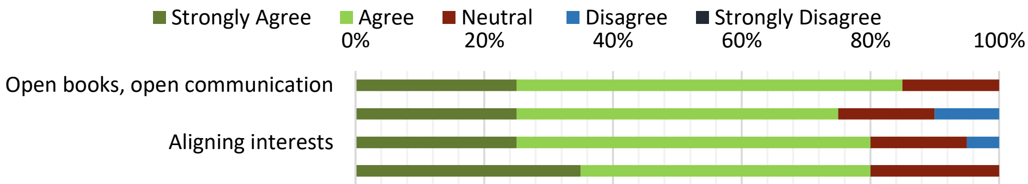

Figure 6: Respondent Viewpoint on Successful Project Criteria

Barriers Against Implementing IPD in Lebanon

To assess IPD implementation barriers, questions in the survey were categorized based on the four IPD barriers: Legal, Cultural, Technological, and Financial identified by Kent & Gerber et al. (2010). These barriers were adopted because they provide a holistic and sufficient representation of the all the identified barriers relating to IPD. Problems related to IPD implementation was identified by respondents based on their experience as follows:

Legal Barriers: Based on the respondent's feedback, most stated the government laws of biding and the current procurement practices as the main legal barrier. In the public sector, the lowest-bidder selection process is mandated by the government instead of value driven selection process. In the private sector, the owner has the complete freedom to decide on the bidder. This freedom promoted the unethical negotiation techniques whereby the owner negotiates with each contractor or design firm on specific prices to reduce the total bidding cost. As a result, incompetent teams are chosen and low-quality projects are generated. Many respondents expressed this concern and voiced that they have to deal with unskilled team members. Moreover, for large scale projects (>50,000m^2) the Lebanese Syndicate of Engineers mandate the contractor and designer to be from different entities. Another legal issue raised by one of the participants when dealing with the public sector is that the Council for Development and Reconstruction-CDR, the largest public owner in Lebanon, harbour their own contracts and are bound to use the FIDIC contracts when the project is funded by the World Bank. Moreover, the wide knowledge and usage of the FIDIC book gives it advantage over any other contract type. According to the respondents, owner entities usually prefer to use the 1987 FIDIC and the new impartial FEDIC 1999 remains not widely accepted among practitioners. This lag in contractual updates serves as another big barrier to adopting relational contracts.

Cultural and Behavioural Barriers: As previously discussed, the Lebanese construction industry still lacks the collaborative attitudes. Projects lack the incentives for collaboration this can be attributed to local optimization practises, self-preservation attitude and corruption within the industry. The owner always tries to shoulder all the risks on the contractor through a well-structured contract which in turn leads to adversarial relationships between the different construction entities. When asked about participating in a relational contract one respondent replied: “If I want to be part of a team that shares risks then why am I paying them”. Most respondents also argued that the Lebanese construction market is full of “immoral” and “self-centred” industry practices which may lead to problems in collaborative and risk sharing. On the other hand, others argued that IPD comprise set of principles that can be practised along with other delivery approaches such as collaboration.

Technological Barriers: Participants were well aware of the industry’s deficiency from the technological perspective given the lack of knowledge in lean principles and IPD tools as shown previously. The survey indicated that only 30% of participants have previous experience with BIM platforms and their experiences is limited to one or two projects where the owner has mandated the use of a shared information platform. Most of the respondents related these barriers to the absence of capable contractors and financial incentives associated with the technological upgrade. However, they were aware that future market demand will require technological upgrades since more than 65% stated that they are willing to invest in technological upgrades opposed to 20% who are willing to invest in Lean tools. The lack of value perception of Lean tools as opposed to BIM platforms can be associated with the heavy BIM marketing and owners demands.

***Financial Barriers*:** According to the respondents, the absence of a financially capable owner who has access to abundant resources of money to invest in and adopt a new delivery system was the main financial barrier. The absence of proper case-studies or evidence for the return on investment of adopting new delivery systems and the lack of knowledge about IPD contracts among owners and developers serve as the main reason behind the respondent’s opinion. IPD is still considered a “risky business” in the Lebanese context.

Lebanese Market Attitudes towards IPD Adoption

The participants were asked whether they foresee the adoption of IPD by the Lebanese market in the future, and, if given the opportunity, they are willing to participate in an IPD project. The results are demonstrated in Figure 7.

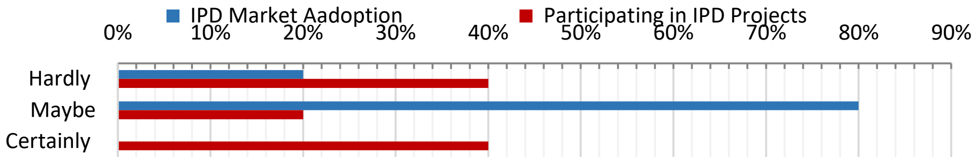

Figure 33: Lebanese Construction Industry Attitudes towards Adopting IPD.

Most of the respondents saw that the Lebanese market may eventually adopt IPD system. As for participating in an IPD project, some expressed willingness while others did not. This indicates that the practitioners are well aware of the inefficiencies of current project delivery practises but not yet confident about the IPD’s ability to blend in the Lebanese environment. Comparing the results of Figure 7 with that of Figure 1 indicates that 100% of the respondents who scored *strongly and somewhat dissatisfied with the contracts* foresee that Lebanon **might adopt IPD**. However, 25% of respondents who were satisfied and 33% who were neutral with the employed contracts foresee it’s **hard to implement IPD** in Lebanon. This indicates that most of the Lebanese AEC firms have experienced the incapabilities of the traditional contracts to serve the growing demand and challenges of the industry and foresee the need for a change, yet they are not sure whether IPD might be the best replacement to the current delivery practises. And the fact that none of the respondents were certain or positive of the market adoption of IPD system can be attributed to the previously identified barriers as participants acknowledge the local industry shortcomings in terms of the technology, financial incentives, cultural inertia to change, illegal practices and self-preservation.

Also, linking the results of Figure 7 to those of Figure 2 shows that 100% of the respondents who scored *strongly satisfied with project performance* scored **maybe** in recommending IPD to their firm. As for those who scored *satisfied with project performance* their distribution among **hardly, maybe** and **certainly** was as follows 9, 64 and 27 %. Respondents that scored *neutral with project performance* were distributed equally among **hardly**, **maybe** and **certainly** (33% each). And dissatisfied respondents were distributed between **maybe** and **certainly** as follows 80 and 20% respectively. In general, it can be deduced that dissatisfied firms clearly sees the benefits of being involved in an IPD project as none of the respondents considered the option **Hardly**. As for the neutral firms, it is alarming to realize that they are unsure whether or not a change is needed.

CONCLUSIONS AND RECOMMENDATIONS

The survey and interviews conducted shed light on the actual state of the project delivery methods in the Lebanese construction industry and voice the concerns of the practitioners concerning current practices that might act as barriers against the implementation of IPD. Although very few firms started implementing lean construction, the majority of the practitioners are either unknowledgeable or have some superficial knowledge regarding IPD systems. The findings of this study indicate that a successful IPD project in Lebanon needs to harbour trust, align stakeholder goals, and show willingness to invest in basic IPD tools. The study also reflects that some firms, though prefer the concepts of IPD standards over other traditional delivery practises, are sceptical to its applicability; this is due to an industry plagued with corrupt construction practices. Thus, a cultural change is imperative to the implementation of successful IPD projects in Lebanon.

Finally, the IPD method should be marketed within the industry. Construction management and contractual consultants who are experts in the field of IPD or Lean Construction should play a vital role in marketing this delivery method along with multi-party contracts within project management firms. Their responsibility would include educating the owners regarding IPD principles, tools and practices and emphasizing the value associated with such delivery approaches, especially at the level of financial gains.

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A CASE STUDY ON IMPROVING STANDARDIZATION IN THE CONCEPTION PHASE BY DEVELOPING TOOLS AND PROTOCOLS

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ABSTRACT

In the Architecture, Engineering and Construction (AEC) industry, the variability nature of construction projects leads to the presence of waste. The standardization of activities and processes can help reduce variability and thus reduce the amount of waste. This paper presents an action research approach to develop and implement a framework to help creating an improved visual mapping of the information flows between the departments of an architectural firm. The aim is to use the principles of Value Stream Mapping (VSM) from Lean Production and Building Information Modelling (BIM) processes to improve standardization in the information flow.

The focus is on the information flow between the various departments of an architectural firm. This study contributes to the field through the development of a framework used to improve standardization in the information flow. Moreover, the findings presented offer practical implications by helping with the improved interoperability of interdisciplinary professionals work with standardized processes and activities.

KEYWORDS

Building Information modelling, value stream mapping, information flow, non-value-added actions.

INTRODUCTION

Building Information Modelling (BIM) was introduced in the AEC industry with the aim to tackle the fragmentation issue by improving interoperability and collaboration among parties involved in construction projects (Eadie et al. 2014). In theory, BIM approach is proposed as a solution to decrease fragmentation and inefficiency in the project lifecycle: it is aimed to reduce information loss by centralizing the production and exchange of information. Therefore, the concept of management of the information flow is crucial when using BIM. Indeed, BIM contributes to translating the client's value proposition into a successful project by implementing a continuous information flow (Al Hattab and Hamzeh 2013). Indeed, a holistic

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BIM process will smoothen information flows, but this has to go beyond merely building a BIM model. Furthermore, several barriers have been identified to explain the problems that prevent to reap the BIM benefits such as the lack of BIM coordination, the quantity and quality of information exchanged between the parties involved, the resistance to change, the lack of understanding of the entire information flows process and the lack of common shared vision (Forgues et al. 2016). The notion of information flow is not a dimension well known in construction, which is problematic for an efficient use of BIM. The notion of flow is inherent to the Lean Production approach (Koskela 2000) with several tools aimed at improving flows. Value Stream Mapping (VSM) is an essential tool used in the implementation of Lean Production to improve material, information and work flows (Rother and Shook 1999). The goal of VSM is to create a map of any productive process to identify and eliminate production waste (Braglia et al. 2011).

With an investigative method based on a collaborative design science approach (Otto and Österle 2012), this paper presents and analyzes the implementation of an approach based on Value Stream Mapping (VSM) principles generated to highlight the potential for standardization in the information flow during the design phase of construction projects. The aim of this research is to provide a framework for the firm that can be generalized for the industry, designed to help increase standardization in the information flows to reduce waste and increase the proportion of value-added activities. The focus is on the inputs and outputs of information regarding the creation of BIM models during construction projects from concept to construction drawings. It is important to note that the processes described in this paper are focused only on the BIM implementation within an architectural firm. The choice was motivated by the fact that this subject is less treated in the literature than the multidisciplinary design approach. Thus, bringing a new vision on the BIM implementation process. Furthermore, despite the presence of existing tools such as the Dependency Structure Matrix (DSM) or social network analysis, the promise of improved information flows that BIM offers is often unmet and that this provides a topic worthy of research in this paper.

REVIEW

Implementing BIM in a construction project also means moving from a document-centric approach to an information-centric approach. BIM has been introduced in the construction industry to improve interoperability and collaboration among parties involved in construction projects (Eadie et al. 2014). However, several issues can be observed with BIM collaboration due to the quality and quantity of information exchanged between parties involved, the resistance to change, the lack of understanding of the entire information flows process and the lack of common shared vision (Forgues et al. 2016). The traditional way in construction is based on producing and exchanging information through documents. From a Lean perspective, it is also called "push planning." This kind of approach is usually done in silos with little communication with the other actors of a same process. According to Crotty (2013), a model-based design (information-centric approach) in the design phase will give tremendous advantages over a document-centric approach. Indeed, there is a better and earlier coordination between all the actors in the design phase, an improvement in the basic design processes giving the ability to test and analyse the design and the most important aspect is a great improvement in the quality of design information produced.

There is a need for tools to help visualize processes and related challenges with existing practices, and to identify necessary improvements. There are tools or approaches from other industries that can help to improve processes in the construction industry such as various tools adapted from Lean Production: The Last Planner System, Continuous flow, Pull System, etc. (Ansah et al. 2016). There are currently some researches focused on improving the design process and/or the information flows in construction projects. For example, Wesz et al. (2013)

have conducted research related to the use of Last Planner System in the design phase with a focus on the engineer's workflow. Jacob and Varghese (2011) explored the integration of the Design Structure Matrix (DSM) in the information flows of BIM design processes. Furthermore, Al Hattab and Hamzeh (2015) presented a new strategy regarding design error management using social network analysis with a focus on team structures, error diffusion and interaction dynamics. Their aim was to compare tradition versus BIM-Lean practices for design error management. These researches provide frameworks to improve the design process in construction with various approaches.

Based on these results, this paper provides a new point of view to improve the information flows in the design process with a focus on the identification and reduction of sources of waste. Moreover, during the design phase, the various actors still tend to work in silo and push their information toward the next actor in the line (Aibinu and Venkatesh 2013). The traditional nature of construction projects is to provide information via documents (plans, budget, estimate, and more) through a document-centric approach, creating barriers to communication and coordination between the different actors of the project (Isikdag and Underwood 2010). Because BIM requires an information-centric approach, the traditional push document-centric approach makes it hard to implement BIM in the design phase. This change in approach brings an interest in the Lean approach that is based on a pull planning system.

BIM and the Lean approach are two different concepts used in the construction industry. Both of them aim to the same goal that is the reduction of waste and the maximization of the value in a construction project. According to Kjartansdóttir (2011), using BIM and Lean principles, the project will have an enhanced construction process, and this will help the project team to deliver the project. Based on these observations, Moghadam et al. (2012) have been able to integrate BIM and lean construction on a modular construction manufacturing process. The authors used VSM, a tool from the Lean approach, in combination with BIM to generate a map of the factory workflow using building components' schedule. BIM provided a way to automate the design and drafting process while VSM was used to visualize the workflow and identify the source of waste, the resource usage, and the time needed.

The VSM is one of these tools available as it was developed to deal with the presence of waste in production and to help implement the Lean thinking. Indeed, the use of VSM has had a major impact in manufacturing over the years. Apart from helping to identify and eliminate sources of waste (Rother and Shook 1999), VSM also help improving productivity (Seth and Gupta 2007) and identifying opportunities for improvement (Singh et al. 2011). The mapping of processes is not only about material flows but also about information flows (Braglia et al. 2011). Several authors have used the VSM in construction to improve supply chains (Arbulu and Tommelein 2002), project delivery (Mastroianni and Abdelhamid 2003), component manufacturing (Alves et al. 2005) or fundamental construction process (Yu et al. 2009). While these researches provide tangible examples of how VSM can help improve construction processes, their focus is mainly put on the workflow and during the construction phase. Other researches have managed to implement VSM in construction to improve the design process (Torres et al. 2018). Through a case study, Leite and Neto (2013) used VSM to improve the information flows in housing design using Lean principles. Their case study research helped visualizing how the design process is developed. However, both of these studies' focus were limited to the identification of time waste on the design process. The notion of time waste is important in construction; however, this source of waste is only one of sources identified in construction. Indeed, authors (Howell, Koskela, Macomber, Bodek and Emond) (Emond 2014) have identified ten sources of waste in the construction context: (1) underutilization of talents, (2) waiting inputs, (3) information transfer, (4) overproduction of information, (5) deficient behaviour, (6) loss of good ideas, (7) achievements unappreciated by the client, (8) make-do, (9) resistance to change and (10) non-management of perception. The authors Aka et al. (2017)

have carried out a research on the identification of waste in the design phase using VSM. Their study focused on the engineering and stopped at the current state with the identification of waste and recommendation of strategies to reduce waste. Based on the researches discussed in the review, this paper aims to fill a gap in knowledge by providing an approach using VSM to identify the ten known sources of waste in the information flows of the design process of an architectural firm. Furthermore, VSM is used to help provide a new approach in the implementation of BIM by identifying and reducing existing waste beforehand.

METHODOLOGY

The methodology used for this research was a collaborative design science approach (Otto and Österle 2012). The aim of this research is to identify activities or information within the design process of an architectural firm possible to standardize between projects to reduce the presence of waste within the information flows. The research protocol was based on VSM mapping exercise to help the members of the BIM core to visualize and better understand their own work and information flows process as well as the processes of the other department in order to formalize a unique and shared framework to manage the information processing. The VSM technique was not used in its entirety in this research. Only the VSM principles to map the processes and identify the wastes were used. The mapping used the standard Business Process Model and Notation (BPMN) to represent accurately and consistently results for each department. BPMN helped to facilitate the understanding of the maps as it provides a standard notation readily understandable by all stakeholders of a project. It was only used as a graphical representation and did not impact the principles of VSM used during this research. This research is organized and separated into three main steps: 1) thinking, 2) operationalization, 3) diffusion (Figure 1). Within each step of the research, a cell composed of members of the architectural firm is implicated in the process.

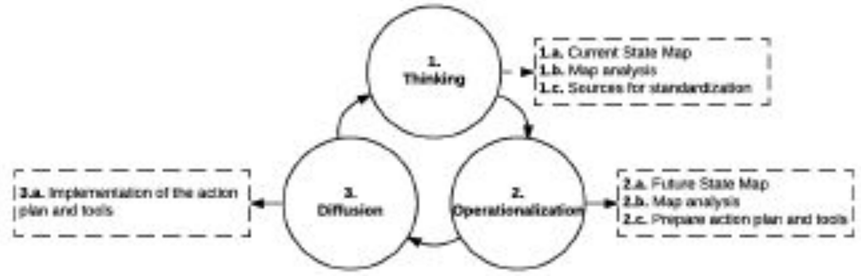

Figure 1: Approach based on VSM used during the research: The role of each cell is to help provide data and information during each step of the process.

The data was collected from an architectural firm focusing on building projects, such as residential buildings or shops. The first stage, current state map creation, occurred from September 2016 to December 2016 through nine focus groups; composed of one focus group per department, and four for the architectural department because four different building projects have been studied. Each focus group was conducted with several members of the department involved, such as directors of departments, project managers, architects, engineers, designers with one facilitator performed by one of the researchers of this paper. The focus groups were consulted twice during 1.5 h interviews: the first for the creation of the map and the second for comments with a total of nine maps created. For the second stage from January 2017 to June 2017, the data collected from the previous phase was used to help prepare an action plan with templates and tools. Five focus groups were conducted with several members of each department as the same manner as during the first phase. During the third and last stage from July 2017 to September 2017, a standardization manual was produced, based on the results from the two previous stages. The manual was distributed to the departments of the architecture firm to inform of the new standardized protocols.

PRELIMINARY RESULTS

THINKING

The first objective of the Thinking step was to create a current state map of the internal information flows of the various departments of an architectural firm during the design stage of a construction project. The cell responsible to run this step was composed of ten members of the firm and one member was responsible for writing down the minutes of every meeting to resume and communicate the information to all the members of the cell. At least one member of each department of the firm was represented in the cell to obtain accurate information from the entire firm. The use of VSM helped the cell mapping the information flows with a set of rules and then helped identify potential sources of information that could be standardized. The figure 2 shows a section of the current state with a highlight of the architectural department realized with the help of the architects. This figure aims to show a typical information flow between the client and the architectural department during the design process at the firm. At this moment, the firm is still using AutoCAD and 2D drawings, as they are currently working on the implementation of BIM. The aim of this mapping exercise was to highlight the input of information needed from the client to produce the drawings, plans or models and then highlight the output of information given by the plans to meet the client's needs. After being refined, the figure 2 shows a process map identifying the input and output of information around the plans created during the design phase. Indeed, several projects were mapped to obtain the most common information exchanges in the firm's projects. The output of information created by the architectural department may correspond to the input of information needed by the other departments, such as engineering to complete their activities.

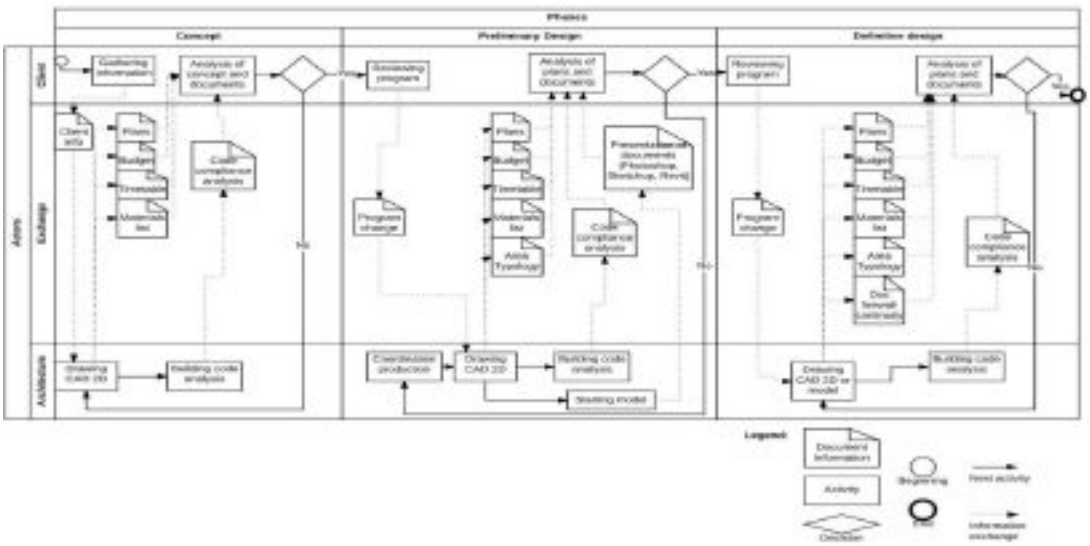

Figure 2: Current State Map of the architectural information flows in the design phase.

The information and documents show information present in each project studied (lists of materials, timetables, budgets or plans). The same analysis was done for the other departments of the firm to determine two points. First, the kind of information or documents that can be standardized from one project to another within each department. Second, from these information and documents identified, which ones can be standardized globally and used by each department in the firm. This paper focuses on the second point and presents several sources of information that can be standardized for all the departments of the firm such as the level of detail between the phases or estimation reports. Furthermore, the Thinking cell, responsible for the first step of the research established the criteria and parameters for each source identified. These criteria were then transferred to the second cell responsible for the operationalization step.

The first analysis phase has resulted in the identification of eight potential sources of information that can be standardized. The criteria and parameters needed for each source are described below:

- **Level of Detail (LOD):** Templates must be created to determine the LOD of the model for each step of the design phase (concept, preliminary design and definitive design).
- **Template:** Several points were discussed regarding the templates of all the documents that are created during the research. First, the goal is to obtain a unique template, however, because of the construction market in Quebec, two templates were created with one using the metric system and the other the imperial system. Second, the template was created on Revit 2016 after a comparison was made with Revit 2015. Third and finally, the language used for the development of the templates was determined to be the French.
- **Dividers and doors tables:** Graphical representation for three-level wall types are accepted by all departments. A quality control template in the architecture department needs to be incorporated into the metric template. A table of hardware needs to be inserted in a standard format with the template. A table of doors need to be inserted in the template including all possible elements composing a door.
- **Materials:** symbols, tables and other information must be defined for each department to keep it constant from one project to another or when the model is used by several departments in the firm.
- **Zoning plans:** In the Revit template, a table must be created to compare the surfaces indicated in the Design brief from the client and the surfaces modelled. Moreover, the operationalization cell must find a way to the design brief data sheets to the concordant parts in the model.
- **Estimate:** During the design phase, there is a need for three different estimates. First, during the concept, the estimate must be made in square feet, the unit prices come from Means' database and the costs are calculated according the applications of the project and its usages. Second, during the preliminary design, the estimate must be done with the system Uniformat and generic walls are used for the estimate. Third, during the definitive design, the estimate is made with the system Uniformat with a high level of accuracy and all the walls types are defined.
- **Coordination per phases:** The conclusion on this topic is that there is a need to develop views or a system to coordinate plans between the various stakeholders internally and/or externally from the Revit model.
- **BIM management plan:** The BIM management plan is being developed by the diffusion cell in accordance with the results and documents obtained from the other sources.

OPERATIONALIZATION

The role of the operationalization cell was to format the template from the criteria and parameters identified by the thinking cell. The cell was composed of ten members of the firm and had the same configuration as the Thinking cell. Furthermore, the cell was responsible to fill the LOD matrix for the whole firm while waiting for the criteria from the reflection cell. The LOD matrix was the first task completed during the operationalization with a study of various references and a formation received by an external firm. The LOD matrix adopted during the research was used regarding every source standardized. Indeed, the design phase in the construction projects of this firm is usually divided into three parts – concept, preliminary design and definitive design – and the LOD of the Revit model is different in each of these parts. A LOD standardization will help normalize the input and output of information, thus, limiting the presence of waste regarding overproduction of information or loss of information because each actor will know the kind of information they need to produce in the model for each phase.

Regarding the dividers and doors' tables and materials, a standardized data bank was created and must regularly updated to allow actors to understand information coming from another department and increase their productivity by gaining time creating models from one project to another. Meetings were necessary between the engineering and the architect departments to coordinate on the families' creation for plumbing and lighting in Revit to standardize their input in the models. Indeed, a nomenclature of Revit families was proposed and adopted based on the needs of each department.

Every change implemented during this step still must be tested in practice. Indeed, this protocol was implemented to facilitate the implementation of BIM in the near future. The standardization of activities and information will help give a better understanding of BIM processes and Revit to the users and finally help the firm limit the presence of waste in the information flows.

DIFFUSION

The first step of the diffusion cell was to identify the existing templates for each department. The cell was composed of seven members of the firm and had the same configuration as the other cells. Moreover, there was a need to identify all the training tools available for Revit software, as most of the projects are currently still done with AutoCAD. During the meetings organized with the diffusion cell, there was a consensus regarding the creation of a training manual serving both to train all the employees on the BIM processes, but also on the Revit software and on the processes by departments. The thinking therefore revolved around the design of a single manual, which establishes BIM procedures. Sections of the manual present specificities per department and a section is devoted to the training of the Revit software. This manual is going to be available on the Intranet of the firm. To share knowledge and keep a continuous improvement, the use of a platform such as Trello or Asana (to be evaluated) is necessary.

Work is still in progress within this cell to create an internal BIM management plan and standard documents that are going to be used by each department for the future BIM projects. This research has given the opportunity for the architectural firm to develop standard tools that will benefit them. Moreover, the results of this research are going to be published to provide a framework on how to increase standardization in the design phase to reduce the presence of waste at the source of a construction project with the use of VSM principles. Furthermore, the approach used during the research will be repeated in the future to identify more potential sources of information that could be standardized in future projects: this protocol can be used as a form of continuous improvement.

CONCLUSIONS

This collaborative design science research uses VSM from lean production to improve standardization in the information flows of the design phase in construction projects. This research aims to facilitate the transfer from a traditional practice to a BIM approach. Because of the tendency that stakeholders have, to keep using a document-centric approach by pushing information they created to the next actor, the BIM implementation usually presents some contradictions and issues with the information processing. This case study provides a clear view that, despite the fragmented nature of construction projects and the lack of repetition in the production process, VSM can be implemented to improve standardization in the design process to limit the creation of waste in the information flows such as overproduction of information. This case study demonstrated the need to improve the information flows in the design phase by increasing standardization. Furthermore, despite the fragmented nature of the construction industry, it is possible to implement standardization on some level in the design phase to improve coordination and reduce waste within the information flow of the design process.

Future work regarding this research should be to complete several iterations of the framework to identify more potential sources for standardization. Moreover, the future discussion will not only focus on the architectural information flow but will integrate several departments of the firm to demonstrate that standardization of the information flow is possible between various actors of a same process. The project will provide a complete and accurate future state map of the information flows in the design phase of construction projects.

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COMPARING LEAN CONSTRUCTION WITH EXPERIENCES FROM PARTNERING AND DESIGN-BUILD CONSTRUCTION PROJECTS IN NORWAY

Eirik Kraakenes[1], Allen Tadayon[2] and Agnar Johansen[3]

ABSTRACT

While the construction industry has long been known for conflicts and adversarial behavior, there are different delivery methods and approaches that have been developed to overcome these shortfalls. This paper aims to compare Design-Build (DB) and partnering through the lens of the lean construction approach. We examine to what extent partnering and DB are aligned with the lean construction's five big ideas and whether Design Build can be improved by adopting elements from partnering.

This study was carried out by conducting a literature study in combination with five case studies. The case studies were carried out via document review in addition, nine semi-structured in-depth interviews. The interviews were conducted with key personnel from target projects to understand the practitioner's point of view and the way that partnering and design-build are practiced in the industry.

In this paper, the authors conclude that partnering aligns to LC and its five big ideas to a high degree and that partnering includes embedded tools and mechanisms designed to meet what literature and interviews consider to be the main challenges with construction projects. It is also concluded that the use of DB can be improved by adopting suitable elements from the partnering approach.

KEYWORDS

Partnering, Design-Build, Lean Construction, Collaboration, Continuous improvement

INTRODUCTION

The benefits of collaborative, rather than adversarial, working relationships within the construction industry are well documented (Walker and Hampson 2002). However, the construction industry has historically suffered from conflicts and adversarial behavior that have led to reduced productivity (Aarseth., Andersen. et al. 2012, Mattias Jacobsson 2014).

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Recent research shows fragmentation, adversarial behavior and conflict equally describe the Norwegian construction industry (Haugseth, Lohne et al. 2014).

Although a number of causes may apply, Lahdenperä (2012) identifies the initial reason for low productivity to be the separation between the design and construction processes. Naoum (2003) also points out that the problem with construction efficiency and performance originates from the failure of traditional procurement methods, where the "low bid syndrome" is a determinant factor behind the commonly experienced adversarial behavior (Lahdenperä 2014). These failures, along with the fact that projects are becoming more complex and uncertain, result in a trend towards employing collaborative contracts (also called relational contracts) in the construction industry (Hosseini, Haddadi et al. 2017).

Despite the fact that the Design-Build (DB) contract evolved out of the need to integrate the design and construction processes, limited progress has yet been made towards facilitating collaboration in DB. According to Kalsaas, Hannås et al. (2018), a close relationship between the designer and the construction contractor appears to be central to project success. DB contracts therefore have the potential to benefit from including collaborative tools.

Meanwhile, relational contracts were introduced to the industry in order to develop better collaboration, increase efficiency and decrease conflict (Young, Hosseini et al. 2016, Hosseini, Windimu et al. 2017). While partnering is a form of relational contract that highly emphasizes collaboration in projects (Bellini, Aarseth et al. 2016), DB uses traditional procurement methods with an emphasis on awarding to the lowest bidder without introducing collaborative tools.

In this paper, we focus on two different objectives. First, we aim to see whether partnering and DB align with Lean Construction and its five big ideas. Second, by looking at five major construction projects in Norway, we explore whether DB contracts can be improved by adopting partnering elements.

To meet these objectives, the following research questions were formulated:

- Do DB and partnering align with LC's five big ideas?
- Whether DB contracts can be improved by adopting partnering elements?

The remainder of the paper is structured as follows. We first present the methodological choices made, then we discuss the theoretical basis for comparing DB and partnering with LC and its five big ideas. The last section discusses the findings in relation to the theory and suggests implications and directions for future research.

METHODS

In order to answer these research questions, a comprehensive analysis of relevant literature as well as a set of interviews were conducted to investigate the experiences of developers and contractors after completing projects using partnering and DB contracts.

The literature review was carried out in accordance with the procedures described by Blumberg, Cooper et al. (2014) to assure an in-depth knowledge of studied concepts. Five construction projects were then investigated through nine semi-structured, in-depth, case-specific interviews with key actors according to the methodological approach described by

(Yin 2009). Each interview was conducted at the interviewee's office based on an interview guide that was established based on the research questions. Document study also was performed on all case projects prior to the interviews as a method of triangulation.

All interviewees were key personnel in the studied projects. The interviewees included four developers, three contractors and two consultants. They were chosen on the basis of their experience in project management as well as their thorough understanding and knowledge of the case project. It is noteworthy that one of the selected interviewees worked as a project manager on the very first partnering project in Norway.

Including both contractor and developer respondents assures balance in the interview findings. Interview duration was 1 to 1.5 hours. To increase data collection reliability, each interview was recorded, transcribed and then sent back to the interviewees for verification. The transcripts were later analyzed using a qualitative content-based analysis method.

To draw the conclusions, data analysis progressed based on the methodology described by Creswell (2013) as follows:

1) Organizing and preparing raw data (transcripts, field-notes, images, etc.) for analysis
2) Reading trough all data
3) Coding the data (hand or computer)
4) Use the coding process to generate themes or description
5) Interrelating themes/descriptions
6) Interpreting the meaning of themes/descriptions

However, some limitations are still present in the research process. First, this paper only investigated five Norwegian construction projects. Second, there are not the same number of respondents from clients and contractors.

Table 1: Presentation of the five cases

Case/Status	Date	Building Size	Contract Type	Cost	Type
Case 1/Delivered building	2017	9,800 m^2	Design-Build	400MNOK	New
Case 2/Delivered building	2018	11,500 m^2	Partnering	247MNOK	New
Case 3/Delivered building	2012	12,600 m^2	Partnering	368MNOK	New
Case 4/Delivered building	2018	3,500 m^2	Design-Build	116MNOK	New
Case 5/Delivered building	2016	1,250 m^2	Partnering	65MNOK	New

THEORETICAL BACKGROUND

In order to compare Partnering and DB using the lens of the five big ideas of Lean Construction, an exploration of the current theory on each topic was undertaken.

PARTNERING

Construction projects are becoming more complex, critical and uncertain (Wøien, Hosseini et al. 2016). These changes are creating a need for closer collaboration among the project participants. Literature argues that this need can be met through employing different forms of cooperative relationships. Although cooperative relationships can be discussed in terms of alliances, relational contracting and partnerships, in the construction industry, partnering is the most frequently discussed institutional form of cooperative relationship (Eriksson 2010).

Partnering also evolved due to the failure of the traditional procurement methods in meeting client needs and project objectives owing to increased project size and complexity (Naoum 2003, Wøien, Hosseini et al. 2016). It is worth noting that partnering is not suitable for all kinds of projects. In small, one-off, less complex projects which are of low strategic importance, the set-up costs simply do not justify an extensive collaborative approach (Eriksson 2010).

While there is a broad agreement about the overall philosophy of partnering (Bresnen. and Marshall. (2000), it is generally agreed that no unified understanding of the partnering concept exists (Lena E.Bygballea 2010, Hosseini, Wondimu et al. 2016). Even though many definitions have been developed, there is no universal definition of the partnering concept (Eriksson 2010). For the purpose of this paper, we have chosen to use one of the first and most widely used definitions of partnering, provided by the Construction Industry Institute (CII) in 1991.

This definition of partnering is provided as follows: "A long-term commitment by two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizations' boundaries. The relationship is based on trust, dedication to common goals and an understanding of each other's individual expectations and values. Expected benefits include improved efficiency and cost-effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services." (CII,1991)

By establishing relations and a pain and gain sharing mentality, partnering aims to accomplish a positive environment in the project and achieve success for all participants (Naoum 2003).

While partnering projects may share the partnering label, they can use different sets of hard elements (Hosseini, Windimu et al. 2017). The literature distinguishes between hard and soft elements in managing projects. Hard elements include elements that either are directly regulated by the contract or have their roots in the procurement process. Soft elements, on the other hand, are not tangible and are usually related to the relationships between the people in the project (Wøien, Hosseini et al. 2016). Having a real pain/gain sharing mechanism and the use of a legally binding partnering charter make up the most important hard elements. Trust, communication, long-term commitment and cooperation comprise the most important soft elements (Eriksson 2010).

DESIGN-BUILD (DB)

DB is a project delivery method (PDM) where the owner signs a contract with a single contractor that undertakes all or significant parts of the design and construction for the owner (Xia, Molenaar et al. 2013, Rolstadås, Olsson et al. 2014, Standard.no 2018). By transferring the authority for the design and construction to the contractor, DB projects demand a lower level of involvement from the owner (Lædre 2012).

Although prior research reveals the use of DB contracting in public procurement gained its popularity (D. Songer and Molenaar 1997), more recent research demonstrates that Design-Build contracts are still increasing in number as the construction industry seeks less adversarial and more integrated project procurement strategies (Lam, Chan et al. 2012). Despite the fact that DB contracts have been used worldwide for more than 40 years Lam., Chan. et al. (2007), DB contracts are still relevant and in high demand today.

Perhaps the greatest motivation and benefit for an owner to use DB is to reduce both the duration of the project as well as design errors by integrating design and construction activities (Koch., Gransberg. et al. 2010). Usually in DB, all responsibility for risk and uncertainty in the areas of time, cost and quality is transferred to the contractor, which also becomes responsible for the interfaces between the contracts of various subcontractors (Lædre 2009).

Commonly, the DB contract is based on a description of the product’s function rather than on a complete and specified design for the construction (Aandahla., Wondimu. et al. 2017). For the contractor, DB gives greater freedom to choose the appropriate set of solutions, which fits with the contractor’s equipment and expertise (Lædre 2009). The contractor’s freedom to choose can, in fact, lead to a disadvantage for the owner, since the contractor might have a strong pressure on price and may be inclined to compromise on quality without the owner having much opportunity to influence the construction along the way (Rolstadås, Olsson et al. 2014).

LEAN CONSTRUCTION (LC) AND ITS FIVE BIG IDEAS

The success of lean as a management philosophy in manufacturing has inspired its adoption into other industries and particularly into the construction industry (Howell 2014, Young, Hosseini et al. 2016). Lean construction has over the last two decades gained widespread interest from academics and practitioners within the construction industry (Bygballe and Swärd 2014). However, there is still no agreed upon definition of lean construction according to Mossman (2018), who goes on to argue that perhaps the easiest way to think about lean construction is in terms of its purpose.

According to Howell (2014), lean construction provides an approach to modern construction that significantly improves collaboration, innovation, delivery control and quality within projects. Lean construction has been reported to create substantial improvement for those construction firms that adopt it (Bygballe and Swärd 2014). Benefits of using lean construction include shorter delivery time and high project performance (Locatelli, Mancinin et al. 2013, Young, Hosseini et al. 2016).

With the aim of reforming the construction industry, the Lean Construction Institute (LCI) (www.leanconstruction.org) launched the five big ideas in 2004 on how generally to organize and implement building and construction projects. LCI claims that there is a solid historical foundation for the ideas that have been developed in connection with the construction of hospitals in California (Kalsaas 2017).

According to Macomber (2010), the Five Big Ideas can transform projects. The "Five Big Ideas" examines five areas in which project progression and innovation can be optimized by including lean principles (Howell 2014). Together they form the foundation for innovating project delivery systems and approaches. Companies around the world that have adopted one or more of these ideas to improve their practices report significant gains.

The Five Big Ideas consist of the following:

1. Collaborate - really collaborate - throughout design and execution.
   Close collaboration between teams early in the project development process significantly reduces scope changes later in the project.
2. Increase relatedness among all project participants.
   Establishing trust and openness, willingness to innovate and ability to learn improves relationships.
3. Projects are networks of commitments.
   Commitments bind teams and their members within projects, allowing for project direction in real time.
4. Optimize the project, not the pieces.
   Collaboration and optimization at a project level reduce conflict and disputes caused by push management and productivity management at the task level.
5. Tightly couple action with learning.
   Continuous improvement can more readily occur when these elements are combined.

These ideals outline the context and circumstances necessary to facilitate the deployment of lean construction. Combining common objectives and relational behavior aligns stakeholder sentiment and generates high value-add procurement strategies (Howell 2014).

FINDINGS AND DISCUSSION

This discussion presents the author's interpretation of the studied literature and collected data through interviews and document studies.

Table 2 shows how many of the five big ideas were present for each case and how the contractor delivered on cost, time and quality.

Table 2: Presentation of findings for the five cases

Cases	LC five big ideas used	Comments
Case 1	Only 3	Delivered on time and quality with cost overrun
Case 2	(1,2,3,5) in use	Delivered on time, cost and quality
Case 3	(1,2,3,5) in use	Innovative project - Delivered on time, cost and quality
Case 4	(1,2,3,4) in use	Delivered on cost, quality and time.
Case 5 overrun.	Only 3 (and weak)	Disaster project - Delivered on quality, cost and time

COLLABORATE - REALLY COLLABORATE - THROUGHOUT DESIGN, PLANNING AND EXECUTION

According to Howell (2014), close collaboration between teams early in the project development process will significantly reduce scope changes later in the project.

One of the purposes of partnering is to help create more collaboration in projects. Partnering consists of hard elements such as **early involvement of contractors (ECI),** which facilitates and creates a close collaboration between the project participants, while other elements such as **continuous workshops** allow the participants to focus on continuously evaluating relationships and strengthening teambuilding.

Findings from the interviews in this study support the literature and demonstrate close collaboration in partnering projects. **Respondent 8** stated, “Yes, in partnering it is collaboration from day one and a better working environment. There are fewer conflicts due to the sharing of risk between developer and contractor.” Moreover, according to **respondent 3**, “Changes are handled in partnering projects where the contractor, subcontractors and developer are involved in defining the project in parallel with the execution of the project. You don’t have the ones that oppose the project.” The latter finding highlights the attitude that is achievable in partnering projects when project teams gather and collaborate as a whole by committing and working towards a mutual goal with shared risk.

On the other hand, the respondents believe that collaboration in DB contracts can be challenging. According to Lædre (2012), in DB contracts the contractor can choose designers and subcontractors who have collaborated well with them on previous contracts and who are familiar with the contractor’s working methods, but there are no collaborative tools or measures to guarantee the desired level of cooperation. This finding highlights that projects in general could benefit from incorporating collaborative tools.

INCREASE RELATEDNESS AMONG ALL PROJECT PARTICIPANTS

Increased relatedness between the project participants is suggested as critical in establishing fundamental relational elements such as trust, openness, willingness to innovate and ability to learn. These factors will consequently affect the growth of relational contracting and largely dictate the culture of the project, whether it is adversarial or non-adversarial (Howell 2014).

With key partnering elements consisting of trust, openness, relationship-building activities and mutual goals and objectives (Nyström 2005), partnering aims to establish a good relationship with a pain and gain sharing mentality. Partnering's use of collaborative tools and risk sharing can achieve a positive environment and a successful outcome for all the project participants. This practice can facilitate increased relatedness more naturally when the project participants are working towards the same direction toward **mutual goals**.

Unlike partnering, the DB contract is formulated in a simpler format and does not contain any specific hard elements to facilitate increased relatedness between the project participants, leaving it up to the project individuals in DB contracts to establish how much they are willing to relate to the other project participants. As one of the interviewees stated, "The collaborative outcome and increased relatedness between the project participants will depend more on whether you have the right people in the project." This finding showcases that projects need a structured way to facilitate collaboration and develop increased relatedness among the project participants.

PROJECTS ARE NETWORKS OF COMMITMENTS

According to Howell (2014), the five big ideas highlight that an effective project consists of a network of commitments rather than just a process or value stream. Furthermore, he states that commitments are the fibers that bind teams and team members within projects, allowing for project direction to occur in real time.

Partnering consists of elements such as **mutual objectives, partnering charter** and **agreement,** all of which aim to align the project participants' (developer, contractor and consultant) goals. This observation was highlighted by one of the respondents when he stated, "in a project in which the project's participants meet and together develop mutual objectives and goals for the project, there will be absolutely a better commitment."

On the other hand, the main commitment in a DB contract is for the contractor to deliver the project according to the agreed-upon price (lowest bid) at the scheduled time and with reasonable quality.

DB contracts have limited interaction between the developer and contractor compared to partnering projects. The usual ongoing commitment in DB contracts could be limited to achieving milestones within a certain time and cost, whereas penalties such as **malus** are important tools for the developer to use against the contractor to make sure the project is following the scheduled plan. Furthermore, according to **respondent 3,** "in DB contracts it is often that the contractor reduces the quality of material and the equipment to deliver a minimum of what is required in the contract, regardless of whether it is a minimal cost to get double the quality."

OPTIMIZE THE PROJECT NOT THE PIECES

According to Macomber (2010), pushing for high productivity at the task level may maximize local performance but it may increase project duration, complicate coordination and reduce trust. However, collaboration and optimization at the project level can reduce conflict and disputes caused by push management (Howell 2014).

One of partnering's main ideas is that the **early involvement of contractors** and key players in the project provides greater opportunities for savings, value creation and project optimization (Brodtkorb 2017). Incorporating contractor's expertise, specifically on constructability, in an early project stage can lead to decreased design cost, increased efficiency, better solutions and building trust (Hosseini, Windimu et al. 2017).

According to **respondent 6**, "Cooperation in the early phase of the project is more important, and more and more people in the industry believe this. It is important because you get the competence that is valuable in order to optimize your project right from the start." This early involvement provides the opportunity to involve the contractor's area of competence early and throughout the execution of the project and not just for individual task and activities. This involvement will be supported by mutual objective-setting and is best for facilitating collaboration and optimizing the project as a whole rather than just the various pieces.

One of the DB contract's great strengths is that it collects planning, design and execution together. Conducting both design and construction opens for a two-way experience transfer between designers and executives (Lædre 2012). Integration of design and construction reduces duration and leads to optimizing the project trough buildable solutions. Furthermore, the DB contractor can choose project designers and subcontractors with whom they have cooperated well on previous projects. By having already established a group of personnel that understands the working methods and cooperates well, participants find that less time is spent on conflicts.

TIGHTLY COUPLE ACTION WITH LEARNING

With respect to the fifth idea, Macomber (2010) states that continuous improvement of cost, schedule and overall project value is possible when project performers learn in action, while Howell (2014) emphasizes regular inspection and control for identifying mistakes to reduce the risk of future re-work.

Partnering conducts **continuous workshops** throughout the project, which plays an important role in continuous improvement and implementation of new procedures. Further, it ensures that participants are following procedures and monitoring team goals and stakeholders' commitment (Hosseini, Windimu et al. 2017). Partnering also uses measurement during the project. Results and process measures are "hard" measures based on performance and progress, while relationship measures are often called "soft" measures and are used to track team activities and the efficiency of the partnering team (Crane, Felder et al. 1999).

Although construction work is often hidden and difficult to inspect (Kadefors 2004), partnering projects do not emphasize client inspections. And while most clients rely heavily on extensive end inspections of the finished work, in partnering projects, it is better to rely more on the contractors' self-control and execute limited random end inspections (Eriksson 2010).

The DB contract does not include any specific elements like continuous workshops, thus relying more on control and inspection to reveal mistakes. However, the control element could pose a challenge for the owner. According to **respondents (1** and **3)**, "often in DB contracts and other projects, it´s about sweeping the dirt under the carpet," making it challenging to control and reveal mistakes. Although DB contracts may use **prequalification** to secure expertise**,** its recommended to include **operational responsibility** of the contractor to secure quality and reduce mistakes.

CONCLUSION

This research has two purposes: first, to see how much DB and partnering are aligned to LC's five big ideas on how to deliver projects, and second, to reveal if DB contracts can adopt partnering elements. The overall conclusion by considering (RQ1) is that partnering does in fact align to LC's five big ideas of project delivery. DB, on the other hand, aligns to a low degree. While DB contracts have integrated the design and construction elements, they lack the inclusion of a structured way of ensuring more collaboration in DB projects. As prior research shows, a positive working relationship between designer and contractor is essential to project success. Without collaboration tools, there is no structured way to facilitate a positive relationship between the project participants.

The answer to the second research question (RQ2) is that DB contracts absolutely could benefit from adopting partnering elements. We suggest including collaborative tools, since this addition is possible without interfering with the DB contract structurally. Other elements also could be beneficial, depending on the project characteristics and client's objectives. As such, the DB contract could remain the same while incorporating partnering methods and tools in its PDM. Based on the findings from the literature study and interviews, it appears that change orders, conflicts, lack of trust, maintaining proper communication and developing mutual goals represent some of the biggest challenges with construction projects. Considering these issues, partnering embeds tools and mechanism for meeting these challenges whereas DB does not. However, DB can benefit from the successes of partnering and practitioners can adopt elements of partnering to overcome DB's shortfalls. What has been highlighted as the partnering's biggest challenge is the limited understanding of practitioners on what partnering is and how it should be practiced. Therefore, this study suggests more research on the practical side of implementing partnering and developing a systematic way to employ partnering in construction projects.

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LEAN CONSTRUCTION PRACTICE: CULTURE, STANDARDIZATION AND INFORMATIZATION-A CASE FROM CHINA

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ABSTRACT

Many construction enterprises in the world are practicing lean construction and benefiting from it. China, with a big construction industry, has promoted lean concepts in recent years, but there are still obstacles in practice. The aim of this study therefore is to introduce one of lean construction practice lead by a Chinese construction company and Nanjing Tec University lean construction research centre, demonstrating some the most successful lean construction outcomes in China.

A case study approach is used with whole process of the project's implementation being tracked. Data are collected from interviews, meetings and statistics. The study shows that three important aspects collaboration lead to the success of lean construction implementation. Relationships among culture, standardization and informatization are explored. The study recommends a lean culture frame of employee value and customer value integration and incentives providing. Standardization is employed as Work structuring tool to provide operability and offer the foundation to informatization. Last Planner®system (LPS) practice is aided by an hour level precision control to improve

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efficiency. This research presents a case for improving lean construction effectiveness in Chinese context.

KEYWORDS

Lean construction, china practice, culture, standardization, informatization.

INTRODUCTION AND LITERATURE REVIEW

In recent years, the development speed of Chinese construction industry is very fast, but the quality can be low. Delays, cost overruns and quality problems are still common in the industry (Bristow M. 2007; Ng E. 2013; Li Shuquan et al. 2017). Lean thinking is identified as an alternate management philosophy to improve construction productivity (Koskela 1992; Egan 1998). The concepts and ideas of lean construction have been introduced into China (Zhenmin Su 2004; Qinghua He 2013; Shuquan Li 2014; Meigui Han 2015); however, the practice is still fragmented.

In 2017, Jiang Su Province took the lead in issuing Jiangsu Construction 2025 Action Outlines, which pointed out that lean construction, digital construction, green construction and prefabricated construction will be vigorously promoted in the future. Some large state-owned construction enterprises in China, such as the Third and Eighth Engineering Division of China Construction, have already begun pioneering the use of lean construction. However, it is used in a Chinese context have not been well studied. The Chinese construction industry comprises many poorly managed, small and medium construction enterprises (Duan Zongzhi 2007; Hu Weifei 2018). The challenge is to enable industry participants accept the lean idea and implement it effectively (Gao S. et al. 2013; Li Shuquan et al. 2017).

Issues around knowledge and culture are some of the main obstacles to successful lean implementation (Alienate HM 2009; Sarhan S. 2012). Green (1998) first highlighted the cultural implications of lean implementation, noting that "*Every improvement initiative directed at the construction sector tends to be accompanied routinely be exhortations in favor of an associated cultural change" (Green, 2011).*

Culture is an area of interest in construction industry (Fellows 2010) for its impacts on project performance (Casson 1993; Adenfelt and Lagerstrom 2006). However, there is little evidence of detailed research on lean culture frame and its work mechanism.

Construction industry in China has been accused of culture shortage and refusing changes (Yang et al. 2004; Zhang S.B. 2006). Recognizing problems of labor force shortage and mobility, lower educated workforce, rough management and inefficiency, defaulting on workers' wages are still afflict the industry (He xuefei 2011; Guodong Dai 2013; Gao S. et al. 2013), and the need for a better understanding of the culture issue will help promote lean construction implementation in China.

Koskela (2000) explored lean theory through the integration of transformation, value and flow (TFV), with the concept further developed by Howell and Bertleson (2001). According to the Lean Construction Institute (LCI), the decomposition of work activities through Work Breakdown Structure (WBS) is at odds with TFV though its application contributes specially to project success (Halli 1993). WBS forms an element of the Critical

Path Method (CPM) which emphasizes activity dependency relationships without enough focus on the flows of works, locations or resources. So Work structuring was proposed to serve as a framework for achieving integrated product-process design, appropriate for the TFV concepts (Howell and Ballard 1999). Nevertheless, Work structuring is a very new concept to Chinese construction industry.

Last Planner® system (LPS) is the most powerful and well-known planning and control system of all the lean construction techniques and tools (Kenley and Seppänen 2010). LPS's purpose is to produce a predictable workflow, and "pulling" as a new way of introducing information and/or materials into a building process is introduced to improve workflow and create sound process (Ballard, Howell 2000; Koskela 2000; Kalsaas, Grindheim and Læknes 2014). LPS has provided good outcomes yet there is little in depth investigation of LPS practice in China (Gao S. Low 2012; Shuquan Li 2014). Elements such as culture, Work structuring and information technology should not be neglected, as lean construction is a system thinking mindset (Koskela 2000; Ballard and Tommelein 2016).

The aim of this paper is to introduce a Chinese sample of lean construction practice, containing the company and its project practice. Three key factors (culture, standardization and informatization) resulting in successful implementation are explored. The research question is how a collaboration model can work, when culture, standardization and informatization are integrated into a framework. Standardization is employed as Work structuring tools to improve operability. Three hypotheses are proposed and validated. The methodology applied in the paper is case study and empirical exploration.

METHODOLOGY AND METHODS

Although there is some research on lean construction by Chinese scholars (Zhenmin Su 2004; Qinghua He 2013; Shuquan Li 2014; Gao S. Low 2012), yet there are no case studies related to project performance or success factors of implementation. As lean concept is new to most of Chinese building professionals, the qualitative research was considered appropriate, then a case study approach is used in this paper. As a pioneer of lean construction practice in China, Jiuzhou Garden residential project No.58 building is studied as one of the most successful lean construction cases in China. The whole process of implementation was tracked. Data were collected from interviews, meetings and statistics.

In order to present a complete process and give evidence of lean practice in Chinese construction industry, and also offer lean knowledge contribution from China, a collaboration model with three key success factors is explored, and hypotheses on their relationship and interactions are discussed.

CASE STUDY

Case background

The case is about a Chinese contractor and its lean implementation practice on a project. The Jiuzhou Garden residential project is in the north of Hu-Ning Expressway of Changzhou City, Jiang Su Province, China. No.58 building comprises 30-story frame shear wall structured housing including one below-grade floor, with a total area of 21,000 square meters. This project is researched because of its experimental use of lean practices. Lean methods and tools such as 5S on-site management, LPS, Work structuring, Value management, Visual management and Takt planning are used.

Contrast sample group

In contrast six other buildings constructing in traditional way concurrently were used as sample group. The case study project and the contrast sample buildings makeup of the whole residential project of 142,000 square meters. Every building is the same size and construction with only difference in organizational methods. None of those above mentioned lean tools are applied in the contrast sample group.

COLLABORATION MODEL AND HYPOTHESES

The framework of the collaboration model

Three key success factors are summed up in the case project and the company, which are culture, standardization and informatization. Figure 1 reveals the relationship among them with a collaboration model.

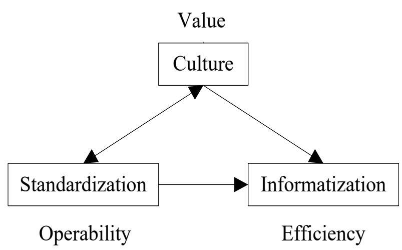

Figure 1: A collaboration model of three key factors

Successful lean practices require a cultural change to unleash the power of workforce or change the way people think (Ted Angelo 2010; Jorge Izquierdo 2010; Keiser J.A. 2012), as a saying of Sanford Smith (2011), *"If you don't embrace the culture, you will not get it right."* Therefore, culture is hypothesized to play a leading role in the lean construction implementation, ensuring the dissemination of lean ideas and values, guiding the direction and normalization of employees' behavior.

Standardized work (SW) is a type of action-oriented procedure that is an essential element of lean management systems (Ohno 1988). Further, standardization means the process of a series of Standardized work realization and improvements (Gibb 2001). In the case company, standardization offers operability and aids scientific management by obtaining data from repeatedly time study and action research, further aided by advanced information technology to achieve improved efficiency outcomes.

Informatization is defined as the process of cultivating and developing new productive forces by intelligent tools (The first National Information work Conference of China 1997). In this paper, informatization refers to the process of employing computer technology, network technology to aid lean tools to improve efficiency.

Hypotheses

The relationship among culture, standardization and informatization has gradually become clearer and been strengthened along with the lean construction implementation and exploration in the company. There are three hypotheses as follows:

- **Hypothesis 1:** Culture has positive effects on Standardization and provides incentives for employees.
- **Hypothesis 2:** Standardization fills the gap between lean culture and the operability, also forms the foundation of informatization.
- **Hypothesis 3:** Culture has positive effects on informatization by promoting employee skills upgrading to improve efficiency.

CULTURE

The lean journey of this company began with cultural change and development, and lean culture serves as direction and supports of lean construction implementation. Customer value of zero quality defects and employee value of cultivating people are integrated to act the leading role of lean culture in the company.

CUSTOMER VALUE CULTURE WITH ZERO QUALITY DEFECTS

The lean strategy advocator and leader of the company insists on craftsman spirits spreading and a high-quality housing as core value of lean construction culture. Craftsman spirit is a kind of professional spirit which is the embodiment of professional ethics, ability and quality. It is also a kind of professional value orientation and behavior performance of practitioners. The basic connotation of "craftsman spirit" includes professional, lean, focused, innovative and so on (Chinese Civilization website 2017). Putting customer value first and setting up zero quality defect goal are implemented throughout the project and satisfied consumers with zero quality complaints. The company has won a high reputation for its residential products with few defects, in contrast to the high of housing complaints reported in China.

EMPLOYEE VALUE CULTURE WITH CULTIVATING PEOPLE

Cultivating people is the other core spirit of the lean culture. People cultivation contains four main elements:

- Create clean and safe project work environments
- Enhance the professional dignity
- Strengthen the professional quality of managers and operation workers
- Pass on and mould craftsman's spirit in construction industry

Lean culture in this company is composed of four parts: the surface layer of Company Image System (CIS); the shallow layer of employee behavior requirements; the middle layer of management and operation work standardization; and the deep layer of double-core value of both customer and employee.

It takes a long time for Lean concepts acceptance and culture development. It's found in the case practice that lean culture and standardization should act on each other to help employees' behavior change and quality improvement.

STANDARDIZATION

Ballard (1999) initially equated the term "Work structuring" to process design, which serves the three goals of production systems: do the job, maximize value, and minimize waste (Ballard, Koskela, Howell 2001). WBS is a description of the project's scope, deliverables and outcomes. In order to design the process and the schedule to reduce waste and improve value, an appropriate level of detailed work breakdown and process optimization are needed. Standardization as a process optimal method is considered to be a part of Work structuring, based on the deepening WBS to optimize both process and value. Six parts consist of the standardization with ultimate goals of waste elimination, on time delivery, as well as quality, safety, and cost improvements are reached. Figure 2 reveals a framework combining WBS, Work structuring and standardization.

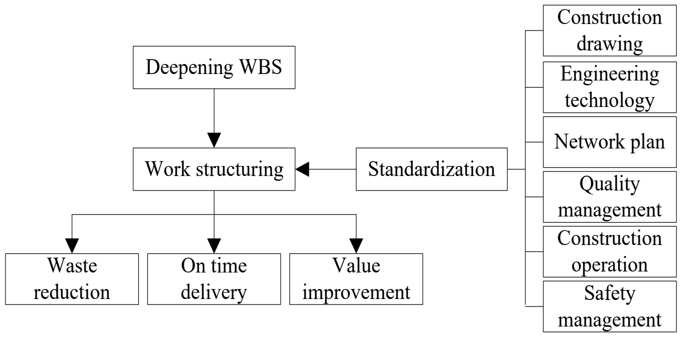

Figure 2: The framework of WBS, Work structuring and standardization

DEEPEN AND REFINE FOR WBS

For effective project control, the WBS must reflect an appropriate level of detail. However, it is possibly the most difficult and overlooked part of project management (Wideman 1989).

In case of No.58 building, efforts have been made to refine the WBS approach in order to develop sufficiently detailed and appropriate criteria for residential construction building. The total amount of decomposed works accumulated more than 1,000 items, which are discussed by experienced project managers.

The deepening WBS is featured in: Work sequence depth; WBS-OBS integration; WBS-LPS mapping; Logical relationship improvement; and Optimization of construction technology. Based on the logically optimized broken down sub-terms, experiments on time and action study are done, and data are collected for criterion written. Managers and workers are trained for the new broken down items and the criterion.

STANDARDIZATION AS TOOLS FOR WORK STRUCTURING

Although Work structuring has been advocated to align with product and process in construction and a guide proposed, further systematic experimentation with concepts and techniques is needed (Howell and Ballard 1999, 2000; Ballard, Koskela, and Howell, 2001). More than one decade of exploration in the company has developed six parts of standardization as tools for Work structuring to improve operational level practice of lean construction.

- Construction drawings standardization

Standardization of construction drawings contains design refining and optimization. In order to eliminate waste such as rework, conflicts and contradictions among different disciplines, cross functional group was set up to work together to standardize the construction drawings.

In case of No.58 building, there had only 101 construction drawings originally, after team work efforts of construction drawing detailing, the number of drawings are accumulated into 1,023, of which 407 are civil works and 616 are water and electricity.

- Standardization of engineering technology

From repeated experiments and demonstration, the "Residential process Standards" (24 books in all) are formed. All of these criteria are summarized and optimized on the basis of construction practices and experiences. More than ten items are contained in every process node, such as progress requirements, construction preparation, operating standards, safety facilities, coordination person, green construction requirements, resource allocation, inspection and acceptance criteria and so on.

- Network plan standardization

Basing on the refined WBS, No.58 building was broken down into 1,587 activities from temporary facilities arrangement to completion and acceptance.

LPS was used to optimize the plan and control process. Construction tasks are arranged in detail to 0.5 days and workers are demanded strictly by precise start time and finish time in the scheduling.

- Quality management standardization

Three aspects are enhanced to guarantee building quality by standardization as mentioned above. Construction drawing standardization ensures construction quality from the source. Innovative craft methods are explored to deal with common quality problems. Standard working procedures help to reduce defects, and downstream work can begin only after upstream-work meeting the criterion and being accepted.

- Construction operation standardization

In order to supply operation workers with a precise guideline to reduce repairs or reworks, save materials and improve equipment efficiency, construction operation standards are developed.

Experiments are carried out for data collection. Enterprise quotas are formed to present clearly standards of every procedural in manpower requirements; material and machine consumption; and cost measurement.

- Safety management standardization

The construction site was arranged according to the CIS standards. 5S on-site management is employed. Enterprise logos, the workers' clothing, and the staff dormitories are unified to offer workers a clean, tidy, safe and dignified working space. Construction safety standards are aided by visualization technology. Three-dimensional graphics library of 16 sub modules are developed to provide site safety guiding.

In view of these, the case company's standardization has proposed a path for Work structuring to offer operability and deliver high quality products to the customers.

INFORMATIZATION

AN HOUR LEVEL PRECISION CONTROL ON LPS IMPLEMENTATION

A schedule management software and Co-office platform are developed, with precision to an hour level control. Pull mechanism of look-ahead planning connecting with commitment planning contributes to LPS effectiveness, and the hour level control system improved the efficiency. The weather forecast is embedded in the software to get nearly 100% of the percent plan complete (PPC).

Precision control on an hour level

Managers are authorized to query, upload data and issue instructions in the schedule management system. Foremen and operation workers are provided with APP use on the mobile phone. Task information about start and end time, quantities, tool use and resource requirements is conveniently transferred. Table 1 shows one of the operating interfaces of the hour level control of scheduling.

Table 1: An hour level control of scheduling

Project Procedures	Working hours	Team	Examiner	Operation standards	Acceptance criteria	Detection method	Monitoring frequency	Safety precautions	supervision or coordination	Rules for Calculating Quantity	Other standards attachment	Remarks	Examination
Preparation	1.50	Project department	Primary structure inspection group	See details	See details	See details	Check before concrete pouring	See details	Builder, Security officer, Crane driver et.al		Link	6.1 Formwork inspection batch acceptance record	1
Ash damper cleaning, wet and hanging	0.50	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling		Security officer, Quality staff	See details	Link	Photos uploading and records retention	4
Formwork clear and watering	0.50	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling		Builders, Quality staff	See details	Link	Photos uploading and records retention	1
Mortar back to pump	1.30	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling		Builder, Security officer, Crane driver et.al	See details	Link	Photos uploading and records retention	1
Concrete pouring and vibration	10.00	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling	See details	Builder, Security officer, Crane driver et.al	See details	Link	Photos uploading and records retention	1
Mold observation	10.00	Woodworking team	Primary structure inspection group							Calculated by floor area			1
Reinforcement observation	10.00	Reinforcement team	Primary structure inspection group							Calculated by floor area			1
Water and electricity observation	9.70	Hydropower installation team	Primary structure inspection group							Calculated by floor area		Photos uploading and records retention	1
Recycling of ground ash	8.70	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling		Builder, Security officer, Crane driver et.al	See details	Link	Photos uploading and records retention	1
Ash damper cleaning and recycling	10.20	Concrete team	Primary structure inspection group	See details	See details	See details	Patrolling		Builder, Security officer, Crane driver et.al	See details	Link	Photos uploading and records retention	1

The pull mechanism of look-ahead planning

Pull planning was implemented through positive task preparations basing on the standardization of engineering technology, construction operation, quality and safety management. Accurate 'tasks made ready' to remove constraints are pulled by downstream requirements including purchase and the resource organization.

Commitment planning

Operation workers have been trained in technical, quality and safety guidance before work start along with clear informed such as working contents, time, location from the mobile phone APP. Commitment planning is guaranteed by workers beginning with their works on time with materials at hand which are prepared by auxiliary workers. As the reverse commitment, they will be paid as soon as the tasks are completed on time and accepted by inspection, and it makes a great incentive.

BIM APPLICATION

BIM technology was used throughout the construction process, supporting for modeling and amounting, field layout, measure model, construction model, deviation adjustment and process model. It is to be mentioned that the BIM use is not yet universal in Chinese construction industry, data exchanges among disciplines remain difficult, so BIM application in this case study contributes mainly in visual communication and supplementary optimization.

HYPOTHESIS VALIDITY

The validity of hypotheses is to answer questions of whether culture and standardization can act on each other to realize the value of both customers and employees; how standardization can assist informatization; and how can culture impact on informatization. Evidences are collected through survey, interviews with on-site workers to check up the hypotheses as follows.

HYPOTHESIS 1 AND 2 VALIDITY

The double core culture concepts builds consensus among employees, assisting lean thinking acceptance, with employees more willing to change and getting involved in improvement. Culture effectiveness is reached rather by providing incentives and operability.

In contrast to most of dirty and messy construction sites in China, site of the case project is tidy and clean benefiting from 5S implementation, construction workers stated, "willing to work in such comfort site though tough demanded".

Zero quality defect goal was achieved by strict operation standards and every stage of standardization, thus to fill the gap between culture and operability. Most on-site workers expressed "we are willing to work under such tough standards if we are told clearly enough, because less rework and few repairs will happen, and we are paid promptly".

Standardization develops process standards and employee behavior norms to improve productivity and quality to reach three goals of Work structuring.

Design drawings are in details, and sample rooms are set up. Animations, charts and concise text descriptions are made to form a craft methods database which facilitates inquires in the company's platform. All standardization offer more opportunities to labor workers to improve constructability and quality.

Standardization optimizing on every stage of waste reduction, constraints removing and value improvement together with data collections offers the foundation of informatization. An hour precision control can't be reached if it is separated from this foundation.

HYPOTHESIS 3 VALIDITY

Informatization of the company is in nature an information technology training process for employees. Peoples' willing to change and involve in is an important part of the culture. Accordingly, informatization is proved to improve efficiency not only by transparent and convenient communication but by facilitating employees' skills upgrading. Most of the workers indicated that they "are pleased to cooperate in data acquisition and testing of operating standards and to use information tools" and appreciated "both increased wages and decent work". The site manager also declared that "once workers are used to using task assignments APP and inquiring on craft methods database, management works will be reduced while safety and quality being better guaranteed".

DISCUSSION

No.58 building started to construct on 18th August 2015 and delivered on 25th March 2017, the case company undertook the project as the general contractor. Compared with the traditional mode, it shortened the duration by 104 days with a shorten rate of 19.62%; skilled worker employing was saved by 16%, and the labour cost was reduced by 2.33%; the total cost save rate was 2.88%. The performance comparison between No.58 building and traditional samples is illustrated in table 2 below. LPS practice supported by an hour level precision control contributes to duration saving, and standardization taken as Work structuring tools results in quality and safety improvement. There presents more orderly and cleaner construction site and energetic workers in the case project in contrast to the contrast sample group.

Table 2: Performance comparison between No.58 building and traditional samples

Compared item	Contrast samples	No.58	Improvement rate
Duration	530 day	426 day	19.62% (-)
Skilled labour	369	310	16.00% (-)
Labour cost	6,390,300 (RMB)	6,241,600 (RMB)	2.33% (-)
Total cost	26,437,960 (RMB)	25,675,957 (RMB)	2.88% (-)
Quality	/	Zero quality defect	/
Safety	/	Zero safety accident	/

The case study also provides some new insights that how lean construction implementation can be adopted in Chinese construction industry. The practice case investigates that lean culture should offer incentives to play a guiding role. As cultural shift is a long-term process, filling the gap between culture and the operability is necessary.

Facing with rapid development but poor management and inefficiency in the industry, this dualistic situation poses a challenge to lean construction implementation in China. It seems difficult to select between culture-oriented or technology-oriented implementation strategies.

The lean exploration of this company has given some answers. Firstly, lean value concepts should be deeply embedded in the culture of both enterprise and project, influencing the employee's behavior norms, and providing incentives. Secondly, efforts should be made to supply workers with convenience to improve efficiency and quality.

Finally, Lean Construction needs to embrace emerging technologies to make work more productive.

CONCLUSION

The purpose of this paper is to introduce a lean construction practice in China, from which a collaboration model is developed to reveal the relationship between three key factors. Culture and people are thought to be the most important elements in the case practice. The effective leadership of the company plays the key role of success. The advocator and leader as a soul figure together with a high executive team has created company-wide cultural transformation and lean implementation. People are incentive to accept lean concepts and provided with convenience to take actions. Standardization, as an exploration of Work structuring, is tried to connect TFV theory with traditional tool of WBS to guide operations. Informatization makes it possible to realize LPS implementation on an hour level precise control. All of these have important enlightenment and demonstration significance for promoting lean construction in China.

Three hypotheses are proposed to explain lean construction effectiveness in Chinese context. Although observation and interviews are conducted to validate the hypotheses, more data collection is required to enable sufficient confirmation. Further studies are needed to investigate other more companies and projects to experiment the model validity.

Moreover, the findings are limited to the contractor practice of lean construction, with few effects to the design stage. Future research will focus on transferring lean ideas from contractors to designers, subcontractors and suppliers to promote the change of the whole industry chain. Development of lean construction solutions under advanced information technology context also will be contained in the next steps of research.

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MEASURING PROJECT'S TEAM CULTURE IN PROJECTS USING THE LAST PLANNER® SYSTEM

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ABSTRACT

At this stage, construction industry is known for bad project performances and a culture characterized by adversarial behaviours. The Last Planner® System (LPS) is designed to improve these circumstances through the enhancement of workflow reliability by involving various disciplines in joint planning processes and a culture of collaboration. How to actually measure related project team culture (PTC) is unknown at this stage. This paper tries to close this gap and compares two defined versions of the Ideal Lean Culture for organizations with the actual PTC in projects using the LPS.

It first presents the two Ideal Lean Cultures for organizations, based on a framework developed for organizations (the Competing Values Framework - CVF). Next, it examines on the basis of three case studies the applicability of the CVF for measuring the actual culture in project teams using the LPS and compares it with the named Ideal Lean Culture conditions.

The paper concludes that the CVF is a suitable tool to take a snapshot of the PTC and that the comparison to the Ideal Lean Culture can give conclusions about the current project team's maturity in projects using the LPS.

KEYWORDS

Project Team's Culture; Last Planner® System; Competing Values Framework; Lean Culture

INTRODUCTION

In the past, the construction industries' tough competition, especially in times of recessive markets, led to unprofitable contracts for the contractors which led to a focus on claims instead of partner-like project conditions (Racky 2008). Adversarial and distrustful relationships between the parties (Beach et al. 2005), antagonistic behaviours (Beach et al. 2005; Johnston and Lawrence 1988) and escalating relationships (Racky 2008) led to a corresponding culture in the construction industry. "Culture" is hereby "the collective programming of the mind which distinguishes the members of one group or society from those of others" (Hofstede 1984, p. 82). As a result, bad project management performance

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(Flyvberg and Sunstein 2016; Owen and Koskela 2006) and slow project progress with problems like low productivity, insufficient quality, time over-runs, and poor safety hindered the value delivered to the customers (Senaratne and Wijesiri 2008).

The LPS has the aim to overcome these conditions. It is a continuous planning process with the aim to "improve the predictability and reliability of construction production" through the management of "relationships, conversations and commitments that together enable program & production planning decisions to be made collaboratively at the lowest possible level" (Mossman 2015, p. 2). LPS' main difference to traditional construction management methods, where the projects get planned through individual professional planners and project managers (Mossman 2015), is that the various stakeholders plan the next work packages in a cooperative and integrative way (Verein Deutscher Ingenieure 2017). The project is divided into various scheduling hierarchies with different levels of detail whereas the preciseness gets refined at each level, as the time gets closer to the start of the task (Frandson and Tommelein 2015). The "Last Planner" is preferably the last person in the value chain (usually the foreman or site manager of the appropriate trade or for planning tasks, the specialist planner or team leader of a discipline (Verein Deutscher Ingenieure 2017)). The schedules get normally visualized through sticky notes in regular meetings.

A corresponding project culture of collaboration is necessary to apply LPS successfully, which differs to the conventional culture at construction projects. To reach such an intended culture, it is necessary to define the target conditions and compare the actual situation to investigate what has to be adjusted (Paro and Gerolamo 2017).

Literature suggests systems to measure and describe the characteristics of organization cultures. One example is the Competing Values Framework (CVF) by Cameron and Quinn (2011), specifically for organizations. Paro and Gerolamo (2015, 2017) use this framework to define the Ideal Lean Culture for organizations.

For measuring projects' cultures, however, the literature suggests a gap (Zell 2009). The differences between the organization- and project cultures occur due to the special project's particularities as their uniqueness, their temporal limitation and their multi-disciplinarily (International Project Management Association 2015). Additionally, the unique circumstances of the construction industry, like the one of a kind production, site production, temporary multiorganization and intervention of regulatory authorities (Koskela 1992), project teams with various interests (Baiden et al. 2006) and LPS's focus on collaboration, influence an appropriate project culture.

This paper aims to close this gap through investigating the application of the CVF at three different case studies that use the LPS. The case results are compared to the Ideal Lean cultures from the studies of Paro and Gerolamo (2015, 2017) and conclusions are drawn. The overall aim of this research is to investigate if the CVF is a suitable tool to measure the PTC regarding the Ideal Lean culture's characteristics in LPS projects.

THE COMPETING VALUES FRAMEWORK AND THE IDEAL LEAN CULTURE

As "Projects today have dramatically increased in complexity, requiring a culturally and functionally diverse mix of individuals who must be integrated into an effective unit – a project team" (Ranf 2010, p. 657), we are interested in the current state of the individual project team's culture and whether it could be influenced to improve the project performance.

Zell (2009) suggested that a method to measure a project team's culture is missing. To close this gap, he created an empirical measurement system with seven dimensions ((1) performance- and quality orientation; (2) cost- and target date orientation; (3) customer orientation; (4) innovation- and safety orientation; (5) strengths and homogeneity; (6) project orientation; (7) trust- and cooperation willingness) to measure and describe the PTC. Unfortunately, data of conducted studies with this model are missing.

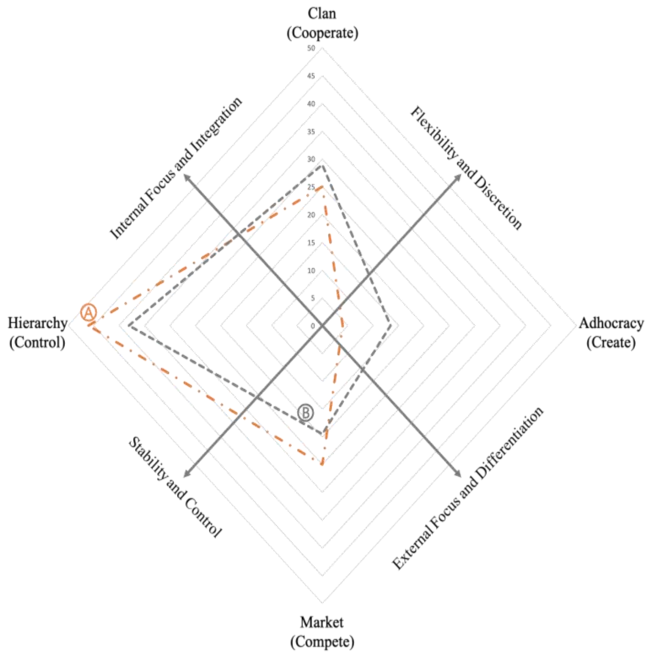
An established method for the measurement of an organization's culture with data from different industries is the CVF by Cameron and Quinn (2011). This framework is selected for this paper because was it used for various studies about the Lean management culture and data was available.

The CVF uses the "Organizational Culture Assessment Instrument" (OCAI) to measure and describe an organization's culture and to facilitate change towards a target condition (Cameron and Quinn 2011). The framework is divided into two dimensions and four quadrants. One dimension "differentiates effectiveness criteria that emphasize flexibility, discretion and dynamism from criteria that emphasize stability, order, and control" while "the second dimension differentiates effectiveness criteria that emphasize an internal orientation, integration, and unity from criteria that emphasize an external orientation, differentiation, and rivalry" (Cameron and Quinn 2011, pp. 38 - 39). The OCAI and CVF are carried out through a standardized survey. The participants have to divide six times 100 points among four alternatives, depending on the similarity of their perceived culture (ibid, pp 29-32). Respectively one of the four questions belongs to one of the quadrants and the mean of the six belonging scores represents the individual score of the quadrant. The mean of the scores of all participants represent the score for the culture (ibid, p. 33).
Rudimentarily described, the four quadrants stand for the following characteristics (Paro and Gerolamo 2017)

1. Clan (Collaborate) – sense for the group or family, focus on the development of people and the team spirit
2. Adhocracy (Create) – characterised by temporary, specific and dynamic focus
3. Hierarchy (Control) – high level of work standards, rules and procedures to keep the control of the internal operations
4. Market (Compete) – external focus on suppliers and customers to obtain a competitive advantage

Paro and Gerolamo (2015) analysed the 14 Toyota Way Principles by Liker (2004) that describe the principles of Toyotas organizational culture as the root of Lean Management and estimated which of the four quadrants are affected by each of the 14 principles.

Shape A in Figure 34 shows their interpretation of the "Theoretical Ideal Lean Culture" (TILC). In their publication from 2017, they renamed it into "Theoretical Toyota Culture". The focus is especially on the "establishment of rules, procedures and standards of work, organizational directives way to be followed by the employees, focusing on operational management or "micromanagement"". The distribution between the market- and the clan quadrant are balanced and the adhocracy quadrant has a low score. In another study, Paro and Gerolamo (2017) conducted a survey with 51 Brazilian Lean System experts who are in charge to implement Lean systems to define the Ideal Lean Culture from their perception. The outcome of this study is presented with shape B in Figure 34.



	Theoretical Ideal Lean Culture (Paro and Gerolamo 2015) A	Lean Culture (Paro and Gerolamo 2017) B
Clan	25	29
Adhocracy	4	13
Market	25	20
Hierarchy	46	38

Figure 34 - Theoretical Ideal Lean Culture by Paro and Gerolamo (2015) and the Lean Culture by Paro and Gerolamo (2017)

Both studies show that the Ideal Lean Culture is mainly characterized by the characteristics of the hierarchy quadrant. The earlier study interprets this section as even more pronounced. The adhocracy quadrant from the TILC is less pronounced than the Lean Culture from the second study: the Brazilian Lean experts see the Ideal Lean Culture more flexible and external focussed. While the distribution of the clan- and the market quadrants are balanced at the TILC, the Brazilian Lean experts evaluate the clan characteristics as lightly more pronounced than the focus on the market characteristics. Paro and Gerolamo (2017) point out that the findings of the second study might be influenced by Brazilian particularities.

This paper compares the PTC's of three cases with both studies to investigate if the application of the CVF is useful for LPS projects and if the comparison to the TILC and the Lean Culture allows conclusions about the maturity of the PTC and the success of the LPS.

CASE STUDIES

The CVF survey was conducted in written form at three cases. In addition, further case study research methods like observations and interviews were done to get a deeper understanding about the contemporary situation and the circumstances of the survey (Ridder 2017; Yin 2018). The selected cases differ in multiple ways in terms of team size, the stakeholder types and the construction activities. These variations allow to obtain information about a phenomenon within various circumstances (Flyvberg 2006) and therefore enhance the generalizability of this study's results. The author, employed by the general contractor of the three cases, is in all case studies responsible to implement the LPS and to facilitate the appropriate meetings. Through this direct participation, background information and observations can be added to the research.

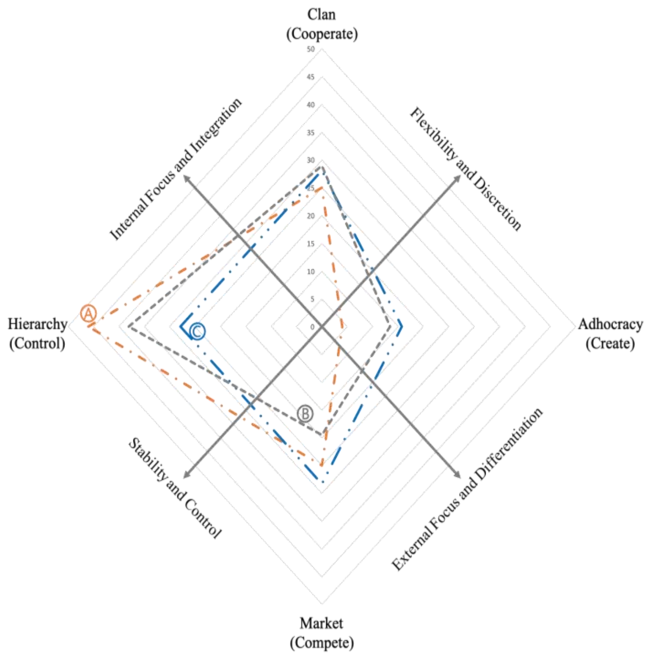
The CVF is designed for assessing organizational culture (Cameron and Quinn 2011, p. 27) and not to assess a project team's culture. As it is assumed that there are differences between organizational cultures and project cultures, the applicability of the CVF is also part of the investigation. Nevertheless, the survey's standard questions were chosen, similar to the original framework.

CASE 1

The first project is the construction of an office building with parts of a historical façade and high-grade rental area for office areas and gastronomy. The investor has divided the project into two contracts with two different contractors: one for the reinforced concrete construction activities and one for the technical building equipment and the interior work (which is a joint venture of two organizations). The participating stakeholders at the regular LPS meetings are the investor (investment managers technique), the contractor for the reinforced concrete construction activities (mostly one senior site manager and one site manager), the joint venture for technical building equipment- and interior work (various site managers and foremen), various specialist planners (commissioned by the investor) and various sub-contractors (site-managers and foremen - commissioned by the joint venture). 16 people, spread over these stakeholder groups, participated in the survey to measure the PTC.

At the time of the survey, the project was in the late construction phase of the reinforced concrete construction activities and in the early construction phase of the technical equipment- and interior work. The detailed design was not finished for all disciplines because not all areas were already rent and the final use could not be defined. The LPS has been implemented for about four months and the current PPC was 83%.

Figure 35 shows that the clan- and the market sectors are evenly divided. The hierarchy sector is medium ranked. Only the adhocracy quadrant shows with lower than average (16 points).



	Theoretical Ideal Lean Culture (Paro and Gerolamo 2015) Ⓐ	Lean Culture (Paro and Gerolamo 2017) Ⓑ	Case 1 (PPC = 83%) Ⓒ
Clan	25	29	28
Adhocracy	4	13	16
Market	25	20	28
Hierarchy	46	38	28

Figure 35 - CVF Case 1

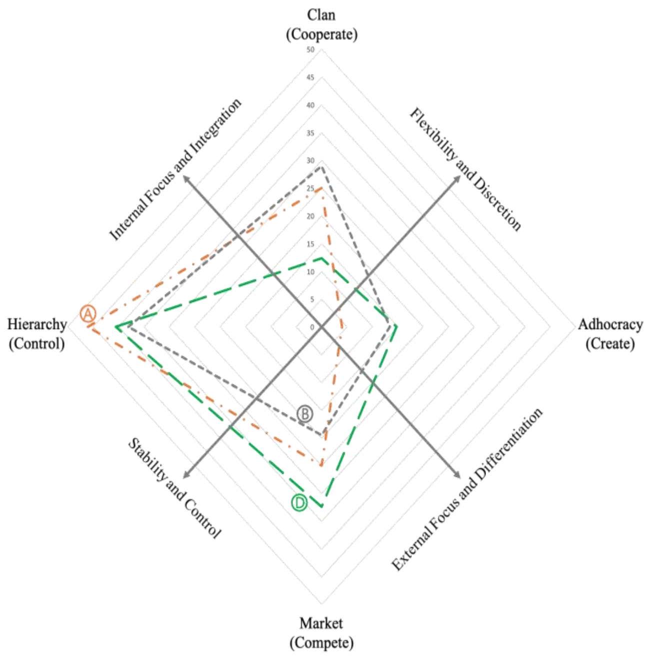
The hierarchy quadrant is less pronounced as the two Ideal Lean Cultures. Accordingly, the actual PTC is not focused on standards and rules as desired by the two studies from Paro and Gerolamo (2015, 2017). The opposing adhocracy quadrant is rated lightly higher than the Ideal Lean Culture would be according to the Brazilian experts, but much higher than the theoretical perception of Paro and Gerolamo from 2015. So, the PTC is more characterized by flexible decisions, based on external influences, than desired by the TILC but comparable to the ideal culture how the Brazilian experts defined it. The uncertainty about the final design of the project and continuous planning changes could be named as reasons for this perception (which is according to Verein Deutscher Ingenieure (2017) typical for construction projects). The Clan quadrant is nearly similar to the two Ideal Lean Cultures. Interviews have shown that the participants see the LPS as a team building activity and that it has increased the feeling of trust, especially within the joint venture in comparison to the early project phases, where the LPS was not implemented. The market quadrant shows slightly higher scores than the TILC and significant higher scores than the Lean culture, ranked by the Brazilian experts. These high scores from Case 1 are even more remarkable because the two Ideal Lean Cultures were defined for organizations that need to pay attention to the competition whereby the project team could focus on the construction project.

Some weeks after the survey was conducted, however, the investor had decided that he and his specialist planners would not participate at the LPS anymore. His explanation was that the participation was no longer necessary. The joint venture's interpretation of this decision hints at contractual reasons due to unclearness of the later use, hence tactically motivating the non-participation at the LPS meetings. This change affected the PTC noticeably.

CASE 2

Case 2 is a construction project, which is still in its design and engineering phase. The participants in the LPS meetings are the investor, various specialist planners and the design manager of the general contractor. The system has been implemented about three months and the current PPC is 51%, which is relatively low compared to the other data from the literature. Four of the specialist planners from different companies participated in the survey to measure the PTC.

Figure 36 shows that the PTC is particularly characterized by high numbers on the stability and control side of the framework. The PTC's hierarchy score is between the two studies from Paro and Gerolamo. It is accordingly characterized by clear "work standards, rules and procedures" (Paro and Gerolamo 2015). The adhocracy quadrant has comparable scores as the Ideal Lean culture from the study from 2017 but higher scores than the TILC from 2015. Accordingly, it is characterized by behaviours that the practitioners view as ideal.



	Theoretical Ideal Lean Culture (Paro and Gerolamo 2015) Ⓐ	Lean Culture (Paro and Gerolamo 2017) Ⓑ	Case 2 (PPC = 51%) Ⓓ
Clan	25	29	12
Adhocracy	4	13	15
Market	25	20	32
Hierarchy	46	38	41

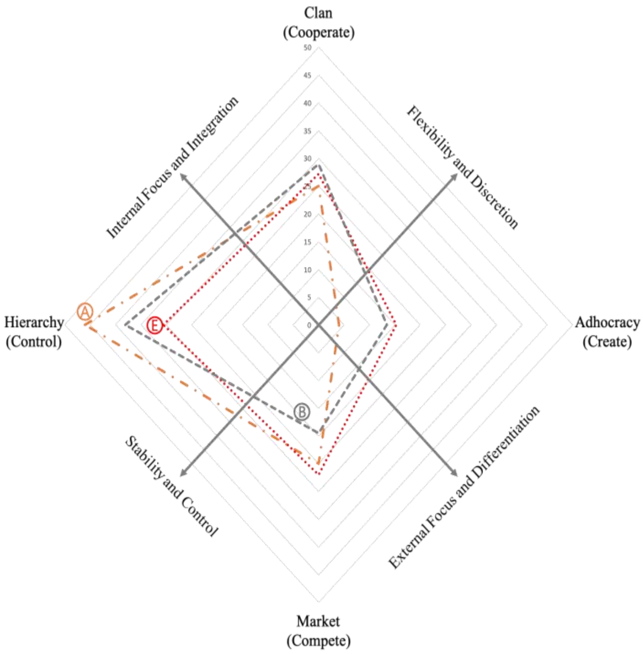
Figure 36 - CVF of Case 2

The PTC's market quadrant has striking high scores, which are higher than the TILC but much higher than the study estimation of the Brazilian experts. The focus of the project team is especially on external influences. This fits also to the low scores of the opposing clan quadrant, which differs most conspicuous in comparison to the two Ideal Lean Cultures. The distribution of the market- and the clan quadrant present the same as observations from the LPS meetings and the arrangements outside the meetings – a lack of collaboration between the various stakeholders and an assumed focus on other projects than on this case. As the collaboration is the main idea of the LPS to improve the cooperation between all parties, the low PPC is not surprising.

CASE 3

Case 3 is a construction project in its early construction phase. The current activities are formwork-, reinforcement and concrete activities. The participants in the LPS meetings are the general contractor's foremen, one senior site manager and one junior site manager. These three persons participated in the survey to measure the PTC. The system was especially implemented at this early stage because the team members did not know each other before and have significantly different pools of experiences. The system has been implemented for about three months before the survey. The PPC is 71% and accordingly better than at conventional construction projects, but slightly worse than common LPS projects as described in the literature.

Figure 37 shows that the distribution between the clan- and the market quadrant are balanced and as desired by the TILC whilst the market quadrant is higher than desired by the Brazilian experts. This is once again striking because of the focus on external influences instead of the focus on the single project. Furthermore, the measured PTC shows a hierarchy quadrant, which is lower than the characteristics of the two Ideal Lean Cultures. The Adhocracy quadrant is comparable to the Ideal Lean Culture from 2017 but much higher than the TICL.



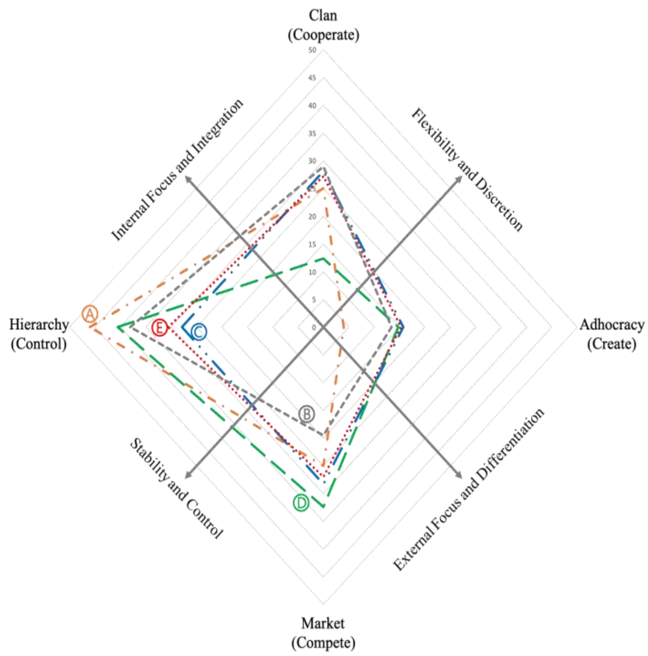
	Theoretical Ideal Lean Culture (Paro and Gerolamo 2015) Ⓐ	Lean Culture (Paro and Gerolamo 2017) Ⓑ	Case 3 (PPC = 71%) Ⓔ
Clan	25	29	27
Adhocracy	4	13	15
Market	25	20	27
Hierarchy	46	38	31

Figure 37 - CVF of Case 3

The design at this project is finished but the project team adjusts relatively often the sequence of the building activities, what could explain the low scores of the hierarchy quadrant. Another reason for the low PPC and adjustments might be that the real "Last-Planner" from the producing organization is not participating at the meetings for different reasons and that the advantages cannot be gained to reach a higher PPC. Despite the relatively low PPC scores, the project team describe the LPS as very helpful and team forming.

COMPARING THE THREE CASES AND THE IDEAL LEAN CULTURES

Figure 38 shows the TILC according to Paro and Gerolamo (2015), the Lean Culture according to Paro and Gerolamo (2017) and the PTC's of the three case studies. It is striking that the PTC's shape of Case 1 with a PPC of 83% is nearly similar to the PTC's shape of Case 3 with a PPC of 71%. The PTC's shape of Case 3 with a low PPC of 51% differs considerably to the other two cases.



	Theoretical Ideal Lean Culture (Paro and Gerolamo 2015) Ⓐ	Lean Culture (Paro and Gerolamo 2017) Ⓑ	Case 1 (PPC = 83%) Ⓒ	Case 2 (PPC = 51%) Ⓓ	Case 3 (PPC = 71%) Ⓔ
Clan	25	29	28	12	27
Adhocracy	4	13	16	15	15
Market	25	20	28	32	27
Hierarchy	46	38	28	41	31

Figure 38 - Comparison of the Ideal Lean Cultures and the three case studies

The adhocracy quadrant is at all three cases and the Lean Culture from the Brazilian practitioners nearly the same but differs in comparison to the TILC. This could mean that the TILC focuses too much on rules and standards and procedures and is not interpreted practically, as the case studies confirm the estimations of the Lean experts from the survey of Paro and Gerolamo (2017).

On the other hand, it could be argued that with the highest PPC score of 83%, the optimum is not reached in any of the cases and that if the behaviours would be even more strictly fulfilled and the adhocracy behaviour would be less pronounced, the PPC could be improved. Indeed the opposing hierarchy quadrant shows that the PTCs of Case 1 and Case 3 with relatively good PPC scores are very similar but lower than the TILC or the Lean Culture. Especially Case 2 with the lowest PPC scores has the highest scores of all cases in this quadrant, between the TILC and the Lean Culture. It can be suggested that a partial focus on hierarchical characteristics is not a guarantee for project success. Rather, the clan quadrant seems to be relevant. The relatively successful projects case 1 and 3 correspondent in this quadrant with the TICL and the Lean Culture whereas the scores of Case 2 are much lower.

All three cases show higher scores in the market quadrant than intended by the two Ideal Lean Cultures. This is striking because of the focus from this paper on construction projects instead of organizations. The authors assumed that the focus would be more on internal project issues than on the market due to the lower relevance of market changes or competition within the project work.

The similar shapes of the relatively successful LPS projects and the distinctive shape of the less successful LPS project let conclude that there is a relation between the PTC and the project's success under the LPS success definition. As this paper is limited to three cases, further research should be conducted to investigate this relation. This could also lead to an adjusted shape of the Ideal LPS' PTC.

CONCLUSION

The aim of this paper was to investigate if the CVF is a suitable tool to measure the PTC in LPS projects and if the comparison of the PTC and the defined Ideal Lean Cultures can give a statement about the project teams' maturity in relation to the LPS success definition. It has shown at three cases studies that the CVF survey is a suitable tool to measure and visualize the PTC and that there is a relation between it and the PPC, so success of the LPS.

This paper could only show snapshots of the three PTC's and as "collaboration is a fluid concept that emerges from individual and organizational interactions" (Suprapto 2016, p. V), the measurement of the PTC can only be used for the current status quo. Especially **CASE 1** has shown that the PTC is continuously developing and that the LPS is only a method to enable best project performances when all participating parties define these equally and as long as they want to collaborate. So a CVF should be done regularly to investigate how PTC's evolve over time and how external or internal influences affect it.

RECOMMENDATIONS

The correlation of the scores in the CVF and the PTC scores of should be investigated. This leads to recommendations on how to improve the PTC and thereby the project success under the aspects of collaboration. Furthermore, the case studies have shown that the assumption of a pronounced clan focus instead of the focus on the market due to the project particularities was not confirmed by this study. The reasons must be investigated in further researches.

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STREAM 16: LEAN IMPLEMENTATION

Amaral, T.G., Oka, L. G., Camargo Filho, C.A.B, and Neto, J. P. B. (2019). "Qualitative Analysis for the Diagnosis of the Lean Construction Implementation." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 975–986 DOI: https://doi.org/10.24928/2019/0145. Available at: <www.iglc.net>.

QUALITATIVE ANALYSIS FOR THE DIAGNOSIS OF THE LEAN CONSTRUCTION IMPLEMENTATION

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ABSTRACT

The paper presents an analysis of the implementation of Lean Construction in the center of Brazil, and an evaluation of the potentialities that each calculation method provides in the diagnosis. The Lean Construction Assessment Tool (LCAT) was used in this research to make critical inferences about the Lean implementation stage in six construction companies in Goiânia, Brazil. Based on the data obtained, the Lean Score was calculated using arithmetic averages, weighted averages and averages based on the Fuzzy Inference System. Based on this analysis, an evaluation of each LCAT criteria was inferred, and its influence on the company's lean score was determined. The advantages and disadvantages of the lean construction implementation process were also evidenced. The measurements obtained presented small variations, such as speed of obtaining the data, interference of other variables in the process, and analysis of specialists. Nevertheless, it was possible to draw conclusions about the different potentialities of the use of each one.

KEYWORDS

Lean construction; evaluation methods; implementation stage; mathematical results.

INTRODUCTION

The current Brazilian construction industry has undergone many changes (FGV/IBRE, 2017). As a result, new systems, methodologies, and tools are needed that will ensure improvements, with less use of resources and without losing the quality and efficiency of the process. In this context, Lean Construction has become a popular concept.

Along with the advent of the philosophy of production linked to construction, managerial changes are taking place, and the market is beginning to perceive changes in relation to new practices, seeking technological and managerial improvement. As part of these changes, there is a growing search for knowledge related to Lean concepts (Silva et al., 2014).

The use of lean construction practices has gradually spread throughout the construction industry. Mechanisms are therefore needed to evaluate their use, making it easier to identify

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the advantages and disadvantages of the Lean Construction implementation process (ETGES et al., 2013).

An evaluation method is used to measure the degree of Lean implementation. However, measuring the degree of Lean implementation is complex, due to (a) the inherent multidimensional concept of "lean"; (b) the unavailability of information on manufacturing practices that could be used for benchmarking when evaluating the degree of leanness; and (c) the subjectivity of human judgment on Lean practices, such as lack of precision and pre-judgment, depending on the evaluator's knowledge and experience (Susilawati et al., 2014).

Silva (2011) presents an evaluation checklist of the degree of lean implementation in construction companies, based on Fuzzy logic.

Carvalho (2008) comments that there are still scenarios in which the company does not obtain satisfactory results, such that the systems begin to operate with low efficiency, leading the company to return to the traditional system because in these cases, the innovation did not provide the expected benefits.

Miron et al. (2016) use a logical structural model to synthesize the literature on the subject, and establish an initial proposal for evaluating continuous improvement programs in the context of lean construction.

The main aim of this study is analyze the application of the Lean diagnosis tool, considering the potential of each average used. It also evaluates each criteria of the LCAT, and determines how it influences the lean index of companies.

Specifically, the application of the evaluation method created by Silva (2011) and improved by Camargo Filho (2017) will be detailed through the application of the developed questionnaire form, in order to demonstrate an evolution from the methods already applied by other authors.

The main contribution of the research is that it provides a better understanding of the metrics that can be used to evaluate the level of implementation of lean construction practices, and that are appropriate for the organizational context of Brazilian companies, using, for this purpose, the evaluation tool proposed by Camargo Filho (2017).

LEAN CONSTRUCTION AND EVALUATION QUESTIONNAIRES

Salem et al. (2006) developed a lean evaluation checklist that presented six categories: Last planner, increased visualization, preliminary studies, huddle meetings, the 5 Ss, and fail safe for quality. The results were rated as: none (N), very low (VL), low (L), moderate (M), high (H), or very high (VH).

Carvalho (2008) produced a questionnaire that evaluated five components: board of directors, engineering, workers, suppliers and projectors. Unlike other authors, Carvalho (2008) consulted clients about their perceptions regarding lean principles at the company. Four levels of implementation were assigned to each topic. A final score was then attributed, based on the percentage of fulfilment of these principles and characteristics.

Etges (2012) developed a protocol for auditing the use of Lean Construction practices, taking into consideration four fundamental stages: a literature review of IGLC procedures (1993 to 2010) and the main keywords of the papers retrieved, definition of sources of evidence to evaluate the use of each category, definition of weights attributed to each practice by six lean construction specialists, and the application of the protocol by a civil construction company. One hundred and three practices were established, and the construction company's performance in each category was presented as a percentage.

FUZZY INFERENCE SYSTEM

According to Susilawati et al., (2014), the Fuzzy method is a mathematical theory that enables ambiguities and imprecisions to be modeled by means of Fuzzy sets. The decision methods based on this logic can help to establish the relative importance raking in the evaluation of the performance systems of measuring.

Silva (2011) elaborated an innovative work in the Fuzzy Inference System application for diagnosis and monitoring of the lean construction philosophy in civil construction companies. Through checklists and subsequent weighting of the variables using Fuzzy, he sought to reduce the uncertainties in the evaluation methods used. Silva et al (2014) present the application of these checklists.

FORM APPLIED IN THE RESEARCH

The main theoretical underpinning of the questionnaire developed by Camargo Filho (2017) is the studies of Womack and Jones (1996). Also created with the aim of evaluating the level of implementation of Lean Construction practices in construction companies, that questionnaire has undergone three revisions, before becoming consolidated in the final version.

Camargo Filho (2017) conducted a pilot application in seventeen companies, with the aim of validating the questionnaire. However, satisfactory results were not obtained in relation to its applicability; it was long and tiring, and not very effective, due to the organization of its criteria, as a large number of them only addressed practices linked directly to quality management, which could compromise the clarity of the results obtained, and the real lean diagnosis of the company.

The author therefore attempted to simplify the questionnaire, making it more precise and direct, and avoiding repetition and rework through the implementation of a logical application sequence. It also removed items that were given as compulsory or related to legislations in force related to health and safety, sustainability and quality, focusing on specific items characteristic of Lean Construction.

The Fuzzy inference system was used, together with the final version of the form, to obtain the diagnostic of companies. A system comprising 81 inference rules was proposed, with four input variables and one output variable.

Camargo Filho (2017) initially elaborated version 2.0 of the questionnaire, which evaluated 98 practices distributed in 10 categories: Quality Management, Cost Control, Safety at Work, Visual Management, Continuous Improvement, Information Technology, Human Resources, Logistics and Supply Chain Management, Project Management and Product Development, and Planning Production and Control. A Fuzzy Inference System was proposed with four input variables and one output variable, with a total of 84 inference rules.

The final version of the questionnaire (version 3.0) is shown in Figure 1. It has 4 categories: Quality Management, Supply Chain Management, Planning Production and Control, and Project Management. Among these categories, there are 84 lean practices, in which the final percentage of fulfilment of the criteria defines how lean the company is. The levels were distributed across three stages of implementation: initial (level 0), maturation (level 1), and continuous improvement (level 2)

CATEGORY	PREREQUISITE	CRITERIA
Quality Management	**Certified Quality Management System**	Worker training
		Problem Solving
		Internal and External Benchmarking
		Use of Poka-yokes and Technological Innovation
		Performance Evaluation
		Motivational Policies and Worker Satisfaction
		Organization of the workplace and construction site
Supply Chain Management	**Defined criteria for supplier selection**	Supplier Selection
		Supplier relations
		Buying process
	Control of delivery of materials in compliance with specifications and quality	Stock and material storage control
		Physical space control
		Internal distribution of supplies
		Controlling costs in the supply chain
Planning Production and Control	**Planning Production and Control Process formalized**	Long-term planning
		Medium-term planning
	Transparent long-term plan	Short-term planning
		Value Stream Mapping
	General defined activity stream	Production Control
		Cost Control
Project Management	**Internal department responsible for project management**	Project Development Planning
		Compatibility and validation of projects
	Project verification process regarding quality and specifications	Identification of the value required by the client
		Identification of problems in projects

Figure 1: Camargo Filho Questionnaire (2017).

METHOD

The research was classified according to its approach, nature, objectives and procedures. In terms of approach, it was classified as quantitative and qualitative, as it analyses the numerical results of the application of the form to evaluate the degree of lean implementation in the six companies evaluated in the city of Goiânia. It is also considered qualitative because it presents meanings, results and theoretical interpretations based on the scores assigned to each category of lean implementation.

CRITERIA FOR SELECTION OF THE PARTICIPATING COMPANIES

In the second stage of the research, the participating companies were selected, based on the following criteria: 1) companies operating in the local market; 2) the existence, within the company, of a Quality and/or Environmental Management System; and, 3) interest in participating in academic studies aimed at improving their processes.

CHARACTERIZATION OF THE COMPANIES

Data were collected from six construction companies in Goiânia between November and December 2016. The companies were classified as medium to large organizations, with more than ten years in operation.

APPLICATION OF THE CAMARGO FILHO QUESTIONNAIRE (2017)

The questionnaire elaborated by Camargo Filho (2017) was applied in the form of a survey. All the scores attributed to each criteria were collected and recorded, with scores ranging from 0 to 2 (0 - the process or tool was not present or in a very early stage of implementation; 1 - the maturation stage; 2 - a tool or process implemented and in continuous improvement).

The application process took around one hour per company, which was spent on analyzing the engineers' responses, attributing scores, and spot-checking some of the items mentioned by the respondents.

The data obtained were drawn up in the form of a table and analyzed in three different ways: arithmetic average, weighted averages calculated from the expert analyses of lean construction, establishing degrees of importance for each criteria, and weighting of the results using the Matlab software.

DATA PROCESSING

The arithmetic average was determined using Microsoft Excel, generating an average percentage of fulfilment for each category, with each category having between 4 and 7 criteria. Thus, the percentage of fulfilment for each category is calculated as the average of the scores for the criteria, in relation to the total fulfilment of the criteria.

The weights to be used to calculate the weighted averages were obtained from the analysis of six specialists in the area of Production Management - Lean Construction in relation to the weight attributed for each of the practices in the Lean diagnosis of a company. (0 - initial phase; 1 - maturation phase; 2 - continuous improvement phase). The aspects analyzed were: importance (essential, very important, not important and irrelevant), complexity (complex, intermediate, or basic), time of implementation of practices (initial phase, maturation phase or continuous improvement phase) and ideal time of implementation of lean construction (starting in the first year of implementation and going up to the fifth year of the process).

The average scores attributed by the experts will be used as a weighting to determine the percentages of fulfilment. Table 1 shows an example of how this weighting was presented for the variable "implementation time" and in Table 2 we can see the factors corresponding to this weighting.

Table 1: Weightings established for the variable "Implementation Time" according to specialists.

IMPLEMENTATION TIME BY SPECIALISTS								
Category	Criteria	Sub-Criteria	S1	S2	S3	S4	S5	S6
Quality management	1	1.1	initial	initial	initial	initial	initial	initial
		1.2	maturation	initial	initial	initial	maturation	initial
		1.3	continuous improvement	maturation	maturation	maturation	maturation	initial
		1.4	continuous improvement	continuous improvement	maturation	maturation	continuous improvement	initial

Table 2: Weightings assigned by each specialist (S1, S2, S3, S4, S5, S6).

Weighting factors									
Category	Criteria	Sub-Criteria	S1	S2	S3	S4	S5	S6	Average of factors
Quality management	1	1.1	0	0	0	0	0	0	0.00
		1.2	1	0	0	0	1	0	0.33
		1.3	2	1	1	1	1	0	1.00
		1.4	2	2	1	1	2	0	1.33

Based on the three results; arithmetic average, expert-weighted averages and the averages obtained from the Fuzzy Inference System, it will be possible to produce bar graphs to improve the analyses and their potential results. The objective is not to compare the averages, but to evaluate the potential of the use of each one.

RESULTS AND DISCUSSIONS

Based on the application of the LCAT tool in the companies, the Lean Score of each company was obtained, i.e. the degree of implementation of the lean construction (Very Low: 0 - 20%; Low: 20% - 40%; Medium: 40% - 60%; High: 60% - 80%; Very High: 80% - 100%).

Nine researchers were responsible for all the applications, but for three companies, it was decided to use cross-application, i.e. two different agents applied the form in the same company for Fuzzy analysis. Companies A, B and C were chosen; two that declared they were implementing the Lean Construction and one that declared it was not. All the researchers applying the form were trained in this task, supported by the theoretical foundation of lean construction, in order to follow best practice in the application of criteria of the form.

Figure 2 shows that the weighted average has the lowest values in relation to the other averages in all participating companies. With the exception of company F, the arithmetic averages presented intermediate values and results of the Fuzzy were the highest in the other companies.

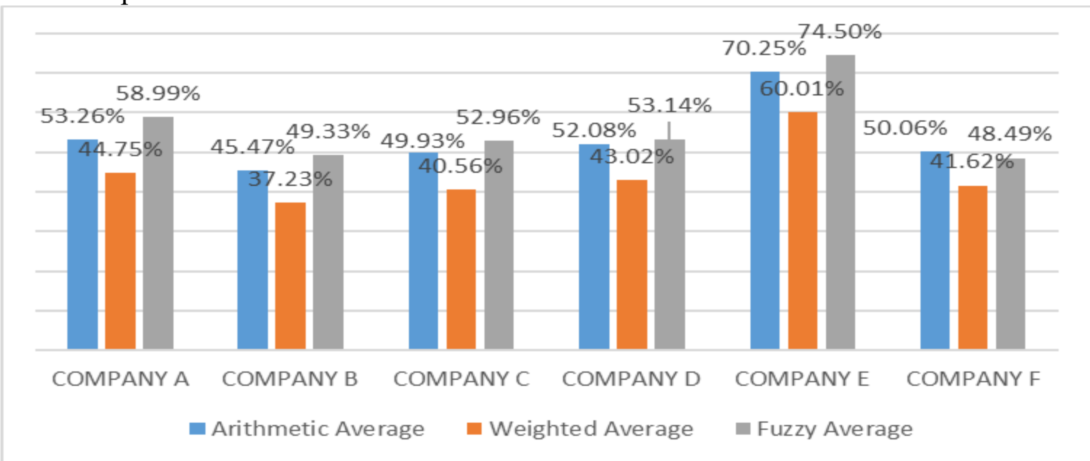

Figure 2: Arithmetic, weighted and Fuzzy averages by company.

ARITHMETIC AVERAGE

The following are the arithmetic, weighted and Fuzzy averages of each company with more details as Figures 3 to 8, listed below.

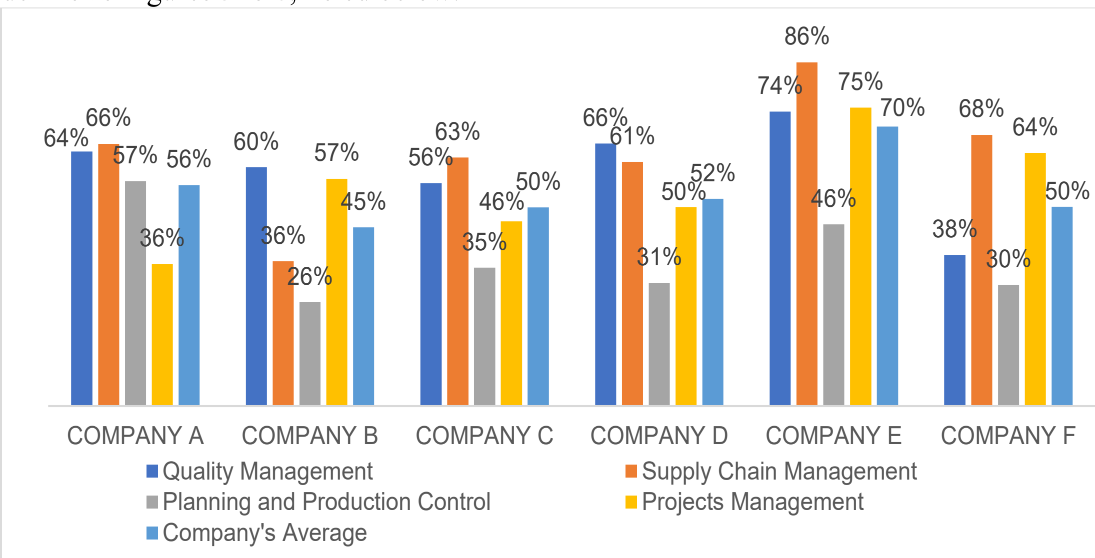

Figure 3: Lean Score by category using the arithmetic averages.

Companies A, B, C, D and F had a Lean Score that ranges from approximately 44% to 56%, demonstrating that there is a process of implementation of lean construction principles. However, it was noted that there are some important stages missing in the consolidation of this implementation, such as value flow mapping and medium term planning, both of which are part of the production planning and control.

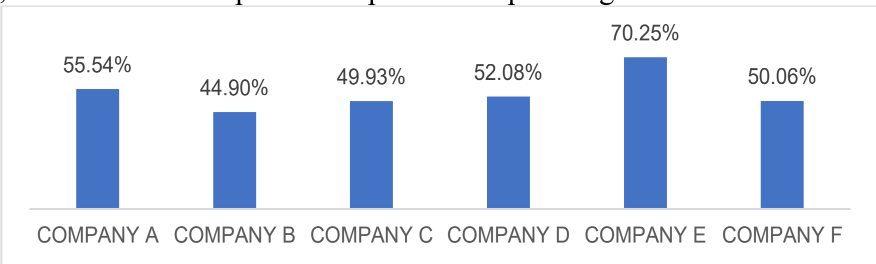

Figure 4: Lean Score by company using arithmetic average.

Weighted Average

The expert-weighted average had the lowest indices when compared to the other averages in all companies. This result is mainly due to the fact that the specialists classified the vast majority of the items in the initial stage of implementation and maturation, therefore, due to the fact that they had a lower weight in the Lean diagnosis, the averages were lower.

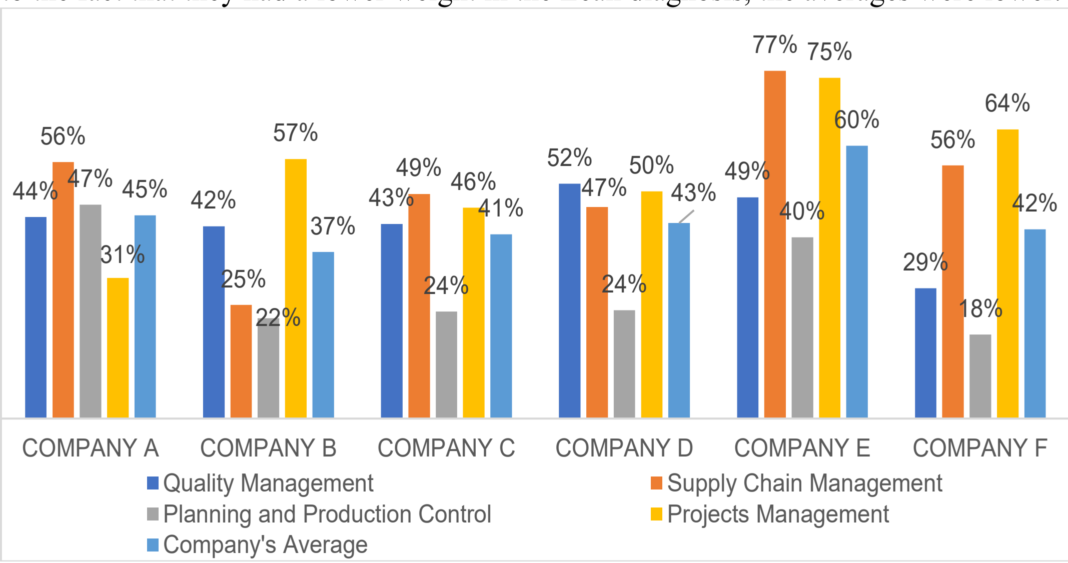

Figure 5: Lean Score by category using weighted average.

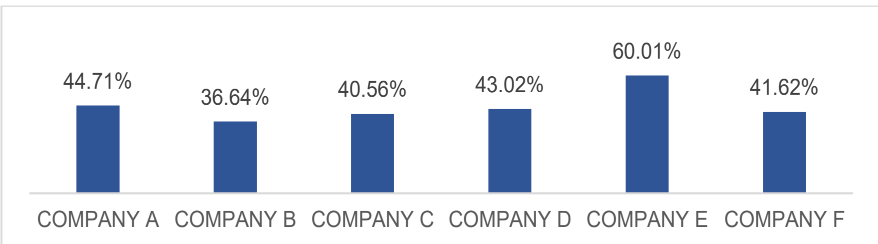

Figure 06: Lean Score per company using weighted average.

Fuzzy Average

With the exception of company E, which presented a high degree of implementation, all the results were similar (Figure 07). These values close to 50% characterize an average degree of implementation, and are explained by two factors. First, the implementation stage considered for all companies was zero, i.e. the companies were just beginning the implementation process and the evaluation was less demanding, with some items not applied. The second reason is the good performance of most companies in the categories of quality management and supply chain management. This was made possible by the maturation of the implementation of the QMS, and the well-coordinated supply management system.

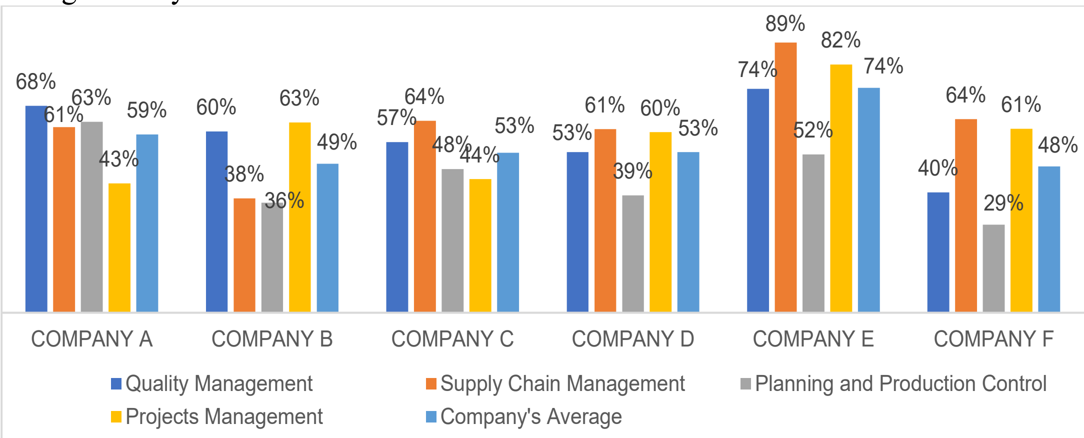

Figure 07: Lean Score by category using Fuzzy averages.

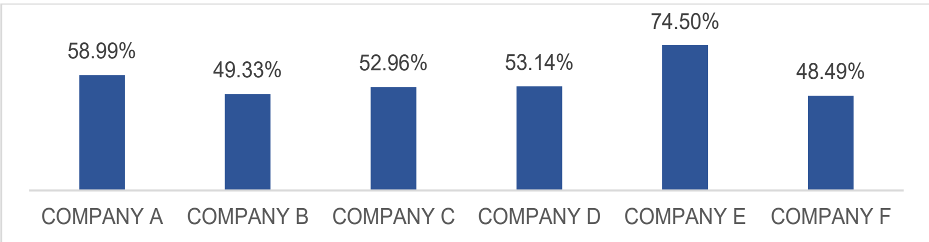

Figure 08: Lean Score per company using Fuzzy averages.

A summary of the Lean Score averages of each company is presented in Table 01.

Table 03: Summary of the Lean Score by Company

	LEAN SCORE		
COMPANY	Arithmetic average (%)	Weighted average (%)	Fuzzy average (%)
Company A	56	45	59
Company B	45	37	49
Company C	50	41	53

Company D	52	43	53
Company E	70	60	74
Company F	50	42	48
Media	54	45	56

It can be seen that with exception of company E, which presented a high degree of implementation, all the other results were close to 50%, characterizing an average degree of implementation.

CONCLUSION

It is concluded that the three types of average used to calculate the degree of implementation of lean construction fulfilled their functions, and had specific advantages. All three results were representative, and there were no significant difference between them.

Of the three averages analyzed in this study, the arithmetic average is the simplest one, and the easiest to interpret. However, it does not present the necessary statistical analysis, except for the judgement of the evaluator on attributing a certain score to each criteria established. The influence of extreme values is another factor that could influence the results, as it does not properly represent the set of values.

The weighted average attributed by specialists enables the opinions of third parties to be considered in the results. It is possible to distinguish the relative importance of a particular item within a set of values. In this case, the Lean Score was also influenced by the time of implementation of the practice.

The averages calculated using the Fuzzy Inference System enables various variables to be considered, such as: importance, complexity, time and stage of implementation. This analysis helps to minimize the influence of the evaluator's judgment, and present more precise Lean diagnosis.

Therefore it is not possible to establish a direct comparison between the three types of average, since each takes into account different amounts of variables in their analysis. The arithmetic average depends only on itself, the weighted average depends on two variables – the average and the weighting factor of the specialists – and the fuzzy average is influenced by five variables: importance of the item, importance of the criteria, complexity of the practice, time of implementation of the practice, and time of implementation of lean construction. Thus, each average has different calculation methods, and there are advantages and disadvantages inherent to each.

Regarding the degree of lean implementation of companies in Goiânia, although there is interest in applying the principles of lean thinking, there is no articulated commitment to implementing specific practices. The companies are interested in becoming "leaner", but they lack the knowledge of lean construction, and the fundamental tools that should be used. They apply procedures that they believe to be "good practices", but they do not have the necessary know-how and scientific theoretical knowledge to maintain them effectively in a way that is economically viable. Moreover, there is no kind of certification or benefit for being lean, which in some companies, leads to a lack of interest in implementing these practices. One limitation of this study is the non-existence of benchmarking in the State of Goiás that could be used as a basis for the process of implementation of lean construction. One of the companies obtained a result of more than 70% in the arithmetic and Fuzzy averages. This represents good performance in lean implementation (by LCAT). However, it cannot be affirmed whether this company used specific processes and tools.

A suggestion for future studies is to compare the levels of implementation and theoretical knowledge of the philosophy with other Brazilian cities, in order to increase the database and the benchmarking between these companies. The results obtained for the construction industry could also be compared with those obtained for other industries, such as the automobile industry, seeking to understand how both work, and how the practices may be related, and bringing benefits for both sectors.

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FROM CONCEPT DEVELOPMENT TO IMPLEMENTATION: CHOOSING BY ADVANTAGES ACROSS AN ORGANIZATION

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ABSTRACT

Decision-making is one of the most important and underestimated activities of every organization. Decisions define the commitment of our most limited resources and are the determining factor between success and failure. How individual decisions are taken directly impacts the decision outcome. Therefore, the method used to decide is of utmost importance. Choosing by Advantages (CBA) is a decision-making method that has been growing in application and acceptance in the last few years within the International Group for Lean Construction (IGLC) community. Existing publications regarding CBA mainly discuss the benefits of the method in theory and in practice, but none of them explain how the method was applied nor if it was also broadly implemented across organizations to the different project levels. This paper closes the gap by giving guidance and insights on the development and rollout of CBA trainings for the construction industry based on the case study of Daimler AG. The authors conclude that the implementation of CBA requires a thoughtful plan that leaves room for adjustments in accordance to the project team's needs.

KEYWORDS

Change, choosing by advantages, culture, decision-making, design thinking.

INTRODUCTION

Baron (2008, p. 6) defines a decision as a "choice of action – of what to do or not to do. [...] made to achieve goals, [...] based on beliefs about what actions will achieve the goals". Decision-making can be defined as "irrevocable allocation of resources, irrevocable in the sense that it is impossible or extremely costly to change back to the situation that existed before" (Howard 1966, p. 97). Both quotes show how crucial decisions and the decision-

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making process are for every organization, because decisions guide the direction and give orientation. Thus, the question of how to make decisions across an organization that fit the purpose and are understandable to all affected parties arises. Suhr (1999) focuses on how to make decisions and states that "[o]ur methods produce our decisions. Our decisions guide our actions. And our actions cause our outcomes" (p. 17). Therefore, to tangibly improve the outcome of decisions, decision-makers have to understand why and how decisions are made. Not knowing the reason for decisions can easily result in a lack of commitment, inaccuracy, or even sabotage against decisions during the implementation phase. Elmuti et al. (1993) emphasize that meaningless or thoughtless decisions are an indicator for, but also cause of, poor communication, invisible leadership and thus a lack of teamwork. Many collaborative decision-making committees suffer when trying to explain the why behind decisions, which leads to frustration and a loss of trust within the collaborative decision-making culture. Employees and leaders alike often report a high level of frustration regarding decision-making. At many large organizations, like Daimler AG, the multiple layers of required bureaucratic alignments lead to an ambiguous and vague understanding of the decision premise and logic which then leads to decisions not being taken, resulting in an unclear decision purpose with a low level of commitment. Therefore, it is important to install a transparent and traceable decision-making process which helps team members to participate in the decision-making or at least understand the reasons and logic behind decisions. Moreover, confident decision-making by a collaborative team will automatically result in a team that is willing to take ownership and who will carry the consequence of decisions taken.

Decisions and decision-making are key not only for industries such as the automotive industry, but also for proceedings in construction projects. Therefore, based on four cases where two projects practically applied CBA to decide between alternatives, Schöttle et al (2018) explain how the decision-making process should be designed to be effective in construction projects. As part of the process, the authors recommend applying CBA as the decision-making method. In addition to this paper, many other papers have demonstrated the benefits regarding CBA in comparison to other decision-making methods theoretically (e.g. Schöttle and Arroyo 2017). All the papers have in common is that they demonstrate the benefits of applying CBA either theoretically or based on a single case. None focus on a strategic widespread implementation across an organization or the construction industry as a whole, although the construction industry is not using its potential to implement new methods and tools quickly through project teams. Therefore, this paper focuses on how to develop a training concept for CBA and how to rollout the method organization-wide. Thus, after a short explanation of CBA and design thinking as well as the research method, the strategic implementation of CBA based on an individual developed training concept for Daimler AG is described. Challenges, findings and learnings from the case are then discussed and theoretically transferred to the construction industry to support the CBA implementation and give guidance for a successful implementation in construction. Finally, the conclusion will be drawn in reference to the research questions.

BACKGROUND LITERATURE REVIEW

CHOOSING BY ADVANTAGES

CBA is a multi-criteria decision-making system developed by Shur (1999) that is based on a clear defined vocabulary and an anchored judgement which compares the advantages of alternatives. Independent of the decision complexity, the CBA system provides different methods. Two methods are the: (1) Two-list method and the (2) Tabular method. The CBA Two-list method consist of five steps (see Figure 1) and is applicable for decisions with less complexity.

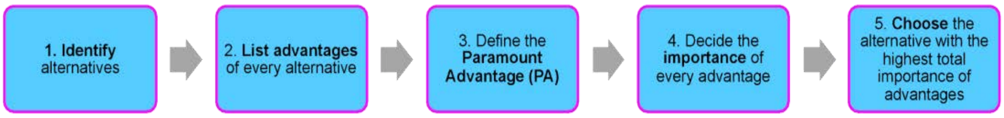

Figure 1: Steps of CBA Two-list Method

If decisions are more complex, meaning that a decision consists of various information, data and alternatives, requires clear documentation, and involves different participants, the CBA Tabular method should be applied (see Figure 2), because it helps to understand the different perspective of the team members. It was reported that using the Tabular method leads to productive conversation, because of less tangential discussions (Arroyo and Long 2018), results in constructive debates, less misinterpretation, and a transparent documentation that is traceable for a party not involved in the decision-making (Schöttle and Arroyo 2017). Furthermore, teams achieved faster consensus and felt less frustration during decision-making when using CBA in comparison to scoring systems (Arroyo et al. 2016) and felt more confident about the decision quality (Schöttle et al. 2018).

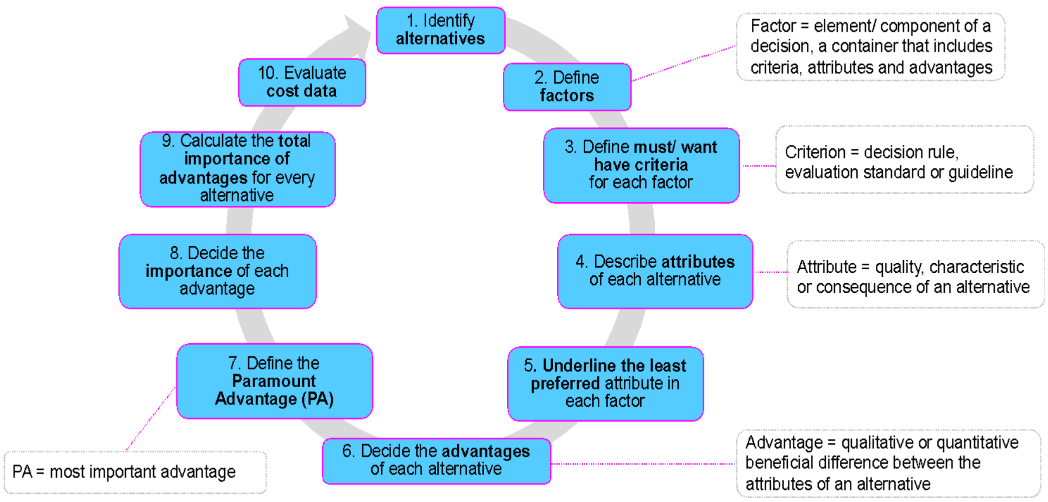

Figure 2: Steps of CBA Tabular Method (based on Arroyo 2014) with vocabulary

DESIGN THINKING

Using the attitude and methods from art and design, Design Thinking (DT) is an incremental and iterative approach to identify human needs and develop new and unexpected ideas based on rational and end-user-focused problem solving (Kelley and Kelley 2013; Brown 2008). Through the application of various creativity techniques and rapid conceptual prototyping, DT describes an effective toolkit when looking for new opportunities or overcoming complex challenges (Meinel and Leifer 2011). Referring to the DT Model of the Hasso-Plattner-Institute, the DT process consists of two phases with six steps (see Figure 3). The main idea of the orientation phase is to gather as much information as possible about the problem and potential user groups as well as to structure and synthesize them into a few but central insights. Based on these insights, concrete ideas are developed in the second, solution-oriented, phase.

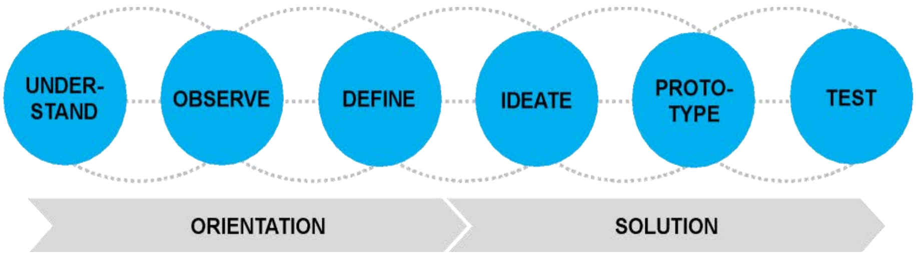

Figure 3: The Design Thinking Model (based on Plattner et al. 2009)

RESEARCH QUESTIONS AND METHOD

The purpose of this research has two objectives. First, understanding the requirements and the user needs to develop a concept for an organization-wide implementation of CBA at Daimler AG. Second, to transfer the findings to the construction industry. Therefore, action research is used to investigate issues and act based on the findings (Dickens and Watkins 1999). The authors of this paper also developed the training concept for Daimler AG. To solve issues which occurred during the development phase and to improve the concept, the authors conducted data through Plus Delta, reflection, short surveys, discussions and direct feedback with attendees based on three main questions: (1) How to implement CBA effectively? (2) How to train users and trainers in the CBA method effectively? (3) How to globally rollout CBA across a whole organization? These three questions will be answered by describing the developed concept and the current status of implementation at Daimler AG. To transfer the learnings and findings to the construction industry, the authors use one research question, which includes two sub-questions: (4) How can the training concept be transferred to the construction industry? (4a) Are there challenges that need to be considered in comparison to the automotive industry? (4b) Does the concept need to be adjusted?

CASE STUDY: CBA IMPLEMENTATION AT DAIMLER AG

Daimler AG is a German multinational automotive company with a headquarter based in Stuttgart, Germany. Due to fast-changing market developments in the mobility provider industry, in 2015, Daimler AG launched the bottom-up initiative Leadership 2020 to modernize and transform its aging leadership culture and cumbersome organizational interactions while achieving cultural resilience and flexibility for the future. The initiative identified Decision Making as one of the eight Game Changers necessary to tangibly realize empowerment, agility and trust within the leadership culture. The Game Changer Decision Making promotes empowering competency within decisions as opposed to the classical cascading hierarchal process. Over 50 global decision processes have been optimized to empower decision-making at the lowest level possible while making them traceable, trustworthy and sound. To achieve this, appropriate tools and methods are necessary to: (1) make better decisions in a collaborative team and (2) to make better decision proposals. Figure 4 presents an overview of the CBA implementation. First, a half-day training workshop was developed; second the rollout concept was created to give more insights regarding CBA and help users with the implementation; and, third, a train the trainer (TTT) concept was established to multiply the implementation across the organization.

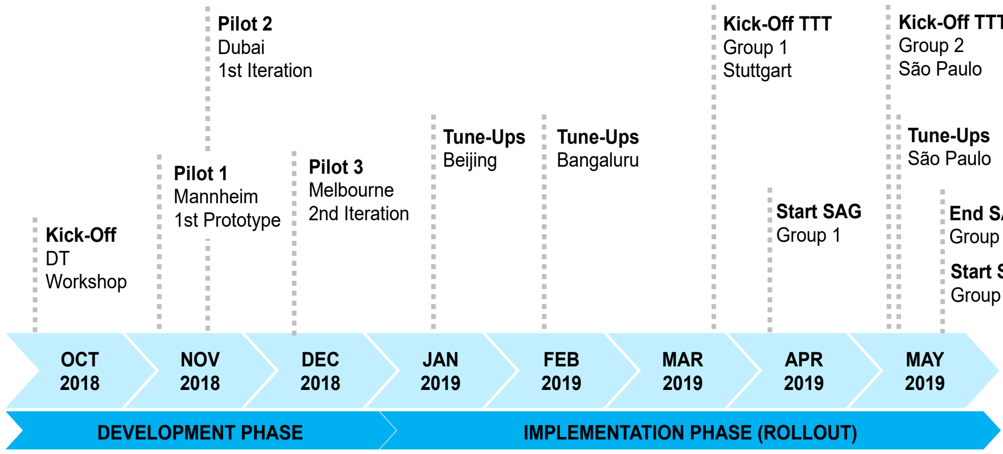

Figure 4: Overview of the concept development and implementation

Development Phase

Considering the deficient experiences with CBA implementation across an organization, the authors defined an iterative process to develop the concept. Two main elements of the approach are an initial DT workshop and the evaluation of various pilot tests with Plan-Do-Check-Act (PDCA) cycles. Results and recommendations from both elements served as orientation framework for the first concept draft as well as for the rollout and adjustment of the CBA training concept within the implementation phase. Thus, the development phase started with a DT workshop to identify the individual needs and demands of the users concerning their decision-making pain points and their learning preferences. Five team members of the global Decision Making squad (including the third author) participated in the Stuttgart workshop, which was facilitated by the first and second authors. In order to physically visualize work in progress and results of the workshop, the team used the approach of a design wall which facilitates every step of the DT process (see Figure 4). First, potential user groups of different management levels were defined. Second, mindsets of the user groups were emphasized to define their specific point of view. Third, with the user point of view as reference, the ideation process followed to develop feasible ideas for a training concept as well as suitable training approaches and tools. During the workshop, important constraints and needs for the training (e.g. time, pre-load examples, or the need for a follow-up after a training workshop) were identified.

Considering the insights of the DT workshop, the first prototype of a four-hour CBA workshop (so called Tune-up) was developed. As DT is described as an iterative process itself, several iteration steps are necessary during the development phase in order to adjust and improve the developed prototype. Within two months, a total of six four-hour workshops were held in different international branches of Daimler (see Figure 4). Using PDCA cycles, the CBA team was able to collect deliberate feedback on specific aspects of the training and to continuously improve the workshop based on the learnings (see Table 1). Both the DT workshop and the PDCA ensured the iterative development of the training, closely linked to the individual organizational demands and needs. After major improvements, the workshop was carried out three times in Beijing, four times in Bengaluru, once in Germersheim, and twice in São Paulo, at various management levels and departments (R&D, IT, Production, etc.).

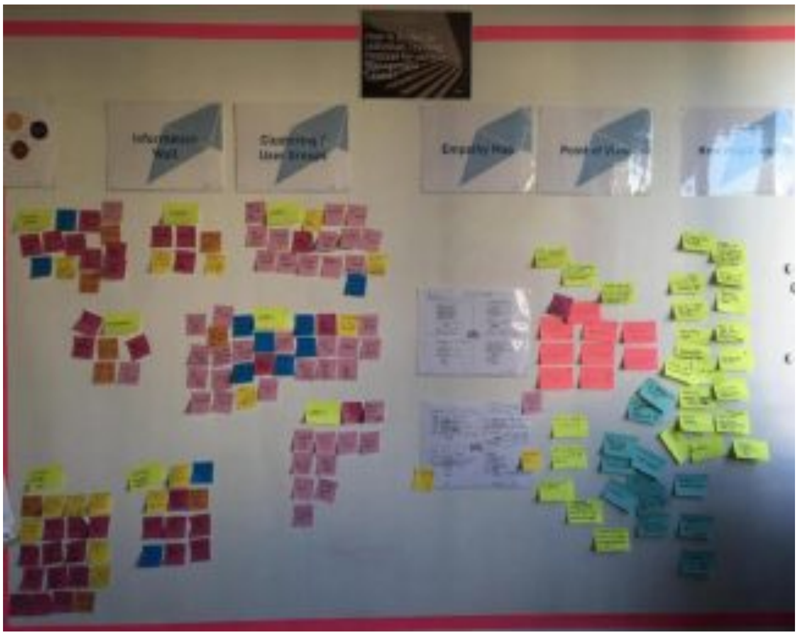

Figure 4: Design wall as result of the Design Thinking workshop

Table 1: PDCA during development phase

Pilots	# Tune-ups	Major learnings
Mannheim	1	– More visualization and active Two-list exercise – Short explanation of terms and an example for pre-load – Present the difference to weighting rating calculating (WRC) – 2 pages with the essentials of CBA as follow-up – Frame the topic in context to Leadership 2020 and the Decision Making squad
Dubai	1	– Better explanation of sound decision-making – Figure with the steps of the Tabular Method next to the template for the Tabular exercise – Simplify the theoretical part of the presentation
Melbourn e	4 (in 2 days)	– Max. number of workshop participants – Max. number of group participants for CBA Tabular exercise – More visualization of the examples in the presentation

IMPLEMENTATION PHASE: ROLLOUT

Continuous iterative cycles based on the evaluation within the framework of PDCA identified that the rollout of the CBA workshops across the organization had to be customized by consulting with the coordinator and management sponsor for the department. Therefore, the major learnings from the various pilots continuously improved and enhanced the initial prototype of the four-hour training workshop. As one of the most important learnings, additional pre-load and follow-up elements were required and have been integrated into the concept. The pre-load prepares the users with a brief pre-reading and a simple exercise to gain their first experience with CBA and to develop real decision examples that are used to exercise the Tabular method in order to make the training more comprehensible, tangible and work-related. Afterwards, the follow-up provides the users with essential knowledge, further reading and support options. Figure 5 summarizes the steps and contents in detail. The training concept helped the users to understand the need for a sound decision-making method and prepared them to apply CBA correctly. Furthermore, participants got motivated and enthusiastic about using CBA in daily business.

The rollout phase started in January 2019 with three workshops with different management levels and departments in Beijing. Especially, the third workshop was further customized to meet the needs of the newly developed team to reflect on their decision-making culture and to improve their collaborative decision process. In comparison to the other two workshops, this workshop was primarily composed of local Chinese participants from the mid-lower management levels. It was important to give them the room to articulate their pain points and their frustrations regarding decision-making using the nominal group technique. Their local decision-making cultural pain points revolved around difficulties in communicate specific market issues with the upper management levels that usually consist of German headquarter-centric perspectives. This underscores that, in both the development and the implementation phase, iterative processes appear to be crucial in order to secure and enhance the success and required adaptability of the CBA training concept.

Figure 5: Training approach to train the users

IMPLEMENTATION PHASE: TRAIN THE TRAINER

To foster internal interested parties to become CBA trainers themselves, an additional training concept was developed. The concept includes capability training and coaching for CBA as well as facilitator skills. As shown in Figure 6, the approach is composed of the three units: (1) knowledge, (2) partner coaching, and (3) advice and support. Unit one prepares the essential concept knowledge through a Kick-off and a Study Action Group (SAG). During the Kick-off and the SAG the participants have to perform exercises to build knowledge and prepare for the facilitation. Moreover, the first unit helps to develop a supportive network between the trainers that creates unit three. Furthermore, trainers get help in preparation decisions such as ready-use templates. Unit two supports the participant to become a trainer ideally within the framework of a three-step-flow partner coaching. Unit three offers additional support and enables qualified trainers to facilitate decisions with CBA. By completing all four pink steps successfully, the participant receives a CBA trainer certificate.

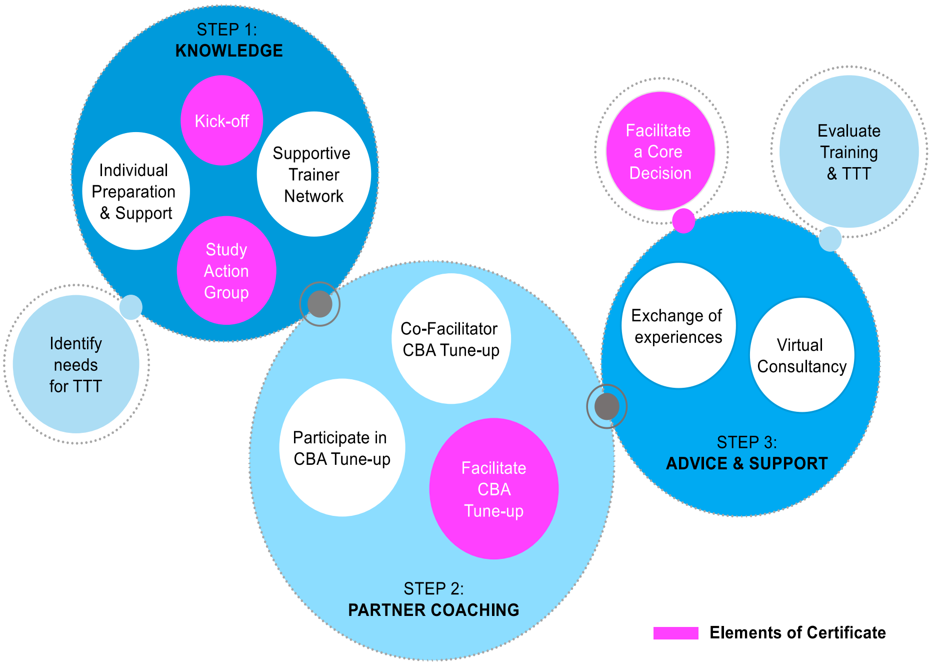

Figure 6: Training approach to train the trainer

FINDINGS AND DISCUSSION

The approach of the Daimler case study provides a broad expert network within Daimler with internal specialists and contact partners for any kinds of questions and concerns about CBA with a strong relevance for the local decision-making culture. The network enables a continuous exchange of knowledge and experiences and is therefore the basis for multiplication. Moreover, the intense evaluation of the feedback enabled continuous improvement, making it possible to deliver a customized and adaptive concept ready to be implemented across the organization. It can be seen that considering cultural difference is important to successfully train CBA in a global work environment. Furthermore, it is also important that potential users can identify and relate to how the CBA method can help them individually, while recognizing its operational benefits. CBA is introduced in a hands-on, content rich and time-efficient workshop format where the participants exercise the two-list method and the Tabular method. Within the workshop the group's decisions were presented by a member of an adjacent decision-example group so that the reliable transparency and the traceable documentation of the CBA method decisions could be experienced. Workshop participants consistently stated that they were able to understand why a group decided how they decided based on the Tabular method of documentation and the easy-to-perceive differentiation between the alternatives. Moreover, during decision-making, participants reported that they were able to understand the clearly communicated perspectives of the different decision-making group members. Thus, by practicing CBA, the workshop participants understood the benefits of the structured CBA framework which helps to make better group decisions and additionally helps to understand the decision without being involved in the process. Consequently, CBA should be trained using examples that reflect decisions of the local workshop participants to achieve a high level of pragmatic application with the CBA method. With pre-loading examples from the workshop participants, learning about the CBA method is ensured. Nevertheless, almost all participants struggle in providing the required information for the pre-load, because they do not understand the difference between factor, criterion and attribute without any consistent support. Thus, the follow-up and coaching of the train the trainer concept is a success factor in ensuring quality of CBA facilitation as well as a tangible improvement and confidence in the decision. By attending just one workshop, participants are mostly not able to use CBA correctly without the help of a facilitator. Furthermore, participants struggled in using the vocabulary precisely. Therefore, knowledge providers such as trainers are necessary to support the decision-maker. Only with the intentional strategic broad-scale rollout of decision-making methods will the organizational decision-making culture be inspired and convinced to transform out of their old hierarchical-biased methods and into a more capable and empowered method of collaborative decision-making.

TRANSFER TO THE CONSTRUCTION INDUSTRY

The construction industry is characterized by a supply chain that is split into several pieces (e.g. Rutten et al. 2009), resulting in knowledge allocation among various regional small and medium-sized companies. The project team therefore also consists of a certain number of different organizations with different cultural backgrounds that must be empowered to make competent decisions that are best for the specific project. The implementation of a new method across the construction industry often needs more time than the implementation across an automotive organization, because more people from different organizations are involved who first need to develop a common understanding. Implementing a method in a company restricts the training area to the number of employees, if the network of suppliers is not considered. In the construction industry, limiting the number to an organization limits the use and the full potential of the method when not applied in projects. However, the construction industry does provide an advantage in spreading the method across the industry, because of its project-based attribute. If project team members experience the benefits, and thus accept and want to apply the method, they will multiply by using the method in future projects. Therefore, when piloting CBA an integrated project team should be trained in and apply CBA for various group decisions in a specific project. Different decisions occur naturally during the different project phases and require different members who participate in the decision-making process. Thus, during project progress new project participants need to be introduced to CBA. Now, based on the named difference, to what extent is the concept transferable? At the beginning, the expectations and conditions should be aligned in order to create a common mind-set. DT is useful to identify the user's needs and clarify expectations. Therefore, the authors recommend starting with a DT workshop or using parts of the DT workshop to better understand the users and at the same time increase the understanding of why to implement CBA. By doing so, the acceptance will increase. The concept itself could then be transferred 1:1, by considering project-specific topics. Therefore, the content of different elements must be adjusted to the specific project. Examples to train the users should be in the context of the usual decisions they face. Furthermore, attending a workshop will give them insights, but not the confidence to apply

CBA correctly. Therefore, at the beginning a facilitator is needed to help the team implement the method correctly and create awareness regarding inclusiveness. Thus, the authors suggest to:

- Start first with the implementation in a specific project, so the benefits of CBA can be communicated within different organizations.
- Start the training with the DT workshop to understand users' needs.
- Adjust the content of the training to the project team or the organizational team.
- Spread the method by transferring experienced team members from project to project.

CONCLUSIONS

This paper presents an approach of how to implement CBA in project teams as well as across different organizations in the construction industry. Based on the iterative development of an adaptive concept that is partially applied within Daimler AG, using DT and continuous improvement in the meaning of PDCA, it can be concluded that the implementation requires a thoughtful plan that leaves room for adjustments in accordance to the project team's needs. Furthermore, in comparison to the automotive industry, there is another factor that needs to be considered when applying CBA to project teams in the construction industry due to the fact that a construction project involves several participants from different organizations. This increases the complexity and makes it even more necessary to apply a concept that works for the project team. This paper does not give insights into training the trainer or regarding the facilitation of decision-making with CBA itself. Here, more research is needed to support an effective CBA implementation across the construction industry.

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ASSESSING THE LEVEL OF IMPLEMENTATION OF LEAN CONSTRUCTION: AN AUDIT PROTOCOL

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ABSTRACT

The implementation of lean construction still faces barriers mainly in its initial stages. It occurs, in part, due to the lack of evaluation tools that enable the acknowledgment of its true value for the companies.

Thus, this paper aims to present an audit protocol to evaluate the level of lean implementation. Developed under Design Science methodological background, the audit protocol was proposed based on literature. To evaluate the applicability, the pilot protocol was implemented and tested into 4 construction companies from the city of Fortaleza, northeast of Brazil. The pilot revealed improvements to improve the protocol. Then, the improved protocol was evaluated and validated by 5 lean construction experts, resulting in the final protocol which was composed by 4 dimensions, 35 categories, 136 items and 223 examples of verifying evidences.

Was verified that the protocol allows more than identify the lean implementation level, but enables a lean journey if used as a guidebook to lean implementation. The proposed audit protocol can be also used to cyclic evaluation that enables the improvements of the identified gaps, through a deep comprehension of the critical factors that can prevent the success of lean construction in the companies.

KEYWORDS

Lean construction, improvement, evaluation tool, implementing lean, integration.

INTRODUCTION

Implement lean is a great challenge for any company from any sector. This is evident in the literature, since the efforts of Womack *et al*. (1990) that results in a generalization of Toyota principles, theoretically applicable in any company (Womack and Jones, 1996). Despite of this efforts, there is no consensus of this generalization, principally if considering the construction industry (Koskela, 2004). In construction industry, the

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application of Toyota principles are based in Koskela (1992), called as Lean Construction by founders of International Group for Lean Construction in 1993 (Koskela, 2004).

Since Koskela (1992), many researchers report the success and pitfalls of lean construction implementation (Ballard, 1993; Alarcón *et al.*, 2005; Sarhan and Fox, 2013; Zanotti, Maranhão and Aly, 2017), indicating that the lean implementation question remains open. This question, can occur due to a poor vision of lean as a tool box (Atkinson, 2010) and because of the lack of evaluation tools that allows the acknowledgement of its true value for the companies (Li *et al.*, 2015a; Cândido and Barros Neto, 2017).

Thus, an alternative to help companies to widespread implement lean in industry is evaluate implementation through audit protocol (see Karlsson and Ahlström (1996), Åhlström (1998), Soriano-Meier and Forrester (2002) and Bhasin (2011)). The use of tools to analyse lean implementation is an alternative for construction industry, as can be seen in previous IGLC proceedings as Diekmann et al. (2003), Hofacker et al. (2008), Valente et al. (2012), Etges et al. (2012, 2013), Nesensohn *et al*. (2014, 2015) and Li *et* al. (2015).

Although this apparent prolific literature, efforts to improve the lean implementation and its evaluation, remains a valuable initiative. Thus, this paper aims to present an audit protocol to evaluates the level of lean implementation. Developed under Design Science methodology background, the audit protocol was proposed based on literature.

The audit protocol to evaluates lean level of implementation was structured based on the 4P's (Liker, 2003): philosophy, process, people and partners and, finally, problem solving. This choice was taken due to the epistemological dispersion in the foundation of lean concepts in its different areas, as Krafcik (1988) seminal paper in the terminology of Lean Production System, Womack, Jones and Ross (1988) and later Womack and Jones (1996) used the terminology Lean Thinking and Koskela (1992) used Lean Construction. This dispersion can lead a misunderstood about of what is lean, as pointed by Koskela (2004). Finally, it is unanimous among the aforementioned authors that they are natural descendants of Toyota Production System (TPS), which justifies the choice of the TPS Pyramid proposed by Liker (2003) as framework of the audit protocol proposed.

EVALUATING LEAN CONSTRUCTION IMPLEMENTATION LEVEL

The implementation of lean construction in the construction industry generally presents strong barriers that can make it unfeasible, as it happens in the adhesion of other processes of organizational improvements. The adoption of lean construction demands investments and measurement of its benefits (Campos et al. 2012), which are frequently misunderstood and considered as shortcoming (Cândido and Barros Neto, 2017).

To correctly guide this process, the use of an efficient audit model in companies that use this philosophy of production management might/may contribute to operational efficiency of lean construction (Etges, Saurin and Bulhões, 2013). As an example in industry, Karlsson and Åhlström (1996), Soriano-Meier and Forrester (2002) and Bhasin (2011), proposes an evaluations to assess the Lean implementation and its benefits. In the construction industry, some authors also tried to evaluate the lean construction implementation level as showed in the Table 1.

Table 1: Models to evaluating the level of lean construction implementation published at IGLC

Author	Dimensions	Maturity Level	Evaluation	Application/ Validation	Strengths	Weakness
Diekmann et al. (2003)	5	No	Organization	No	- Justify the importance of the evaluation categories based on literature	- There is no application or validation - The categories are evaluated superficially
Salem et al. (2006)	6	No	Construction Site/ Project	Yes, a unique case study	- Simplicity - Relates the expectations and the currently level of implementation of lean tools	-Limited number of lean practices - Unique case study
Hofacker et al. (2008)	6	12	Organization	No	- Simple and rapid to applicate	-Limited number of lean practices - There is no discussion about each category
Campos et al. (2012)	06	12 to lean and 5 for sustainability	Organization	Yes, tow applications	- Relates the level of lean implementation with sustainability	- There are no improvements in previously frameworks used to evaluates lean as well as sustainability
Valente et al. (2012)	7	No	Construction Site/ Project	Yes, four construction sites	- Enables a continuous improvement for lean practices - Assume the variation of level of leanness according the construction phase	- Developed for a specific company - There is no external validation Focused only production issues
Etges et al. (2012, 2013)	15	No	Organization	Yes, 18 experts and application in a unique case study	- Robust and extensive list of lean practices - Demands different source of evidence to evaluate lean practices	- Requires a lot of time-consuming to apply (4 hours)
Nesensohn et al. (2014, 2015)	11	5	Organization	No, validated through experts' interviews	- Robust and extensive list of lean practices - Demands different source of evidence to evaluating lean practices	- There is no external validation - There is no discussion about each category
Li et al. (2015)	6	No	construction site/project	Yes, 300 projects	- Extensive empirical data collection - Demands different source of evidence to evaluating lean practices	- Measuring only the results of lean and not its really usage - Limited number of lean issues

Based on this literature, the dimensions were compared between them as well as the evaluation items, from which the pilot protocol was proposed.

METHOD

This paper was developed under Design Science methodological background, based on Lukka (2003), Hevner et al. (2004) and Van Aken (2004). The research process is showed in Figure 1.

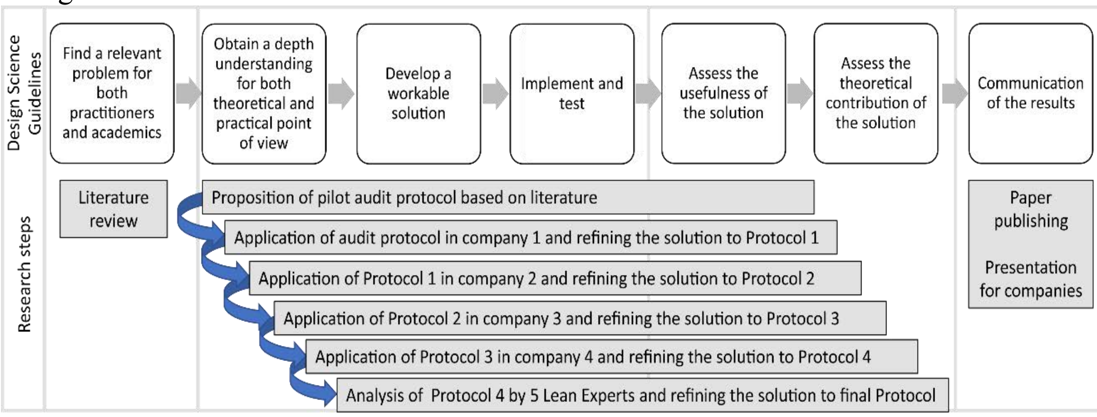

Figure 39 - Designed Research Process

Initially, a literature review was conducted focused in IGLC proceedings, from which five papers that proposes an evaluation of lean implementation was found. Through the exanimating of its references Salem et al. (2006) work was found and added into content analysis. Then, a pilot audit protocol was proposed based on literature and refined through four applications in four building companies from Fortaleza, city of Brazil. The main characteristics of the four companies are presented in Table 2.

Table 2: Building companies' characterization

Company	Market segmentation	Age	Time of lean application	Interviewed
A	Residential, corporate and industrial building	37 years	05 years	Planning Coordinator
B	Residential and corporate building	23 years	13 years	Planning Manager
C	Residential and corporate building	29 years	19 years	Technical Director
D	Residential and industrial building	40 years	13 years	Lean and Green Coordinator

In each of these cases were analysed the applicability and the understanding of the interviewees about the items of evaluation. Regardless of several types of evidence were requested and analysed, increasing understanding of how companies are fulfilling the items evaluated. Propositions of improvements for the audit protocol were performed, which increased the depth of understanding for both theoretical and practical point of view and the workable solution demanded by methodological background.

Finally, the interviewees analysed the usefulness of solution, they reached consensus about its useful. The main critic noticed by the interviewees was the high consumption of time for the audit process, about 2 hours. After the cycle of implementation, test and refining, the refined protocol was evaluated and validated by 5 lean construction experts (Table 3).

Table 3: Lean construction expert characterization

Expert	Formal Education/ High degree	Professional Experience	Level of LC knowledge*	Involvement with LC*
A	Bachelor's degree in civil engineering and business administration, PhD in civil engineering and post doctorate in construction and housing economy	41 years, currently is professor at State University of Ceará	10	7
B	Bachelor's degree in civil engineering and master's degree in industrial engineering	27 years, currently is Technical Director in a building company	8	8
C	Bachelor's degree in civil engineering and master's degree in industrial engineering	19 years, currently is Technical Director in a building company	8	10
D	Bachelor's degree in architecture and urbanism/ master's degree in civil engineering and master's degree in industrial engineering	10 years, currently is architect at Federal Institute of Ceará	8	8
E	Bachelor's and master's degree in civil engineering	08 years, currently is professor at Federal University of Ceará	8	10

Legend: * 0 to 10.

Each expert evaluated the dimensions, categories, evaluation items and the scale of points. They approved the audit structure and scoring, however they suggested a rearrangement of categories and new items. Moreover, there is no consensus about the importance among each principle of Toyota pyramid suggested by Liker (2003). Finally, there was wide consensus among the interviewees about the applicability of the audit protocol, as well as its reliability for measuring the lean implementation level.

PRESENTING THE AUDIT PROTOCOL TO EVALUATE THE LEVEL OF LEAN IMPLEMENTATION

An audit protocol can be analysed as a performance measurement tool. Thus, the audit protocol can be structured in two components (Cândido, Lima and Barros Neto, 2016): architectural and processual framework. The architectural framework of the final audit protocol was structured in three levels of aggregation (Yu *et al.*, 2007): dimensions (based on Toyota model), categories and evaluation items that need evidence in action. The processual framework was structured in three steps, based on Franco-Santos et al. (2007): (1) data collection and manipulation; (2) results communication and performance evaluation; (3) system review.

ARCHITECTURE OF AUDIT PROTOCOL

The characterization of audit protocol is presented in Table 4.

Table 4: Audit protocol characterization

Dimensions	Category	Evaluation items	Source of evidences
Philosophy	Lean Culture	05	10
	Lean Behavior	06	11
	Customer Focus	07	15

		Environment	04	07
		Waste management	06	12
		Wellbeing and safety work	05	08
Subtotal		**6**	**33**	**42**
Process	Flow	Work Flow	11	19
		Material	09	18
		People	03	05
		Equipment	03	05
	Tools	Quality control	05	09
		Autonomation	05	10
		Standardized Work	07	14
		5S	06	11
		Transparency	04	04
		Knowledge and Information Management	04	10
	Planning and Control	Design Planning and Control	06	10
		Production Planning and Control	06	11
		Cost Planning and Control	06	11
	Subtotal	**23**	**75**	**137**
People		Lean Leadership	05	09
		Learning and growth of internal clients	05	06
		Learning and growth for supply chain	06	08
Subtotal		**03**	**16**	**23**
Problem Solving		Problem identification	03	06
		Problem Solving	03	05
		Continuous improvement	06	10
Total		**03**	**12**	**21**
Dimensions: 04		**Categories: 35**	**items: 136**	**evidences: 223**

Due to the size of this paper, in following, we present an example of evaluation item in Table 5.

Table 5: Example of evaluation items to the dimension 'Philosophy' in the category "Lean Culture "

Item	Question	Evidences	Reference
01	Does lean construction cover all sectors of the company from planning to execution of the project?	* Interview senior management to see if the implementation of lean construction covers all sectors of the company; * Find out if the company has expert advice to support the implementation of lean construction.	Nesensohn et al. (2015)
( ) Yes.Tot ( ) Yes.Part ( ) No ( ) N.A.		What are the evidences that prove the attendance of the question?	
02	Is lean construction being propagate as a strategic vision of the business, and are all constantly striving toward this direction?	* Interview top managers to see if the implementation of lean construction is part of the strategic planning of the company; * Interview the senior management to find out if is included in the financial investment plans of the company, funds intended for the implementation of lean construction.	Hofacker et al. (2008), Carvalho (2008)
( ) Yes.Tot ( ) Yes.Part ( ) No ( ) N.A.		What are the evidences that prove the attendance of the question?	

The audit protocol is presented in full in Comelli (2018), a M.Sc. Dissertation, and as a supplementary document of this paper available at <http://bit.ly/2ILus0H>.

PROCESS OF AUDIT PROTOCOL

As previously stated, the process of auditing was structured in three steps. The data collection and manipulation are conducted through interviews sections, documents and observations. Thereinafter, the score of evaluation is assigned according with Table 6.

Table : 6 Scores of evaluations item

Evaluation item	Interpretation	Scores
Fully implemented	The item is systematically evidenced in action	1.0
Partially implemented	The item is inconsistent evidenced in action	0.5
Not implemented	The item is hardly evidenced in action	0.0
Not applicable	There is no applicability in the evaluation	Not computed

It should be noticed the difference between not implemented (zero) and not applicable (not computed). The Lean Construction implementation level in the particular dimension (LILD) is calculated as a percentage of scores obtained relative to maximum for each category. Thus, when an item is assigned as 'not implemented' he is not counted for the percentage. This option was made due to the difference among them (Table 4). For example, there is 33 evaluation items in Philosophy dimension and and 77 in Process dimension. Consequently, there is more possibilities to score in process dimension than Philosophy.

The results communication is initially exhibited through a radar chart, in which each axis corresponds to a dimension analysed, and a list of items from 'Partially implemented' to 'Not implemented' is presented, clarifying the opportunities of improvements. In Then, the LILD is calculated.

Based on the LILD achieved is provided a profile for the company (inspired in Succar (2009), from which is possible to classify into 4 categories as showed on Figure 2.

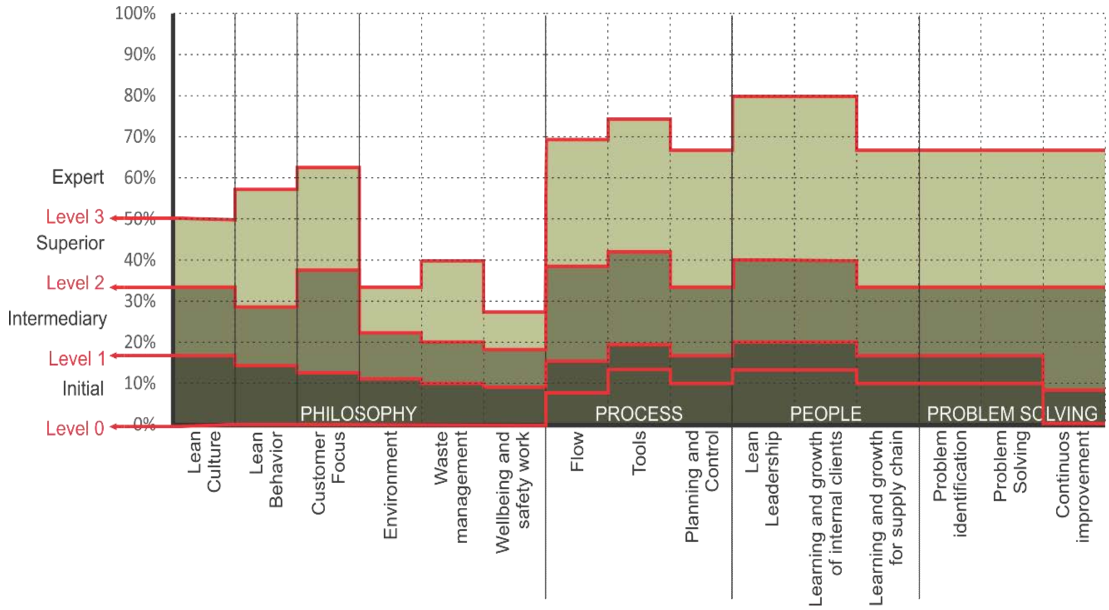

Figure 2: The final classification

Propose a profile, instead of an aggregate result, in the view of the authors it is more suitable because of the lack of agreement about the relative importance of each principle of TPS Pyramid. In a second reflection, it is hard to think in terms of practices hierarchization in different project contexts, which led the proposition of classification to be based on the sum of efforts to implement lean. For example, to a construction site located in an urban context, like housing build, it is easier to establish partnership with suppliers than in a road construction site. In vertical building construction is more important to invest in safety than in a simple house construction site.

Despite of this, in Liker (2003) is suggested majority of "Lean companies" are skating at process level. According to this author, to be "lean" is not copy the tools from Toyota in a specific production process. To be "Lean" is develop right principles to its own organization, in order to achieve a high performance of continuous value generating to the clients and society.

Based on that, it is possible to affirm that the use of Lean Tools does not characterize a company as lean, which originated the level zero in the proposed classification or pre-lean level. In this level are companies that reach until 10% of the practices listed on the audit protocol for process principles.

In the level 1, called as initial, is expected an early awareness formation in the top administration about the benefits of lean. This leads to commitment to lean deployment and consequently education to the other levels of the company – assuming a top-down approach. This early awareness is caused by visible and immediate result achieved by companies in its production process. The percentage of practices adopted to stablish this level was 20% of the practices to each category analysed.

It is worth to notice that 20% of evaluation items related with Lean Culture, with 05 items, corresponding a 1 practice, while to Flow, with 26 evaluation items, corresponding a 5. This justify different percentage into y-axes presented in Figure 2.

In the level 2, called as intermediary, is expected to advance up to 40% in all categories, which enables the early signals of a lean awareness in both mid and operational employees (internal clients). From this level of lean implementation, the philosophy permeates all company, although it does not reach the supply chain (external clients), which is expected in the level 3. Some initiatives aimed to buyers and end users (as customization) are under development as lean culture arises.

In the level 3, the lean awareness and practices are sedimented in the companies and to continue improving its performance its is necessary a step forth: integrates the external clients in the supply chain. At this time, is expected accomplishes the roles 1 and 2 of supply chain management in the construction industry, as proposed by Vrijhoef and Koskela (2000), e. g., intensification in development and improvement of specifics supply chains, such as prefabricated concrete elements. Moreover, mass customization and maintenance services to end users are implemented as the lean culture is sedimented. The percentage of practices adopted to stablish this level was 70%.

In the expert category, is expected a prominent lean awareness and the atmosphere of the companies is founded in a Lean culture. As proposed by Liker (2003), in this level, the companies are capables to develop its own lean business model, i.e., new propositions and improvements arises and increase lean mentality itself. It is expected the accomplishment of the roles 3 and 4 of supply chain management (Vrijhoef and Koskela, 2000), as well as the involvement of clients and users in early stages of the construction project – conception and design of building.

It should be observed that the proposed methodology does not take into account, for the moment, if such management actions are successful. They are taken as successful at this stage to evaluate the actual level of lean implementation. Thus, the efficacy, efficiency and results of this actions are not the object of this evaluation.

The last step of the auditing is the system review. In this step, additional items of evaluation can be proposed by both practitioners and academics. In addition, any evaluation items can be removed, enabling the continuous improvement of the audit protocol. Moreover, as proposed by Franco-Santos *et al*. (2007), an evaluation tool should be flexible and upgradeable not only in terms of items of evaluation, but also in terms of the criterions of evaluation. Thus, the suggested scale can be refined whenever necessary.

CONCLUSIONS

This paper aims to present an audit protocol to evaluates the level of lean implementation. Thus, based on literature review a pilot audit protocol was proposed, which was applied and refined in four cycles into four building companies. Thereinafter, 5 lean experts criticize the protocol, refining it to definitive version.

Then, the final protocol was composed of 4 dimensions, 35 categories, 136 items and 223 examples of verifying evidences. As differential, the presented audit was developed in cooperation with both academic and practitioners, providing a widely and depth understand about lean construction that can helps in its implementation and diagnostic.

Moreover, the final protocol aims to support the lean implementation providing a diagnosis of the current stage and points out directions for a company to improve itself. During the Lean evolution is expected a gradual advance in all dimensions, mainly because the awareness formation pushed by Philosophy sedimentation that will press the others.

As a limitation, it should be observed that the proposed methodology does not take into account, for the moment, if such management actions are successful. Another type of evaluation is necessary for this analysis. Further, the audit protocol can be applied and analysed in different building companies to increases its value in future research.

To conclude, the proposed protocol contributes to better lean construction implementations, suggesting a huge amount of actions organized into TPS dimensions and introducing performance measurement criteria to evaluate them. In the end, through the proposed protocol the lean journey can be tracked by its agents and might prove the actual final purpose of its implementation for both clients and managers, supporting the institutionalization of lean construction in its companies.

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LESSONS FOR CONSTRUCTION: DELIVERING MEGA PROJECT ON TIME THROUGH CULTURE AND HOSHIN KANRI

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ABSTRACT

Managing risks in mega projects has received a lot of attention in the construction community. However, very few empirical results have reported on-time and on-budget deliveries. This paper presents a case study from a closely related industry, offshore oil and gas construction, where the lean project management and culture method Hoshin Kanri was implemented on a mega project. The results of implementing Hoshin Kanri in this case have been very positive, with project lead time reduction of 10 percent, risk incentive account of USD 1 billion saved, and a potential of an additionally revenue of 2.8 million USD/day due to reduced lead time and early production startup. The paper reviews how Hoshin Kanri is implemented in this specific mega project, and compares it to other industries, processes, and previous IGLC research to extract lessons to be learned for the construction industry. The implemented Hoshin Kanri was found effective in developing the interlinkage between the strategy and project organization from upper to lower levels. The contribution of this paper is to illustrate the benefits of Hoshin Kanri and to propose further development of this within the construction community.

KEYWORDS

Hoshin Kanri, Mega project, Visual management, Culture, Collaboration.

INTRODUCTION

Through analyzing 205 mega projects in offshore oil and gas, EY (2014) finds that 73 percent of these report schedule overruns and 65 percent report cost overruns. Further, EY (2014) divided the projects with cost overruns into six regions and analyzed the average budget overruns to be: North America (51%), Latin America (102%), Europe (57%), Africa (51%), Middle East, (68%) and Asia Pacific (57%). EY (2014) findings reveal that managing mega projects in oil and gas involves great challenges and emphasize the need for a shift in management approach in mega projects in offshore oil and gas.

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Not only EY (2014) has documented the complex nature of mega projects and its many risks. Sanchez-Cazorla et al. (2016) present a literature review of previous research on risk in mega projects across several industries (listing both construction and oil and gas) and conclude that cost overrun and schedule delays are everyday life, but no detailed and consistent categorization of risk exist due the complex and adverse nature in these types of projects. Flyvbjerg (2014) adds to this by outlining that only one in ten construction mega projects is delivered on time and budget. Flyvbjerg et al. (2003) further describe construction mega project economy, risks, and impacts on society and environment. Kardes et al. (2013) elaborate further on these impact factors and categorizations that define a mega project. According to Kardes et al. (2013), projects with above 10 diverse teams, multi-million-dollar budgets, complex contract structure, and time frames stretching across multiple years can be defined as mega projects. Furthermore, authors agree that the multiple high complexities accumulate and increase the risks in these types of projects (Bruzelius et al. 2002; Flyvbjerg et al. 2003; Kardes et al. 2013; Sanchez-Cazorla et al. 2016).

Looking at EY (2014); Flyvbjerg (2014); Flyvbjerg et al. (2003); Sanchez-Cazorla et al. (2016), it becomes clear that mega projects within both construction and oil and gas contain large risks and share the trend of overrunning budget and time, strongly indicating that they are very much alike.

Within manufacturing, similar complexities arise; hence, productivity, risk, and cost management have been focus areas for decades. The Toyota production systems (Liker and Meier 2006) and lean has cemented itself as a highly functional toolbox to accommodate these focus areas (Dennis 2010; Womack and Jones 2003). Giordani da Silveira et al. (2017) describe how Hoshin Kanri, another lean tool, can assist organizations in achieving goals and improving their performance through their most important resources—the people. Hoshin Kanri has been described by Hutchins (2016); Jolayemi (2008); Nicholas (2016); Tennant and Roberts (2001a) as a method for strategy and policy deployment that strengthens the continuous improvement culture.

In this industry paper we will address how the lean method Hoshin Kanri is successfully being used to manage a five-year-long and USD 4.6 billion large offshore oil and gas redevelopment mega project, within both planned budget and schedule. The paper is highly relevant for construction for two reasons: 1) both construction and oil and gas mega projects are project-based construction, contain large risks, and face the inherent nature of overrunning budget and time. 2) Looking at EY (2014), keeping a mega project like this within budget and schedule is remarkable, especially since EY (2014) argues that projects executed on deep water are the most complex.

Looking at previous research, lots has been published on both mega projects and Hoshin Kanri, but not the two together. Thus, this paper will contribute to the body of knowledge by presenting how Hoshin Kanri can successfully be applied in a mega project.

CASE DESCRIPTION

This industry paper focuses on an offshore oil and gas production field with its platforms located in the North Sea. The case platforms hold wellheads, processing facilities, accommodation, flare stacks, risers, etc. The field was brought online in 1984 and produces daily 60,000 barrels of oil and 6.7 million m^3 of gas. The extraction of gas from the field's gas reservoir has been done without water injection, meaning that the pressure has continuously depleted, causing the subsurface to steadily subside. As a result, the case platforms (among others in the field) have since 1987 subsided from their original designed air gap of 20 meters to now a 14–15meter gap between sea level and platform.

As a consequence of the reduced current gap, platforms are no longer in compliance with the structural code described in ISO 19902. This means that a risk exists of extreme waves hitting the platforms, causing partial or full collapse. The case owner has thus initiated a comprehensive redevelopment project of the entire offshore oil and gas field. This redevelopment project will ensure that platforms will comply with the ISO 19902. The redevelopment project will over a period of five years (2017–2022) re-establish inherently safe operations at the offshore installations by:

- fabricating new topsides and bridges and installing these with appropriate gap to sea level.
- installing a new process module and a new utility and living quarters module.
- removing and disposing of redundant facilities.
- safe guarding production from the southern oil fields during the shut-in.

The redevelopment project budget is USD 3.6 billion with a risk contingency budget of an additional USD 1 billion, giving a total budget of USD 4.6 billion. The project is approximately halfway through and currently below budget and ahead of schedule. The redevelopment project will enable the field to continue full operation until 2047. The following will show the steps which were crucial for the successful implementation of Hoshin Kanri in this offshore oil and gas mega project. The case materials have been captured by one of the authors direct involvement in the project organization as a change agent. The author has previously worked with strategy implementation and found the Hoshin Kanri approach, to be a supportive structure, with a focused way to keep the plans and execution thereof on the right path. When starting up on the mega project, he realized that it could be handled with this approach, to act upon deviations and focus the efforts where most value is created. This involvement led to longitudinal access to the organization and data such as progress and milestone reports. Having an active role in the implementation and sustention of this, enabled the understanding of the dynamics throughout the developing progress with Hoshin Kanri since 2017.

HOSHIN KANRI—THE ENABLING STRUCTURE

Hoshin Kanri is a management methodology designed to use the collective thinking power of all employees to make the organization the best in its field (Hutchins 2016). Hoshin means "compass needle" or "direction," and Kanri means management" or "control." The goal is to get everybody pointed in (and working toward) the same direction, often referred to as "true north."

The philosophy behind Hoshin Kanri is that people are highly motivated by relations and results (Hutchins 2016; Nicholas 2016). To get the results, people need the right structure for delivering a good job (Dennis 2010). Such a structure is enabled by the right behavior, which was addressed in the latter and could be summarized in the following way: ownership, focus, relations, and leaders taking an active role in removing obstacles from the progress. The following presents the structure necessary for developing and sustaining the Hoshin Kanri deployment in the organization.

The structure operates in three different layers:

- Yearly cycle: Setting the focus and priorities for the coming year (Hutchins 2016)
- Monthly cycle: Monthly check-ins at milestones and leading indicators using the PDCA cycle
- Weekly cycle: Weekly meetings at team and project level to empower the whole organization using the PDCA cycle

Yearly Process

The purpose of the yearly process is to define the Hoshin Kanri X-matrix (Hutchins 2016); Tennant and Roberts (2001a) and SMART targets (Doran 1981). The X-matrix is also known as the Hoshin Kanri policy deployment foundation (Tennant and Roberts 2001a) and requires SMART targets (Specific, Measurable, Achievable, Relevant, and Time-bound), that allow managers to measure their performance. Inputs for the X-matrix and SMART targets comes from a cascade of information from the lower levels of the organization and upward with each team reporting progress and deviations from the original plan.

Based on the reportings from the monthly and weekly cycles, the leadership team perform the yearly cycle, which is divided into two sessions, “status” and “target setting,” focusing on current and future project performance. Outcome of these sessions is the status from the previous year and the improvement areas (targets) needed for the project to succeed toward the ambitious stretched target (shortened schedule). The overall project targets are registered in the Hoshin Kanri X-matrix for the project level (Hutchins 2016). For each project priority and major activity, a milestone certificate is created. This creates a plan covering the path toward to delivering on the priorities and contains actionable steps toward the target result for the activity.

These are the steps for the project leadership improvement area and target session:

- Align targets with critical success factors
- Ensure targets are in compliance with Team ONE manifesto

- Make sure they follow established processes (cost, planning, risk, etc.)
- Prioritize, analyze, and choose targets and record and high-impact improvement areas
- Define project targets and measures for the coming year
- Assign accountable department for each improvement area and provide accountability

After the project leadership team has set targets and priorities, the accountable departments are decided. Then the "catchball process" within the project teams starts. A series of sessions are held with the individual teams to define how the different teams can support the overall targets and improvement areas. These sub-milestones end up in the X-matrix developed at team level. All steps (sub-milestones) are also defined as SMART targets to finish the yearly cycle. The process is done according to Tennant and Roberts (2001a) and the aim is to define the activities, focus areas, and targets that each project team needs to carry out in order to deliver on the targets and priorities defined by the leadership team. When the X-matrix for the project team is developed, the other teams adjust their matrices to fit into the overall X-matrix as described by Hutchins (2016); Tennant and Roberts (2001a).

Monthly and Weekly Follow-up

The aim with the monthly and weekly follow-up is to ensure performance accountability. This is done by having project and team performances checked against the plan, and target owners present challenges in their areas. This is done so all activities and milestones from the project plan and X-matrices can be broken down into tangible sub-milestones and sub-activities. These are then continuously monitored and followed up on by the responsible managers. The sub-categories are broken down by each individual activity or milestone owner, which could be considered equal to the foremen's social interaction during Last Planner System (LPS) (Ballard 2000) meetings, where obstacles are identified as a team. These follow-up meetings are interlinked, meaning that lower levels feed upward. This enables decisions to be taken at the right level of management and allows the project leadership team to make proactive decisions and thereby timely corrective actions. The leadership team meetings are all held in the project war room. Picture 1 shows the war room and its visual boards, which contain the following information:

- Critical success factors and leadership team manifesto
- HSSE information (Health, Safety, Security, Environment)
- Integrated risk schedule, including all activities, major milestones, and sub-milestones
- 90-day outlook for each of the teams in the project (high level)
- Cost and schedule performance
- Risk and opportunities

- Relevant performance and soft skill measures (e.g., happiness Likert scale)

Picture 1: Project management war room with visual boards

Weekly Process

The weekly processes follow the activities with small intervals, ensuring that deviations and actions are closely monitored. Throughout the year, the project has follow-up meetings on a weekly basis using visual management boards. It is an iterative process where the individual team/department meetings feed into the weekly project leadership team meetings. This creates transparency and increases the ability to act in a proactive manor toward any of the identified challenges. All team boards include the supporting activities for all deliverables and progress tracking measures. Activity owners update their parts of the board according to the progress principle by Amabile and Kramer (2011).

Miscellaneous Meetings with Stakeholders

All major stakeholders, joint venture partners, energy agencies, and corporate functions are briefed from the public visual management board area. The briefing contains activities, status, achievements, and challenges to constantly ensure transparency and trust from all key stakeholders in the project. The global project team is briefed weekly from the board area via video conference.

HOSHIN KANRI IMPLEMENTATION STRUCTURE

The mega project leadership team has throughout the implementation of Hoshin Kanri been assisted by a facilitator (first author), who has continuously coached and trained the whole project team to follow the Hoshin Kanri processes to ensure organizational alignment. The implementation of Hoshin Kanri has been done in parallel with soft-skill development in both the project leadership team and project organization. Having a large focus on developing soft skills and hereby the wanted culture of openness and trust is a direct consequence of Peter Drucker's famous quote: "Culture eats strategy for breakfast." The following sections will first present how this project defined the critical success factors and behaviors that all soft skill development was steered by. Second, the structure necessary for managing a megaproject by Hoshin Kanri is outlined by explaining the structure of the yearly cycles, monthly cycles, and weekly follow-up meetings.

CULTURAL FOUNDATION—CRITICAL SUCCESS FACTORS AND BEHAVIORS

The project leadership team consists of directors, engineers, HR, procurement, planners, transport, operations & maintenance managers. This leadership team have developed the critical success factors with the project end state and goal in mind. These are absolute preconditions for designing and sustaining the Hoshin Kanri strategy (Nicholas 2016). The critical success factors from the case are presented below in Figure 1:

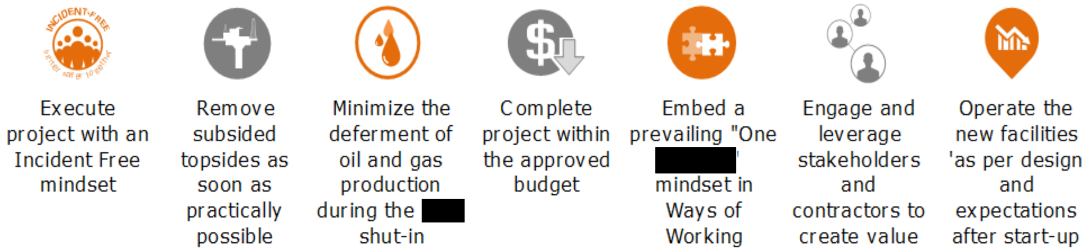

Figure 1: Project critical success factors

Figure 1 illustrates how the leadership team perceives the team dynamics and required mindset throughout the project. Successful delivery of the critical success factors is underpinned by the organization culture, capability (i.e., having the right people in the right place at the right time with the right mindset), and deployment of the Hoshin Kanri method. The focus on organizational culture, capabilities, and Hoshin Kanri is what drives the continuous improvement process and is the process which sustains the long-term goals at all levels of the team. Focus on project goals throughout the organization eliminates waste generated from inconsistent direction and poor communication (Nicholas 2016). The observed benefits from this approach are listed below:

- The teams have experienced increased participation, alignment, and involvement toward breakthrough objectives.
- Deviations and improvement actions are handled as the continuous improvements are built into the planning cycle.
- It has created focus on "a few vitals rather than trivial many."
- Outcome of the increased participation has been integration and cross-functional co-operation between teams and their members.
- The performance and deviations have been carefully monitored, leading to fast feedback and transparency of progress.

Knowing, as a team member, that one's effort feeds directly into the overall project goals motivates to support the corporation and helps to sustain a learning environment where both successes and failures are used to drive improvements. The importance of ensuring that the project team understand how ones behavior is affecting the whole is also addressed by Neve et al. (2017). Often lean (or other equivalent) activities fail because organizations neglect the importance of getting the right culture and capabilities in place before progressing. In this project, the project leadership team established a "project manifesto" that underpins how the project team works together, makes decisions, communicates, and behaves to build the desired culture.

We prioritize TEAM ONE	We believe in good intentions	We drive simplicity	We win and lose together	We speak with one voice
We build on trust, respect and empowerment	We know results come from having the right	We create better interfaces between our teams	We explore how to make each other successful	We are all ambassadors for the project
We take an interest in each other	We take the difficult discussions if we have to	We promote collaboration at all levels	We speak up and ask for help when needed	We share important information
We celebrate our successes and have fun	We always look at the bigger picture	We empower decision making	We shield our teams	We always back the decisions

Figure 2: Project team values and statements

These values and statements are illustrated in Figure 2, and can be summarized into seven steps to successful execution, presented below:

1. Focus on the customer by integrating collaboration in design, planning, and execution.
2. Enable integrated collaboration by ensuring strong relations between project teams and key stakeholders through a trustful learning environment where mistakes are opportunities for improvements.
3. Plan and front-end load all major activities, including a coherent set of indicators (leading ones) covering the full activity set.
4. Establish one truth by prioritizing data governance and mandatory fit-for-purpose tools (i.e., do not use Excel to run a business).
5. Commit to transparency to avoid "big company disease" (Dennis 2010) by displaying all relevant information on visual management boards in public spaces.
6. React decisively (take immediate action) as soon as anything deviates or is outside a desired range.
7. Link actions with learnings though continuous sharing of learnings on a regular basis and lessons learned from major activities throughout the project.

ACHIEVED RESULTS

Main issues during the implementation were prioritizing of actions and handling how this can lead to "no action" as everything can't be important. Furthermore it took team effort to understand the importance of working according to plan, which required focus on distinguishing between improvements and operations according to plan.

The achieved results of using Hoshin Kanri in this offshore oil and gas mega project are presented below: 1) budget and schedule; 2) culture—the backbone of Hoshin Kanri.

BUDGET AND SCHEDULE

- The project is on track and the ambitious stretched target (reduced schedule) is to start production in December 2021 instead of July 2022. This is a potential 10 percent reduction of the overall schedule duration. Furthermore, the risk incentive budget of USD 1 billion is not expected to be used due to early project delivery.

- This stretched target's impact on revenue streams is huge knowing that the average production value of oil and gas is approximately 2.8 million USD/day.

CULTURE – THE BACKBONE OF HOSHIN KANRI

- Open culture is lived, meaning that people flag concerns and focus on continuous learning. For example, this had an impact on one of the production work scopes that was executed 15 percent faster than estimated, saving USD 2.5 million.
- The open culture results in constructive cooperation with the partners in the joint venture, allowing the team to reach out and utilize knowledge from the partners.
- Work happiness is measured on a quarterly basis. The development from August 2018 to January 2019 revealed a 12 percent improvement on the happiness score and is considered to have had a direct impact on performance and appraisal among colleagues.

DISCUSSION

COMPARING CASE TO HOSHIN KANRI AND MEGA PROJECT LITERATURE

The results show that this offshore oil and gas mega project is staying within planned schedule and budget. The early project finish and early production start are forecasted to generate additional revenue. Compared with EY (2014), this is a big achievement, since the majority of the 205 analyzed oil and gas mega projects finished late and over budget. It is argued that success is mainly due to a high focus on three key elements: 1) a sustainable strategy, 2) bringing risks to the surface early, and 3) the cultural foundation of trust, necessary for using Hoshin Kanri. Wood and Munshi (1991) argue that the top-down approach combined with bottom-up planning leads to a sustainable plan. Further, Wood and Munshi (1991) argue that Hoshin Kanri implementation fails if cross-functional cooperation is not present. Finally, they argue that implementation fails if the "catchball process" is not handled across the departments and if planned activities are not integrated with budget cycle. The latter described yearly process outlines of how the leadership team and organization mitigated these procedural risks by assigning accountable departments and using the "catchball process" across the organization. But is a sustainable strategy enough for successful execution? Giordani da Silveira et al. (2017) argue that cultural resistance becomes a main challenge for implementation of Hoshin Kanri. Melander et al. (2016) argue that SMEs through Hoshin Kanri introduce trust in their organizations, as the employees are involved in translating objectives into actions. In this case, the "catchball process" became the translation of priorities into tangible targets throughout the teams in the organization. Tennant and Roberts (2001a) argue that cultural resistance can be reduced by involving the different levels of the organization in the strategy work, which has been a focus area for the case organization. Bruzelius et al. (2002) argue that transparency and performance specifications could improve accountability in mega projects and potentially lead to successful completion. The mega project case chose visual boards to openly share their performance measures, creating transparency and enabling proactive decision making. Flyvbjerg et al. (2003) argue that the accumulation of risks is what delays mega project. Thus, managing risks (identifying, tracking, and handling) has been a continuous effort throughout the case project. The case project used throughout the yearly, monthly, and weekly cycles, the PDCA understanding, and the Hoshin Kanri FAIR model as Tennant and Roberts (2001a) also describe. Maybe the results could have been achieved without usage of visual boards, but no previous example of this is available.

COMPARING CASE TO LEAN CONSTRUCTION LITERATURE

The Lean construction conference has through the years brought various perspectives on how to plan and control construction projects. The Last Planner System (LPS) by Ballard (2000) has had a large impact on the community and industry. The LPS method, which has similarities to PDCA, focuses on achieving healthy tasks and social interaction between the last planners in lookahead and weekly meetings. The lean community has recognized the importance of the lookahead and make-ready process for a stable workflow (Ebbs and and Pasquire 2018; Hamzeh et al. 2012). As the case project has a multiple-year duration, the yearly, monthly, and weekly meetings could be argued to have similarities with these making ready processes. But, as some of the case deliverables require more than a year of preparation, 6–8-week cycles would not be sufficient to make these ready. When talking lean construction community, the Location-Based Management System (LBMS) (Kenley and Seppänen 2010) would have to be taken into consideration as well. Seppänen et al. (2013) tested the LBMS ability to forecast activities in order to reduce risks and problem occurrence on construction sites. Similar to the Hoshin Kanri method, LBMS relies on actual progress to forecast outcomes. But where LBMS only looks at the project schedule, Hoshin Kanri forecasts on multiple levels. Kala et al. (2010) illustrated how 3D models and flowlines combined with commercial figures became an integrated 5D model for the foundations in a complex hospital project. The integrated 5D model elevates LBMS and develops the understanding of the project progress and status. Further research would be required to compare these in depth. The intentions of generating project flow and reduce the risks from variants are identical for LPS, LBMS, and Hoshin Kanri, but the focus of the methods are different, thus potentially working well together as already presented for LPS and LBMS in Seppänen et al. (2010).

IMPLICATIONS FOR THE CONSTRUCTION COMMUNITY

Kalsaas (2013) introduced LPS to the offshore oil and gas industry, with the intention of increasing constructability. This reveals that similarities could exist between the production systems of construction projects and oil and gas projects, which supports the argument that Hoshin Kanri has implications in the lean construction community and construction industry. Sanchez-Cazorla et al. (2016) argue that general risk categorization can be difficult due to the project complexities. Here the transparency that the Hoshin Kanri method generates could have the implication that allows its decision-makers to identify risks early, on multiple organizational levels. Other implications could be the combination of Hoshin Kanri along with other already known methods within the lean construction community, as it has been seen with takt, LPS, and LBMS in different contexts (Frandson et al. 2014; Seppänen et al. 2010). The authors propose that a hybrid or integrated solution might be applicable as proposed Olivieri et al. (2016) for integrating LBMS, LPS, and CPM. A hybrid could be argued to have Hoshin Kanri as the overall project management system, with LBMS for construction planning with LPS procedures to ensure healthy deliverables of milestones. Further research and development would be required to fully understand the potential for Hoshin Kanri as a strategic project management method for construction mega projects.

CONCLUSION

The case has illustrated the positive outcome of implementing Hoshin Kanri in a mega project in the offshore oil and gas industry. It was found crucial for the implementation and successful project progress that the culture was shaped through values and critical success factors. The culture further enabled flagging of potential risks and proactive decision-making, which led to risk reduction. The organization and meeting structure further enabled the continuous improvements and strategy processes. This paper sets an example of how Hoshin Kanri can be used in mega projects, but further examples are needed to fully understand its potential.

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QUALITATIVE ANALYSIS OF LEAN TOOLS IN THE CONSTRUCTION SECTOR IN COLOMBIA

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ABSTRACT

This descriptive research identifies the lean tools applied worldwide in the supply chain of housing construction recognizing which are the most common tools across different countries, the least explored and which tools have the most reception in Colombia.

Through a literary review of 84 academic papers from 22 countries, 254 mentions of 30 lean tools were detected, developing a qualitative content analysis from identified trends of the main differences and similarities in the adoption of lean construction (LC) in Colombia, Latin America and the different continents.

The results derived from a Pareto chart and an affinity analysis in which lean tools were reduced to 23 categories, show that the main practices of lean manufacturing and lean construction are Last Planner System, Building Information Models, Visual Management, among others.

This study is part of a subsequent project that will take the conclusions of this qualitative analysis to suggest a guiding tool (based on the continuous improvement tools found) that correlates applicable lean approaches with the main actors of the supply chain of high value housing projects in Bogotá.

Taking into account the research gap found, this study could serve as a basis for lean construction studies in countries similar to Colombia.

KEYWORDS

Affinity analysis, last planner system, lean construction, Pareto chart, visual management.

INTRODUCTION

The construction sector in Colombia has become, in recent years, in a considerable contributor to the country's income, thus actively contributing to the Colombian economy. Revista Dinero (2018) documented in one of its publications that the real estate and building market, after being one of the most affected industries during 2017, felt an

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improvement in 2018 due to the greater disposition of households to invest in real estate and the rebound of the offer, projecting the industry firm and constant, being one of the best in Latin America[4].

However, despite its importance in the national economy, this industry has the least technological progress and development at both a national and international level in comparison with other Latin American countries [5]. To reduce this disadvantage, methodologies focused on improving the planning and monitoring processes have been studied, offering tools with easier decision making, mitigation of risks and reduction of time and costs. Lean thinking tools help the efficient planning of activities in productive systems, such as construction, and the reduction or elimination of waste.

Porras, Sánchez and Galvis (2014) affirm that in Latin America the countries that show advances in the use and study of lean construction are Brazil, Chile, Peru and Colombia. Unlike United States and Europe, where lean construction is part of the curriculum in civil engineering related careers, in Colombia lean construction has been studied and practiced in private sector, while at universities there have not been advances on the subject. In Latin America, the country where LC is part of the civil engineering curriculum is Chile[6].

The above shows the academic gap exist between Colombia and European, Asian or North American countries and the scientific relevance of this type of researches. In fact, only about 6% of the sources consulted in this investigation are from Colombian and 37% are from Latin America.

At present, the lean implementations in Colombian construction companies are not widely known and nowadays most of these companies present problems due to non-compliance of real estate deliveries to clients. This evidences the need for the implementation of lean tools in construction to exercise control over the unnecessary factors that generate cost overruns, achieving savings in financial and administration costs, quality in the final product and greater profitability.

If we review the great acceptance that lean practices have had in the world and the proven cases of continuous improvement that have arisen with the implementation of lean thinking tools, and starting from the fact that lean construction is a philosophy that encompasses some approaches of lean thinking, that does not obey an order or a set of fixed rules to be implemented and that its application can be adapted according to the needs and objectives of each company and each project, it is worth reviewing the tools that can be implemented in the construction and check the applicability of lean construction in the supply chain of this sector.

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4 According to National Administrative Department of Statistics (DANE), the construction of buildings currently generates annual investments of \$ 77 billion and contributes \$ 46 billion to the national economy. However, the construction sector continues to contract despite the progressive economic recovery of the country (Revista Dinero, August 30, 2018).

5 A report from The Economist Newspaper assures South America in general has a low productivity for every hour worked in construction sector. Even so, the cases of Chile and Argentina stand out as two countries with low growth, while Colombia, Brazil and Mexico have regressed (World Economic Forum, October 25, 2018).

6 In Europe there are already construction companies implementing lean construction. At the Polytechnic University of Valencia there are 2 master's degrees that include the Lean Construction subject since 2012 (El Constructor Newspaper, October 27, 2017).

Taking the problem described above, this paper develops a review of the literature to examine the existing knowledge about lean approaches implemented and their characteristics in the construction industry. As a result, a theoretical framework is proposed playing a decisive role in the formulation of a global guiding tool that adapts to the supply chain of high value housing projects in Bogotá (understood as a guiding tool to the set of the different selected lean thinking tools that apply to the chain), and which will be the basis for further research studies such as the implementation and evaluation of that methodology or the creation of others.

COLOMBIAN CONTEXT

As mentioned by Araque et al., (2017), civil construction sector in Colombia is one of the main development axes for multiple families linked to this industry, representing an important national economic proportion. However, the characteristics of the workers and the working conditions of the sector have demonstrated the need for continuous improvement and evolution in search of formalization and technification of the associated activities[7].

The conventional system in Colombia to plan and execute construction works differs from lean thinking, that is, there are currently few companies that implement this work philosophy (Rojas, et al., 2017).

According to a document issued by Revista Dinero (2018), a good future is predicted for this economic sphere in Colombia because of the positive change in the building activity thanks to the development in terms of access to housing and non-residential and industrial construction, among others. The progress of the sector has had satisfactory effects in terms of economy, generation of employment and reduction of the housing deficit.

In Colombia, unfortunately, most constructions regardless the type are carried out with poor planning, due to incomplete designs, imprecise budgets, disarticulated schedules, non-assertive communication among the different parties involved, absence of internal coordination, confusing instructions, weaknesses in business philosophy, lack of supervision, etc., that in most cases leads to an increase in costs and delays in the different construction activities.

Additionally, most traditional construction processes are carried out manually, which means that the productivity of each process depends mainly on the organization of the activities and the performance and experience of each worker, making the "productivity" into a critical point.

The Colombian Association of Systems Engineers (ASIS), on its website (2019), affirms lean construction acts on construction companies, in each process, adjusting deadlines, resulting in more quality, and ensuring deliveries without delay. Colombian construction companies must adopt lean because in a crisis scenario in the region, with scarce financial resources, only companies that apply this philosophy will be able to

[7] Construction is, worldwide, the industry with the least amount of increase in productivity in last 20 years. While manufacturing grew its added value by 3.6% and the world economy made it 2.8%, construction only did so at 1% (World Economic Forum, October 25, 2018).

produce more and better using the same resources. Regarding compliance with deadlines, today the construction companies can not delay more, because it has a direct impact on the utility of the project, and it would cause fines and sanctions.

Research on lean construction in Colombia began in 2002 (Botero and Álvarez, 2004), where the tools Value Stream Mapping (VSM), Last Planner System (LPS), Kanban, Building Information Modeling (BIM), 5S, Pull Planning System (PPS), Just in Time (JIT), Jidoka, Kaizen, among others, have been adopted. According to Pons (2014), techniques from the automotive sector such as concurrent engineering, value engineering, benchmarking and balance lines have been incorporated quickly to manage the integration of information with production cycles.

However, tools as such are not everything. From another point of view Hackler (2017) exposes the importance of building a lean culture in organizations and selecting teams that really want to adopt lean, because accelerating the understanding and implementation of lean in a company is based on change management. Also the lean team requires the support of management at all levels from training the workers on practical tools to educating them on the lean principles as a general way to execute their projects.

RESEARCH METHOD

As a first instance, the state of the art of lean construction and some lean thinking tools used worldwide in the housing construction sector were reviewed, finding that there are different practices, including own ones, that have been developed in this sector to meet the needs of this industry.

Subsequently, the selected articles were classified reviewing whether they mentioned the implementation of a lean tool in a success case; in addition, the author or authors were taken into account, the country in which it was developed and the year of publication.

Consecutively after this classification, the results were recorded in a database and the affinity analysis was generated and then the Pareto chart.

To describe the system, the Mayring methodology (2014) entitled Qualitative Content Analysis was used[8], starting with the selection of the object of analysis, the linking of the research question with the theory; the development of the pre-analysis through the bibliographic consultation of experts, identifying the lean tools used in the construction field; the definition of the sample and the method of data analysis by means of an affinity and Pareto analysis; and the analysis of the coherence of the study carried out.

SEARCH FOR EXPERTS

Based on the referential framework, which allowed dimensioning the variety of existing concepts related to lean construction, a search of sources related to this topic was made in order to know which lean tools are used in this sector.

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[8] The central idea of qualitative content analysis is to start from the methodological basis of quantitative content analysis but conceptualizing the process of assigning categories as a qualitative-interpretative act following content analytical rules. In this sense, qualitative content analysis is a mixed methods approach: assignment of categories as a qualitative step and analysis of the frequencies of categories as a quantitative step.

This consultation provided the necessary information to recognize the particular conditions that the system to study can have and the environment in which it is immersed, also defining the primary guidelines for classification of the tools, as well as finding a large number of lean tools common to several authors about the focus of study.

Knowledge gathering was done taking secondary sources of information from experts, understood them as the authors who document information on the factors directly or indirectly related to this problem, that is, their publications and opinions, expressed mainly in research articles, by national and international authors.

84 documents between nationals and foreigners were consulted, majority of them were published on the website of the International Group for Lean Construction (IGLC) in the last five years (in this article only 23 references are presented). This database presents a complete collection of lean construction publications, so this was the main reason to select it as the prevailing source for this research. From these documents, a total of 254 mentions of lean thinking and lean construction tools were obtained, which were categorized by means of affinity in 23 selected causes according to relevance and being the most named by the experts.

The nationality of these authors is concentrated in twenty-two countries as shown in table 1. However, the most representative countries are Germany (Dlouhy, et al., 2017), Brazil (Franco and Picchi, 2016), Chile (Salvatierra, et al., 2015; Matta, et al., 2018), United States (Smith and Ngo, 2017; Alves, Azambuja and Arnous, 2016), India (Patel, Karia and Pandit, 2018), England (Tezel, et al., 2016) and Norway (Torp, Knudsen and Ronneberg, 2018). Other authors consulted came from Australia (Shou, et al., 2017), Ecuador (Martínes, Tommelein and Alvear, 2017), Estonia (Leonova, Ballard and Gehbauer, 2017), Finland (Singh, 2018), Ireland (Kemmer, et al., 2016), Lebanon (Hatoum, et al., 2018), Morocco (Hicham, Taoufiq and Aziz, 2016), Mexico (Dlouhy, et al., 2018), New Zealand (Hunt and Gonzalez, 2018), Netherlands (Vrijhoef, Dijkstra and Koutamanis, 2018), Peru (Murguía, Brioso and Pimentel, 2016), Palestine (Enshassi and Abu Zaiter, 2014), South Africa (Monyane, Emuze and Crafford, 2018) and Pakistan (Memon, et al., 2018).

Table 1. Characteristics of the experts consulted by geographic context

Country	Number of experts from the country	Percentage of experts
Germany	5	5,95%
Australia	1	1,19%
Brazil	15	17,86%
Chile	9	10,71%
Colombia	5	5,95%
Ecuador	1	1,19%
United States	12	14,29%
Estonia	1	1,19%
Finland	1	1,19%
India	7	8,33%
England	5	5,95%
Ireland	1	1,19%
Lebanon	4	4,76%
Morocco	1	1,19%

Mexico	1	1,19%
Norway	8	9,52%
New Zealand	1	1,19%
Netherlands	1	1,19%
Pakistan	1	1,19%
Palestine	1	1,19%
Peru	1	1,19%
South Africa	2	2,38%
Total	**84**	**100%**

Nearly 6% of the authors consulted are Colombians (Forero, et al., 2015, Mejía, et al., 2016, Cortés, et al., 2018, Porras, Sánchez and Galvis, 2014, Guevara, et al., 2011). Of the remaining experts consulted, 31% are from Latin American countries, 26% are European, 61% North American, 15% Asian, 4% come from African countries and the remaining 2% are from Oceania. This variety allows a greater proximity to the landscape of lean construction developed in Colombia and surrounding countries. Figure 1 shows a description of the nationality of the authors consulted.

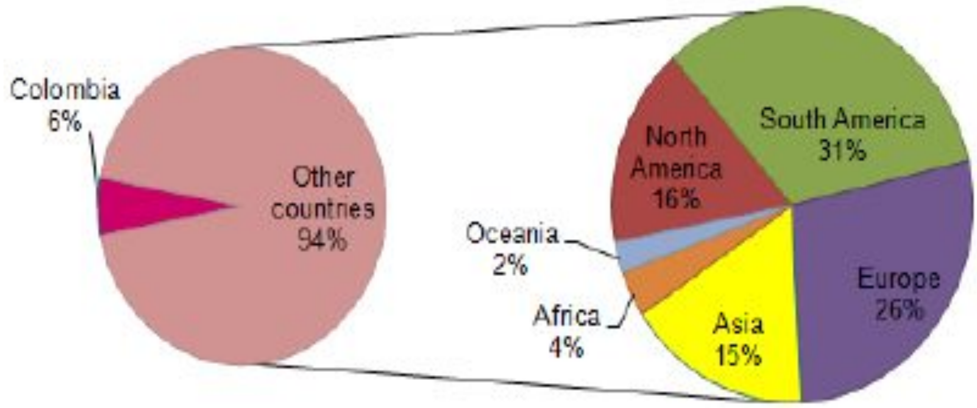

Figure 1. Nationality of the authors

Regarding the age of the documents reviewed, Table 2 shows that more than 97% of the information was prepared less than five years ago, and that was an aspect of interest in the search given that the objective is to review the current trends in lean construction. However, two articles presented at IGLC conferences, prepared in 2011 and 2013, of Colombian and Brazilian origin respectively, were reviewed because there are not many Colombian papers presented in IGLC and all those from Colombia that could provide information of interest to this investigation were reviewed.

Table 2. Characteristics of the sources by nationality and age of the publication

Characteristic	Total	Percentage
Colombian authors	5	5,95%
Foreign authors	79	94,05%
Sources of up to 5 years	82	97,62%
Sources over 5 years	2	2,38%

AFFINITY ANALYSIS

After reviewing and consolidating the 30 lean tools, the affinity analysis was carried out, by means of which these tools were classified into 23 categories, seeking to concentrate in the same group those that had similarities or that some authors expressed that they were related to others (see Table 3).

For example, according to the Lean Construction Institute (LCI) (2017), Building Information Modeling (BIM) is a useful tool for the process of generation and management of data during the life cycle of a project (building) that includes geometry of construction, spatial relations, geographic information, quantities and properties of building components, among others. But taking into account that BIM uses a three-dimensional dynamic building modeling software (3D) and that can also include four-dimensional (4D) simulations to see how part or all of the installation is designed to be built and the 5D capacity for estimation based on models, in this category the BIM and 4D BIM tools mentioned separately by some authors were included (See Table 3).

Table 3. Proposed affinity of lean tools

Initial category	Fine-tuned lean tool
Building Information models (BIM) 4D Building Information Modeling (BIM)	Building Information models (BIM)
Choosing by Advantages (CBA) Best Value Procurement (BVP)	Choosing by Advantages (CBA)
Waste walk Gemba	Gemba walk
Value Stream Mapping (VSM) Overall Process Analysis (OPA)	Value Stream Mapping (VSM)
Visual Management Poka Yoke Customization choice board Display boards	Visual Management (VM)
Chrono-analysis Work Sampling (WS)	Work Sampling (WS)

In the same way, the resulting category Choosing by Advantages (CBA) groups the Choosing by Advantages (CBA) and Best Value Procurement (BVP) tools. According to LCI glossary (2017), CBA is a solid, proven and effective decision-making system developed by Jim Suhr in 1999 to determine the best decision when analyzing the benefits of each option. Regarding the Best Value Procurement (BVP), Narmo, Wondimu and Laedre (2018) state that it is a procurement system created in 1992 that analyzes factors other than price, such as quality and experience, when selecting suppliers or contractors. This method was developed in the United States and is one of the ways to award contracts based on qualification instead of the price.

On the other hand, as stated by the LCI (2017), Gemba is a Japanese term for "real place", which is often used for the workshop or any place where a work of value creation actually takes place. The lean experts refer to "going to the gemba" or doing a "gemba walk" to make walks in the workplace and see how things really are done and where there is an opportunity to eliminate or reduce waste. Similarly, other authors such as Beck da

Silva Etges, Bronzatto and Salgado (2018) refer to the same concept with the term "waste walk", so for purposes of this work are grouped in the category "gemba walk".

In Lean Lexicon (2008), the Value Stream Mapping is a simple diagram of each step involved in the flows of material and information necessary to carry a product from the order to the delivery in the current conditions. In the study by Theis, Tommelein and Emdanat (2017) the General Process Analysis (OPA) refers to a one-time analysis that aims to identify the different areas of work and define the steps of the process and the sequence of operations in each area. Since these two tools have the same purpose, they are grouped in the same category in this research.

As mentioned by the Lean Enterprise Institute (2008), Visual Management refers to the location at a glance of all the tools, parts, production activities and performance indicators of the production system, so the state of the system can be understood at a glance by all the parties involved. Reviewing the consulted publications, several authors mention different visual management tools such as Poka Yoke, visualization boards and personalization tools to name some visual management tools implemented in different contexts, which based on their nature, can be categorized into a single tool: Visual Management.

Finally Etges, Pereira and Silveira (2018) mention “Chrono Analysis” as a tool that consists of an uninterrupted time of filming during a long period (minimum of 4 hours) to observe the level of added value in complete cycles of activities. On the other hand Pothen and Ramalingam (2018) mention the “Work sampling” that consists of a series of instantaneous observations of the work in progress that are taken at random over a period of time to measure productivity. This method provides information on the amount of time that workers spend doing productive, supportive and non-productive work. Therefore, they are grouped into a category called "Work sampling".

PARETO ANALYSIS

The Pareto analysis consists in organizing the lean tools in a descending manner depending on the frequency of mention by the experts consulted. By ordering each of the 23 categories according to the number of appearances, the relative frequency was calculated against the total of 254 records and the accumulated frequency. Table 4 shows the ordering and the tools enunciated by the authors.

Table 4. Lean tools most named by the experts

Fine-tuned lean tool	**Frequency**	**Accumulated frequency**	**% total**	**% total accumulated**
Last Planner® System (LPS)	46	46	18,11%	18,11%
Building Information Models (BIM)	41	87	16,14%	34,25%
Visual management (VM)	26	113	10,24%	44,49%
Value Stream Mapping (VSM)	17	130	6,69%	51,18%
Target Value Design (TVD)	16	146	6,30%	57,48%
5S	16	162	6,30%	63,78%
Integrated Project Delivery (IPD)	14	176	5,51%	69,29%
Choosing by Advantages (CBA)	13	189	5,12%	74,41%
Kanban	12	201	4,72%	79,13%
Takt Planning and Takt Control (TPTC)	8	209	3,15%	82,28%
A3 report	8	217	3,15%	85,43%

Andon	5	222	1,97%	87,40%
Set-Based Design (SBD)	5	227	1,97%	89,37%
Gemba walk	5	232	1,97%	91,34%
Just in Time (JIT)	4	236	1,57%	92,91%
Heijunka	4	240	1,57%	94,49%
Work Sampling (WS)	4	244	1,57%	96,06%
RFID	2	246	0,79%	96,85%
5 Whys	2	248	0,79%	97,64%
Jidoka	2	250	0,79%	98,43%
Value Engineering	2	252	0,79%	99,21%
Modelo Means - End	1	253	0,39%	99,61%
SMED	1	254	0,39%	100,00%
Total	**254**			

With this analysis it can be seen that the nine lean tools that represent 80% of all tools are Last Planner System®, Building Information Models, Visual Management, Value Stream Mapping, Target Value Design, 5S, Integrated Project Delivery, Choosing by Advantages and Kanban, adding 201 mentions of the total 254.

In Figure 2 the Pareto chart is presented with the ordered categories of Table 4 on the horizontal axis and the absolute and relative frequencies on the vertical axes, the trend line shows the accumulation of the opinions given by the experts.

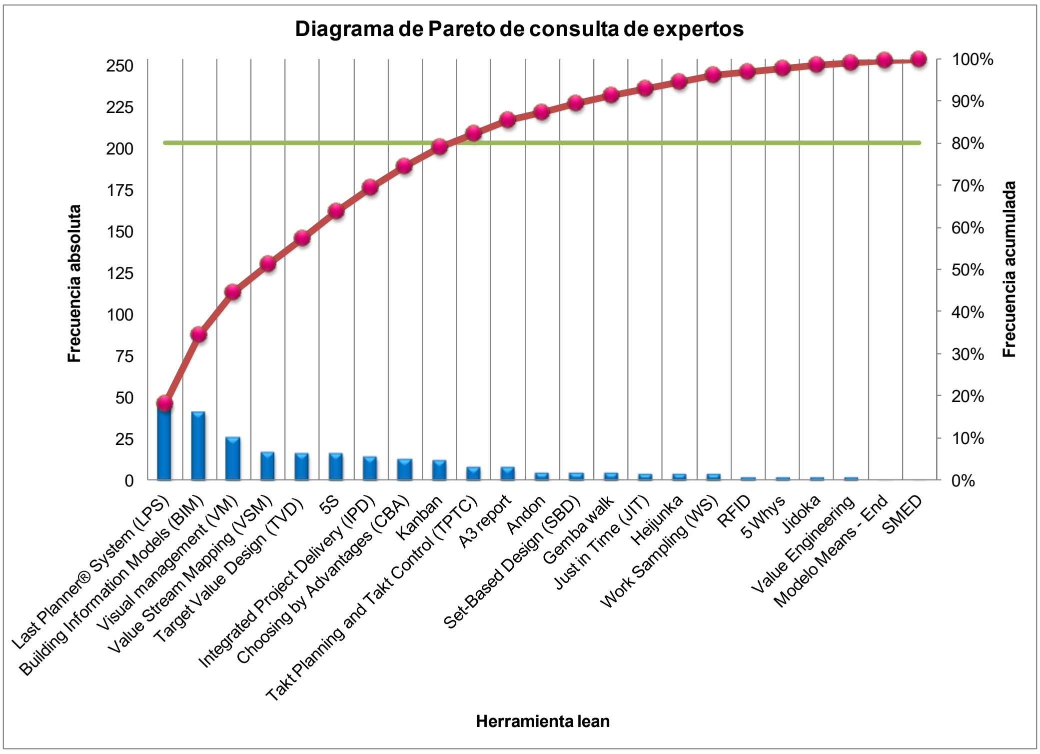

Figure 2. Pareto chart.

All these lean tools must be taken into account when proposing the global tool of lean construction in construction of housing in Colombia, because it has been evidenced, by experience in the sector, not even the basic tools such as 5 Whys, 5S, A3 report, Heijunka, are well implemented or even have a minimal idea of how to practice them.

It is worth mentioning that the Last Planner System requires a certain level of lean understanding in order to be properly implemented, especially since multiple stakeholders are involved in this method. Considering that in Colombia the level of understanding and application of lean construction is not very widespread, it is important to start with an organizational change management and continuous training that implies the introduction of basic lean methods which would be a good start with raising lean awareness and pave the way to adopt the findings of this paper, specifically, the last planner system as a global guiding tool to resolve the gap addressed.

CONCLUSIONS

Lean construction is an application of lean thinking. It requires a change of philosophy in the construction companies and in the relation with suppliers and clients for the tools to be effective. Additionally it needs a change of culture and strong commitment from all stakeholders at medium term for the assimilation and application of the concept.

Hence, lean construction should not be conceived as a model or system in which only a few steps are followed, but as a thought aimed at the creation of tools that generate value for the activities, phases and stages of construction projects.

Although lean construction reduces operating costs, increases economic benefits, reduces material waste and improves the productivity and quality of life of people working in the construction industry, in Colombia the use of this tool has not taken off properly, remaining in practices developed in single projects on an experimental basis without any transcendence or reproducibility of its results.

Conventional construction in Colombia differs from lean thinking in the planning and execution of civil works, with only a few companies implementing this philosophy of work due to the industry still settles on many craft processes with a high level of inefficiency.

In Latin America, Brazil and Chile are the countries that have excelled in the development of advanced technologies to improve productivity in the construction sector. Of the 84 studies reviewed, only 6% are of Colombian origin and 37% of the total of authors is from Latin American. Lean construction represents an opportunity for the sector to take advantage of the benefits that have been evident in other countries.

The Last Planner System® is the most used lean tool for the planning of works through the use of balance lines as a tool for visualizing the master plan and weekly meetings and daily walks. It is convenient to review the functionality and use of other tools in order to obtain improvements in the construction processes.

To stay in the market, construction companies must improve the organization of their processes, maximizing value and reducing waste through the application of lean construction. Companies are realizing the importance of incorporating this philosophy in organizations, guiding the purchase of software and looking for management systems that already have the methodology incorporated.

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AN ACTIVE CARING APPROACH THROUGH PSYCHOLOGICAL SAFETY IN CONSTRUCTION PROJECTS

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ABSTRACT

Guided by the lean principle of respect for people, it is key to recognize the value of construction workers feeling psychologically safe on site. Psychological safety is proven to be a driver for learning behaviors as it allows workers feel confident about asking questions to get clarity on their work, asking for help, or speaking up when errors occur on site to avoid repeating mistakes. The authors framed the understanding of psychological safety in the context of a construction project and analyzed worker's perception regarding factors that foster a psychologically safe work environment. In this study, different trades shared their perception about factors that made them feel safe or unsafe while working at the job site. Outcomes highlighted human behavior characteristics such as how the willingness of workers to speak up when they see someone doing something unsafe changed depending on whom they are talking to. Results were analyzed with the project's leadership team and action items were set in place. Changes implemented included using English and Spanish during weekly meetings and the establishment of an on-site safety committee to strength relations between and amongst different trades as well as discussion with foremen to keep growing psychological safety on site.

KEYWORDS

Psychological safety, behavior, active caring, learning, safe, sustainable change.

INTRODUCTION

Since the concept of psychological safety was introduced, many researchers have analyzed its correlation and outcomes in different industries such as healthcare (Kessel et al. 2012; Turner and Harder 2018), manufacturing (Lee et al. 2011 and Edmondson 1999), technology (Bergmann and Schaeppi 2016), etc. However, the applicability of the concept in the construction industry is still an on-going development. Howell et al. (2017) showed the relationship between the lean principle "respect for people" and psychological safety. In parallel, many studies have been developed to predict safety outcomes on construction projects considering factors such as safety risks of trades or tasks (Esmaeili and Hallowell 2013), attribute-based risks (Esmaeili et al. 2015), and number of employees (Camino Lopez et al.

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2008; Hinze and Gambatese 2003). Nevertheless, apart from Howell et al. (2017), little consideration has been given to psychological safety. Some efforts that partially overlap with psychological safety have been done to analyze safety from the psychological side such as behavior-based safety (Lin et al. 2015; Choudhry 2014) and safety climate (Newaz et al. 2018; Fang et al. 2006; Hon et al. 2014; Mohamed 2002; Glendon and Litherland 2001; Johnson 2007). However, in isolation those prediction models do not seem to be a sustainable solution since rates for safety incidents do not reflect a significant improvement. Even though the predicted correlations may be there, failure to improve safety performance may have resulted from not adequately acting on the driving factors. According to the Bureau of Labor Statistics (BLS 2018), more than 20% of worker fatalities in private industry in 2017 were in construction. In response to the need to find a sustainable solution that deals with upstream behaviors, we referred to Newman et al. (2017) who expanded on the benefits that psychological safety brings to organizations in different levels, the situations in which it is most influential, and the factors that may lead to its development. Kahn (1990 p.708) defined psychological safety as “feeling able to show and employ one's self without fear of negative consequences to self-image, status, or career,” which means that in a safe work environment, individuals can be comfortable being themselves and they will not be afraid to admit an error because they expect to receive help, not harm from confessing. Later, Edmondson (1999 p.350) defined psychological safety as “a shared belief that the team is safe for interpersonal risk-taking” with the expectation that individuals will mutually respect each other and not get embarrassed, rejected or punished for speaking up. Nembhard and Edmondson (2006) suggested that when individuals feel psychologically safe, they speak up freely and are not constrained by others’ disapproval or negative responses. For this study, psychological safety can be seen as a mood, and like all moods, it is based on assessments of the future. When grounded (e.g., construction workers hide errors because they fear punishment, ranging from being fired to being made fun of), the only way to change their mood is to remove the reason for their fear. They might be afraid because that is what has happened on previous projects, in which case demonstrating that speaking up does not bring punishment can change their mood of psychological safety. Studies have documented the usefulness of constructing a psychological safe environment that is a necessary foundation for trust and for establishing a learning culture. Particularly in hazardous situations, psychological safety is critical because people speak more freely about their concerns, provide feedback on the processes they are executing, and reduce potential errors (Newman et al. 2017).

Psychological safety greatly influences people’s behavior, consequently, a lack of psychological safety can cause people to feel intimidated or reluctant to ask for help or be unwilling to raise concerns or ask questions for fear of a sanction (Edmondson 1999). Common fears from workers tend to be related to damaging their reputation or putting at risk any potential promotions or raises (Edmondson 1999). Some of the same fears are shared by construction workers. The authors found common factors that help workers feel safe or unsafe in the field. Behaviorally, psychological safety allows workers to raise their concerns, ask for help, and increase their sense of belonging on a team (Pearsall and Ellis 2011). In construction, field workers directly add value to the process at the front-end of operations; therefore, creating a psychological safe work environment where they can actively participate asking questions or giving suggestions during operations design fosters ownership of their work and increases the sense of responsibility for the outcomes. To improve project performance, Wu et al. (2017), Hardison et al. (2014) and Stiles et al. (2018) identified some practices that generate leadership behaviors such as individualized consideration, inspirational motivation, innovative changes and meeting employees’ emotional appeal to improve site safety. Edmondson (1999) stated that a psychologically safe environment can be fostered by a supportive coaching-oriented leader. Leaders can co-create an environment under certain conditions that modify team beliefs and therefore team behaviors in the pursuit of increasing team performance. Also, Hardison et al. (2014) listed other practices that build leadership behaviors for site supervisors such as establishing effective communication and positive leader–member exchanges. Some of these practices were used to implement changes and foster psychological safety in the project site studied.

RESEARCH DESIGN

As the authors were actively engaged in the research group and the effort to build psychological safety in the project under study, the paper is written as the first intervention of a larger action research cycle. Somekh (2005) suggested action research as a proper research method for a study that involves successive actions in a cycle of testing and improving. Similarly, Lewin (1946) emphasized the fact that action research allows practitioners to test if certain action result in improvements. The authors intervened and documented a project specific case where the project team aimed to build psychological safety for field workers through the implementation of certain actions.

The plan of each iteration in the action research process includes: i) an initial assessment of the current state, ii) discussion on action items to mitigate any deviation from what is described as a psychologically safe environment, and iii) testing whether such intervention brings the desired outcomes and adjusting the plan as needed for another intervention. First, the first author conducted observations on site that involved attending site orientations for new employees, daily safety meetings, coordination meetings, and all hands weekly meetings. Second, the authors designed and administered an extensive questionnaire to obtain quantitative and qualitative information from the workers regarding the current state of psychological safety in the project. Third, a discussion session with the project leaders and the research team was developed to decide on action items based on outcomes from the observations, the administered survey, and conversations with workers in the field. The research also investigates the different beliefs or perspectives from workers on a construction site regarding their role and their supervisor's role in creating a safe site. The authors reduced risks of social reactivity such as the Hawthorne Effect that suggests that causal factors can be caused for the fact of being studied (Colman 2015) by explaining the field workers and their leaders the reasoning behind the study and the benefits expected from their collaboration. A level of trust among the researchers and the study participants was established through continuous interaction on the field. Survey findings indicated substantial room for improvement in certain areas which supported by suggestions from experienced people in the field gave the study the level of accuracy needed to create a baseline which will be used in later studies.

PROJECT DESCRIPTION

The project under study is a 12-story concrete building with a structural steel penthouse and a total area of 359,703 square foot. This building will be the Center for Neurovision Science Building of the University of California, San Francisco - Mission Bay Campus. Webcor Builders is the general contractor in the project, leading the effort to foster psychological safety. At the time this study was documented, the phases of the project under construction were superstructure build out and interior rough in.

DATA COLLECTION

The instrument used for data collection was a survey distributed to 100 craft workers. No personal information about respondents was included in records. There was a response rate of 64% to the first survey. 25% of the responses were from the general contractor self-perform work groups and 75% were from the subcontractors' workers.

Procedure

The survey questionnaires were distributed and collected personally by the first author. There was a series of one-on-one conversations with each worker to make sure they understood the study purpose and to make them feel safe to answer questions truthfully.

Data collection lasted for over two weeks, and the respondents completed the surveys during regular working hours. The questionnaire included 18 questions[6], some of the statements asked the participants whether they agreed with each statement and to what degree, while others were open-ended questions such as “what makes you feel safe or unsafe on site?” Statements graded by participants had a 7-point Likert-type scale (1 = strongly disagree, 7 = strongly agree). Among the questions, reverse-scored questions were included to verify that workers were reading the questions carefully and answering the survey honestly. A reverse question example is “If I make a mistake, my co-workers do/do not teach me how to avoid making that same mistake again.”

Participants

Workers from different trades participated in the study. Table 1 summarizes the number of participants who submitted their responses per trade.

Table 15: Study Participants per Trade

Trade	Number of Participants	Trade	Number of Participants
Carpenter	9	Iron Worker	4
Labor	9	Water Proofing	4
Drywall	12	Plumbing	9
Roofing	6	Electrical	6
Fire Sprinkler	3	NA: Not specified	2

RESEARCH FINDINGS AND DISCUSSION

CARING ABOUT EACH OTHER - AN ACTIVE APPROACH

It tends to be an intrinsic belief that people speak up whenever they see someone in dangerous conditions and prevent potential accidents on site. However, the study results show that there are certain conditions in which people are more willing to speak up than in others. One of the statements included in the questionnaire stated: “If I see someone on my crew doing something unsafe, I speak up.” 43 of the 64 respondents said they Strongly Agree with this statement, but only 24 did so when asked if they would speak up “If I see someone on another crew doing something unsafe, I speak up.” Fewer were willing to warn people from other trades even though they might be as much at risk of injury. Also, two other statements were related to showing an active approach on site (see Table 2). Both statements positively show that craft workers in the project tend to feel that they have the support of their co-workers from the same crew to correct work and they are also satisfied with the commitment to work safely on the project site.

Table 16: Statements Related to Caring About Each Other and Participant's Answers

Statement	Rate (1: Strongly Disagree / 7: Strongly Agree)						
	1	2	3	4	5	6	7
If I see someone on my crew doing something unsafe, I speak up	0	0	0	0	5	16	43
If I see someone on another crew doing something unsafe, I speak up	1	0	1	1	17	20	24
If I make a mistake, my co-workers in the crew help me learn how to do the work correctly	0	2	0	2	3	31	25
I am satisfied that there really is a commitment to a safe work environment where I am now working.	0	0	0	0	4	25	33

SUPERVISORS: ROLE MODEL FOR SAFETY

In the study, questions about whether workers' supervisors acting as a role model who commits to safety have an average rating of 6.0 point between the 4 statements (Table 3), meaning that leaders are overall trying to create a safe culture in the project through role modeling, which resonates with the field observations from the first author.

Table 17: Statements Related to the Worker's Perception About Supervisors

Statement	Rate (1: Strongly Disagree / 7: Strongly Agree)						
	1	2	3	4	5	6	7
My direct supervisor is a good role model for safety	1	4	0	1	6	19	33
My direct supervisor is understanding and helpful when I make a mistake at work	3	1	1	0	8	32	19
My direct supervisor is willing to listen to my ideas for improving how work is done	0	3	1	4	8	27	21
I feel comfortable talking to my direct supervisor about my safety concerns at work	0	2	0	0	10	22	30

However, it is worth noting that the first two statements in Table 3 have a few low-rated responses, e.g. five participants indicating that they Strongly Disagree or Disagree with "My direct supervisor is understanding and helpful when I make a mistake at work." Results suggest that an area for improvement for the team is working towards building confidence that supervisors are a useful and helpful resource for facilitating information, solutions, and help when problems arise. For instance, previous studies have shown such correlation, e.g. Edmondson (1999) and Roberto (2002) analyzed the role of the team leader in supporting and coaching the employees to build a safe work environment. Also, Grill and Nielsen (2019) found that site managers see their function as role models for behaviors of field workers at the sites and Hardison et al. (2014) analyzed the safety competencies that are most important for construction supervisor leadership.

CREATING A SAFE ENVIRONMENT – EXPECTED BEHAVIORS IN HOUSE

To improve psychological safety on site, the research team and the leaders of the project discussed action items that were to be implemented on site based on the survey outcomes and observations on the field.

Foster or Increase Safe Conditions and Behaviors

To get a better understanding of the different factors affecting field workers comfort and sense of confidence, a couple of open-ended question were included in the survey. The first question asked "What make you feel safe on site?" and the second one asked "What would help you feel safe to speak up – to raise concerns, to ask questions, to feel confident that if you make a mistake, you get help, not punishment." Responses varied as people's motivations differ from each other. For example, for the second open-ended question, a worker from one crew said, "getting a signed paper that says I won't be fired for making a mistake"; however, another worker explained for the first open-ended questions that "seeing a clean place whenever I move to another zone" would make him feel safe. Responses for both open-ended questions were categorized in common groups such as communication, safety manager, clean place, etc. To facilitate visualization of the different responses, the authors used a word clouds (see Fig. 1 for open-ended questions 1 "What make you feel safe on site?") to show which factors had more impact than others by analyzing which answers were more repetitive in participants' responses.

Figure 40: Word Cloud with Factors That Make Workers Feel Safe

Based on this analysis, some ideas were discussed with the project team and later implemented on site to foster a psychologically safe work environment for craft workers:

Errors as Opportunities for Learning not to Fear: Carmeli and Gittell (2009) suggested that when individuals feel respected and confident that they will not be blamed, ridiculed, or punished, people are more likely to speak up, admit errors, look for help and learn. Employees' personal beliefs grounded in psychological safety help workers to have better communication among each other and admit errors without fear (Newman et al. 2017). On site, there was an effort to let the workers know that no one is perfect and free of mistakes, but each member of the team was expected to commit with continuous improvement and their feedback was needed to do a better and safer job as a team. Also, the project team rewarded workers to speak up with a practical campaign of giving free lunches to workers who showed learning behaviors by sharing their ideas, concerns or requests either with their supervisors or submitting them to the suggestions box located in the field. Also, the project implemented a "Doing it Right" campaign in which it recognizes workers for their behaviors, sharing ideas, concerns, or requests. This is directly supported by day to day conversations, having suggestion boxes on the job, and sharing team's information such as cell phone numbers on their hardhats so every worker can reach out for help, suggestions or requests to improve the site.

Focus on Learning Behaviors: A psychologically safe workplace allows innovation to occur, and it provides opportunities to learn from others' errors and to correct and address common mistakes (Guchait et al. 2014). Another statement included in the questionnaire was "I'm always learning new skills working with this crew," the average rating was 6.4 points with 31 respondents saying they Strongly Agree, which showed that there was a sense among workers that they were actually learning from their peers and it made them feel safe. Many authors suggested that psychological safety is linked to greater knowledge sharing (Newman et al. 2017; Siemsen et al. 2009). Also, Wilkens and London (2006), Liu et al. (2014), Ortega et al. (2010), and Roberto (2002) established positive links between psychological safety and learning behaviors. According to Edmondson (1999), learning behaviors include seeking feedback, sharing information, asking for help, talking about errors, and experimenting. On this project, the team has tried to overcome the problem of reoccurring mistakes that put workers in hazardous situations by implementing a near miss reporting tool. The reporting and sharing of near misses have helped the workers feel free to speak up and has given everyone a chance to learn from others. Near misses are discussed during plan of the day meetings, posted in the workers' lunch area, and shared across the company to bring awareness of dangerous conditions or behaviors. Similarly, with the spirit of knowledge sharing, the team captured key examples that were developed in the project using prevention through design methods and share them as success stories with the workers in order to encourage knowledge sharing and innovation. Such examples were included in the on-boarding presentation that the safety manager of the project uses during introductions to the project. The team pursued to create a project learning environment where operations are designed for a safe execution.

Increasing Familiarity Among Groups: Sanna and Shotland (1990) described the direct impact of audience or other work groups in the performance of an individual and Edmondson (1999) suggested that by increasing the level of familiarity among teams we might potentially lower interpersonal threats and encourage people to ask for help, admit errors and discuss problems. Moreover, Roberto (2002) highlighted that prior interaction or familiarity among team members is a key driver of psychological safety. Some thoughts had been discussed in the project to encourage workers to get together such as integration events or gather together meetings. A couple of ideas that had been implemented after the survey was done are explained below in greater detail.

English and Spanish in All Hands Weekly Meetings: In order to improve communication on site, the project team decided to use both languages to make sure that the messages were delivered in a way that all workers can understand expectations and instructions and feel free to communicate it in the same way. Given the high percentage of craft workers for whom Spanish is their first language, it was worth it to convey the most important messages to the field in both English and Spanish.

An Active Safety Committee: To build psychological safety on site, the project team decided to create certain routines to systematically increase strength and cohesiveness on the team. Newman et al. (2017) suggested that psychological safety is more potent and meaningful at the team level. A safety committee was established as a grassroots-level organization led by a project engineer from the GC. The safety committee was composed of one member from each of the trades; with different level of experience, from apprentice to foreman. It serves as a community platform that strives to change the safety culture from within. Leadership, or a purposeful lack thereof, played a key role in the success of the committee. The committee's purpose was not to push a single agenda but to empower each committee member to look out for one another. The project engineer's role was to set up the meetings, identify the locations and area of focus, and start the conversation. The project team, followed the example of the Leader Standard Work that originated with Toyota, which includes routine activities intended to promote psychological safety and to develop learning behaviors—centered around periodic job walks between supervisor and supervised (Poksinska et al. 2013). Monthly safety walks and weekly check-ins were held with the committee. The purpose of the walks was to identify things that are going well, things that need to be improved, and a way to track progress from the previous months. Cross-pollination of trade's knowledge and experiences also played a key role in breaking barriers and frustrations within trades, and to develop trust with each member of the committee. Once trust was built within the committee, the team focused on building trust with the rest of the field crews. To do so the committee emphasized anonymous reporting and no repercussions on individuals who brought up issues. Once trust was built in the field, safety concerns started to surface that were not brought up before, giving the committee the opportunity to address the new concerns.

Mitigate or Reduce Unsafe Conditions and Behaviors

Argyris (1982) said that when people face the potential for threat or embarrassment, their learning is inhibited. In construction for example, site managers tend to suffer from time pressure which affects their behaviors and normal performance on site. The survey included another question to identify which factors make workers feel unsafe on site. Responses are summarized in a word cloud below (Fig. 2). Also, some means to mitigate factors making workers feel unsafe are discussed.

Figure 41: Word cloud With Factors That Make Workers Feel Unsafe

People's Behavior – Errors as Opportunities for Learning not to Fear: Carmeli and Gittell (2009) highlighted that errors tend to provoke fear, but they are also a rich opportunity to learn. Edmondson (1999) also suggested that there are two conditions that compel workers to feel more motivated to speak up: i) if they believe they will not be rejected, and ii) the new uncovered information will be using to generate useful results. On site, there is a "Speak Up for Safety" initiative which can be seen around the project on banners in both English and Spanish. This initiative is carried by everyone on site and all levels of management are responsible to convey the message that workers can freely speak up about any concern and feel confident that they would get help.

Be Respectful with Other's Space – Clean as You Go: The safety manager played a key role in delivering the message that maintaining a clean area is more productive and safer. During on-boarding for new workers, "Clean as you go" policy of the project is described as removing trash as work is being done and not at the end of the day. Expectations regarding cleanliness are clearly communicated to the workers as they come to the project.

Improve Sharing Information and Communication: Increasing communication on site was suggested from the survey and the project team started sharing information in the plan of the day meetings to help crews to understand work flow. Also, as the project is being built around Lean, the principle of "respect for people" is applied in different scenarios. To improve communication for example, as the team recognized that not all workers are proficient in a language, the safety manager provides the option to workers to choose which language to use during orientations. Clear conversations increase the likelihood of making sure the messages are understood. This helped to show that the management team cares about their workers, but also improves understanding of work sequence, and thus avoided having congested areas.

CONCLUSIONS

The study showed that there are common patterns that help construction workers to either feel more safe or unsafe working on site. Psychological safety has proven its potential to impact team performance, and factors affecting psychological safety on construction sites should be studied. Responses to the question seeking factors that make workers feel unsafe on site allow identifying areas where leaders need to focus. Moreover, providing the conditions that help workers feel safe on site is as important as mitigating the unsafe conditions. The way site managers and superintendents behave plays a key role in shaping craft workers' feelings and behaviors. It is the project leaders' responsibility to promote psychological safety and learning behaviors on teams. This necessary condition must be matched with consistent supervisory behavior down all chains of command. How "my" boss treats me trumps everything else.

If a project team is looking for their collaborators to feel free to speak up, a good alternative is sharing experiences in which mistakes did not lead to rejection but rather had the team engagement in solving an issue together showing true interest. By doing so, behaviors shift to a more active approach to create a psychologically safe work environment. The study provided empirical evidence that when a project prioritizes psychological safety, the workers recognize the change and feel free to give suggestions for further improvement. The findings also highlighted that actions taken to keep building psychological safety on site such as the content included in the personal orientations, the way issues are handled and addressed, the increase of interrelatedness by the creation of a safety committee as well as using both languages during weekly all hands meeting can highly positively impact the workers' perception about how much the company cares about them, and then they also started caring about each other in the same way. The study uncovered some of the workers' main concerns; for example, they cared a lot about other people's behavior and it helped the team directing efforts towards building upstream behaviors that are translated into an active care approach.

LIMITATIONS

The limited amount of samples do not allow for generalization in particular findings, but rather the authors aimed to set a baseline for future studies and convey the different thoughts and expectations from a sample project and shared some of the initiatives that the project team put in place and can be replicated in other projects.

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MENTAL HEALTH IN THE CONSTRUCTION INDUSTRY: A RAPID REVIEW

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ABSTRACT

Principles of lean construction have been suggested as strategies towards improving health and safety (H&S) in construction. Previous research has typically focused on the physical aspects of H&S; yet individuals who work within the construction industry have an increased risk of suffering from mental health conditions. This is an area which is gaining attention but is yet to be researched in depth. Through a rapid review of literature, this paper identifies 15 studies, and reviews the current literature concerning mental health within the construction industry. Theoretically, results suggest that mental health is a significant problem within the construction industry; and practically, it is recommended that organisations should consider evidence-based suggestions of ways to address this issue through approaches such as alternate work schedules, and the use of validated detection tools. The results of the review revealed that the current literature is limited, both in terms of quantity and research approaches adopted, and therefore, further high-quality studies are required in this area. The principles of lean construction present an opportunity for addressing the issue of poor mental health in the construction industry, thus expanding the application of lean construction beyond addressing merely the physical aspects of H&S issues.

KEYWORDS

Lean construction; waste; safety, quality, health; employee well-being; mental health

INTRODUCTION

Lean construction is a concept suggested for mitigating construction health and safety (H&S) problems (Forman, 2013). The principles of lean construction have been used to promote physical health and safety as a way of improving productivity and minimising costs on construction projects (Bashir et al., 2011). Yet the application of lean construction to H&S has typically focused on the physical aspects of H&S, such as accidents; rather than the potentially less visible aspects, such as negative impacts on mental health. The consequences of poor mental health can be substantial. For instance, a report in the UK found it was the leading cause of sickness absence, accounting for 70 million sick days in a year (Davies, 2013). The costs associated with mental health problems are staggering, with an estimated 25 billion forgone in gross value added to the UK economy in losses

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through absence, turnover and productivity (Unum, 2016). The construction industry is an environment that can be particularly at risk to poor mental health (Sherratt et al., 2018; Lingard & Turner, 2015), and losses associated with mental health problems, such as absenteeism, can have direct implications for lean construction principles. This paper aims to review the current understanding on mental health and wellbeing within the construction industry, and consider the application of lean principles within this area. This research takes the form of a rapid review of the contemporary literature concerning mental health within the construction industry, thus taking a crucial first step in understanding the theoretical and practical implications of mental health and well-being within the industry's workforce and the potential for lean to enhance future developments.

MENTAL HEALTH IN CONSTRUCTION

Mental health conditions are significant in their impact on individuals, as well as their families, respective organisations and communities in which they work and live. The Health and Safety Executive (n.d) in the UK noted that one in four people will have a mental health problem at some point. Business leaders are becoming more aware of the productivity-related costs which poor mental health can cause through employee absences and wasteful on-the-job productivity practices (Goetzel et al., 2004). One of the main pillars of lean construction is waste reduction. While this has previously been associated with material wastage amongst construction personnel (Alarcon, 2014), contemporary lean principles are seeking to look beyond this to other forms of wastage. Hence, wastage should be viewed more broadly, and also encompass opportunity costs (Alarcon, 2014). A mentally unwell workforce is an opportunity cost, as high stress and burnout levels will likely reduce efficiency and productivity. Lean construction approaches have targeted reducing costs in the workplace (see, for example, Zimina et al., 2012), yet cost-saving through mental health promotion and prevention has arguably not received the attention it deserves. Previous work has highlighted that there is also a clear business case for implementing positive mental health strategies and preventing mental illness in workplaces, with mental health costs in the United Kingdom estimated at over £100 billion every year (Knapp et al., 2011).

The construction industry is particularly vulnerable to mental health issues, as the environment contains many occupational stressors such as: high production pressures, dangerous work, complex decision-making and 'not feeling tough enough', all of which can contribute to poor mental health (Sherratt, 2018). The way work is structured through long supply chains involving transient work, insecure temporary contracts, and long working hours also creates mental health risks specific to the industry (Sherratt & Turner 2018). Perhaps unsurprisingly, research focusing on construction shows that its workforce is particularly at risk of poor mental health (Gullestrup et al. 2011; Milner et al. 2014; Roberts et al. 2013). Research (Meltzer et al. 2008; Milner et al. 2013) is consistent in showing that male construction workers have a higher rate of suicide when compared to males in other occupations; and Borsting Jacobsen et al. (2013) revealed that the incidence of mental distress in construction workers is double that of the level of the general male population. This has prompted workplace-based suicide prevention through intervention programs, such as Mates in Construction (see Gullestrup, et al., 2011). Workers have also identified that there is a need to create a work environment which is supportive of healthy behaviour (Lingard & Turner, 2015), yet relatively little research concerning mental health in construction has been conducted. With the construction industry representing such a large portion of the global workforce, the mental health of construction employees arguably warrants critical attention.

RESEARCH METHOD

While there is no universal definition of a rapid review, it has been described as ‘a type of knowledge synthesis in which components of the systematic review process are simplified or omitted to produce information in a short period of time’ (Khangura, 2012:8). When there is a lack of relevant research, rapid reviews are often useful for aiding decision-making (Haby et al., 2016). While physical H&S in the construction industry has been studied for many decades, research within the mental health and well-being space is much less prominent. Hence, a rapid review is considered appropriate for capturing the little research that has been conducted to date. The rapid review was conducted as per the following steps:

Forming the research question/aim;

Defining parameters and identification of biases;

Consultation with a librarian for database selection;

Screening, selection and application of a quality framework; and,

Discussion of papers selected through the process.

The parameters for inclusion and exclusion criteria were based on journal quality, as defined by Scimago Institution rankings. This indicator accounts for both the quantity of journal citations, and the prestige of the journals where such citations emerge. The top quartile (Q1) and second quartile (Q2) journals were selected as appropriate for screening journal quality. The bias risks associated with only one reviewer undertaking this process were reduced, by having an additional reviewer also undertaking the screening, and application of the quality framework in the later steps of the review. Other bias that are worth noting include, i) the exclusion of grey literature, meaning there is a risk of missing unpublished literature, and ii) only studies in English were captured, risking missing literature in other languages. In terms of exclusion criteria, it is important to note that physical health studies were excluded, as were multi-disciplinary studies on mental health that had no findings specific to the construction industry. Furthermore, only studies conducted later than the year 1999 were selected, to ensure relevance and applicability to present day.

An experienced librarian’s advice for which databases would be most appropriate was sought. Eight relevant databases were highlighted, two of which, ICONDA and Science Direct (Elsevier) were deemed most suitable for the study. Key words in the multidisciplinary Science Direct (Elsevier) included: construction wellbeing, construction well-being, construction mental health, construction stress, and construction psychosocial. In ICONDA, an international construction database, searches included: wellbeing, well-being, mental health, workplace stress, and psychosocial. The results section illustrates the papers identified and selected for this research.

SUMMARY OF FINDINGS

Fifteen studies that met the criteria were conducted between the years 2005-2018, and of these, 10 studies were conducted over the last 5 years (see table below). Studies investigated the mental health of construction workers (blue collar) and construction professionals (white collar). The studies primarily focused on the negative aspects of mental health; these included stigma, psychosocial risk factors, stress and burnout. However, a couple of studies also investigating ways to improve, such as exploring appropriate work-life balances and ideas for the promotion of health and wellbeing.

Table 18: Overview of the 15 relevant studies in the rapid review

Participants	Country of Study	Author & Year	Journal/ Quality	Approach reported	Results
682 male construction workers	Australia	Milner et al. 2018	SSM - Population Health (Q2)	Survey intervention to address self-stigma.	Self-stigma was relatively low, and intervention not significant.
11 construction workers	USA	Jebelli et al. 2018	Automation in Construction (Q1)	Electroencephalogram signals to test for stress at work.	Can determine early detection of workers' stress.
879 health and safety professionals	Ireland & UK	Leitão & Greiner, 2017	Safety Science (Q1)	Survey of members from an institution of occupational health and safety	The construction sector needed improvement in reducing psychosocial risk factors.
256 construction project managers	China	Yang et al. 2017	International Journal of Project Management (Q1)	An job-specific burnout scale was created	Construction project managers have high levels of job burnout.

80 trades workers	UK	Eaves et al. 2016	Applied Ergonomics (Q1)	Interviews, Nordic Musculoskeletal Questionnaire and Work Ability Index.	Over 250 ideas for health and wellbeing.
216 construction workers	China	Jia et al. 2016	Applied Ergonomics (Q1)	A grounded theory approach into heat stress risks and the relationships	Construction heat stress risks were socially constructed
676 construction professionals	South Africa	Bowen et al. 2014	International Journal of Project Management (Q1)	Survey and factor analysis of 13 factor relationships with perceived stress.	Existing occupational stress theories were not completely supported.
1500 supervisors and bricklayers	Holland	Boschman et al. 2013	Applied Ergonomics (Q1)	Dutch Questionnaire on work experience and evaluation.	Psychosocial risk factors for bricklayers and supervisors.
289 construction employees	Sweden	Tholén et al. 2013	Safety Science (Q1)	Questionnaires, and modelling analysis.	Supportive psychosocial conditions influence individual safety perceptions.
626 construction professionals	South Africa	Bowen et al. 2013	Engineering, Construction and Architectural Management (Q2)	A survey was developed to determine perceived workplace stress and examined various stressors.	Harassment and discrimination were experienced by all surveyed South African construction professions.
269 architects, 179 quantity surveyors, 168 civil engineers, 60 construction project managers	South Africa	Bowen et al. 2013b	Journal of Construction Engineering and Management (Q1)	A survey determined perceived workplace stress, and the exent of job demands and job control	Most respondents have high workplace stress levels; and architects have higher levels than engineers.
73 construction workers	USA	Omosefe et al. 2011	International Journal of Industrial Ergonomics (Q2)	Survey investigated job demands, envoironmental and organizational stressors.	Stressors that are non-physical should be included in injury risk models.

449 construction professionals	Australia	Love et al. 2011	Journal of Construction Engineering and Management (Q1)	Use of the International Survey of Stress and Mental Health Survey.	On-site workers had higher levels of self-stress than consultants.
23 wages employees, and 19 salaried employees	Australia	Lingard et al. 2007	Journal of Construction Engineering and Management (Q1)	Questionnaire surveys to evaluate employees' view on moving from a 6-day to a 5-day week, and semi-structured interviews.	Alternative work schedules could improve the work-life balance of construction employees
100 Construction project managers	UK	Love & Edwards, 2005	Engineering, Construction and Architectural Management (Q2)	A questionnaire survey containing valid and reliable scales for job demand, job control, social support and psychological well-being.	A job strain model could significantly predict employees' psychological wellbeing, with social support having significant main effects.

DISCUSSION

The results generated from the rapid review illustrated that the challenge of mental health within the construction industry is an area of growing research interest, with studies conducted across continents: including Australia (n=3), America (n=2), Africa (n=3), Asia (n=2), and Europe (n=5). As the challenge of mental health issues for employees within the construction industry is felt globally, further research is warranted in the area. While the extant literature shows that blue-collar workers have an increased risk of mental health issues and suicide (Milner et al. 2013), it is worth noting that research has explored mental health for both white and blue-collar workers. White-collar workers refer to employees for whom a large portion of the work is office/administrative based; for the purposes of this research, white-collar workers are identified as project managers, architects, engineers, and other professionals within the industry. In comparison, blue-collar workers refer to employees whose work is mainly site based and involves manual labour; and therefore, this research identifies blue collar workers as construction labourers/workers from various construction trades. Out of the 15 studies identified, 6 (40%) focused on a sample of blue-collar workers, 6 (40%) focused on white-collar workers and 3 (20%) focused on both white and blue-collar workers, indicating that the mental health challenge applies to both categories of workers within the industry.

There were no studies that directly aimed to quantify the costs of mental health issues in the construction industry, but many noted that mental health was a problem. For instance, Leitão & Greiner (2017) highlighted there was a need for improvement; Yang et al. (2017) revealed construction project managers suffered from high levels of job burnout; and Bowen et al (2013b) found that most survey respondents experienced high levels of workplace stress. Employees that are highly stressed or suffering burnout will not be operating at high productivity levels, and will more likely be inefficient and wasteful. One of the main pillars in lean construction is the reduction of waste, with a reduction in physical H&S accidents and incidents being viewed as an example of waste reduction (Bajjou et al., 2017). The mental health issues highlighted in this review suggests that lean construction principles should also be applied to this branch of H&S, with emphasis on the mental health and well-being of the workforce.

The literature provided evidence for improving workplace mental health, such as alternate work schedules (Lingard et al., 2007); evidenced-based ideas for improvement (Eaves et al., 2016), and ways of early detection of stress (Jebelli et al. 2018). Further research studies are required to build upon this literature in order to advance extant knowledge into how construction mental health problems can be identified and managed to produce a healthier workforce that ultimately, will reduce construction costs. Previous work has found that specific lean strategies, including continuous improvement programmes, seem to have some positive effects on safety (Nahmens and Ikuma, 2009); and hence, it can be argued that the relationship between such lean strategies and mental health in construction, should also be investigated.

From a research methods perspective, with the exception of three studies (Jia et al., 2016; Eaves et al., 2016; Lingard et al., 2007), all studies adopted a quantitative-only approach. Indeed, the majority of studies have focused on the assessment/testing of the mental health wellbeing of construction employees. This methodological hegemony may indicate limitations in the current body of research on mental health in the construction industry, both in terms of quantity, given the limited samples identified in through the rapid review, as well as breadth of research investigations/approaches adopted in its examination. In the field of construction safety, Zou et al. (2014) highlighted that there could be a misalignment between the research studies that have been undertaken and the industry's practical needs. Oswald et al. (2018) also argued that approaches needed to go beyond the dominant paradigms, which attempt to prove and measure, typically through questionnaires, and instead to initiate methodologies that reveal more exploratory insights. Such findings are likely to be limited and lack the richness of data able to inform and support the development of practical and effective interventions in practice. This rapid review found a dominance of quantitative methods, rooted in positivist traditions; and therefore, makes a call for the mobilisations of other research methodologies, which can arguably be extended from physical safety, to also include mental health in the construction industry.

CONCLUSION

Lean construction principles have been suggested as strategies for improving physical health and safety in the construction industry. In studies focusing on health and safety within the industry, the mental health of the construction industry workforce has received less attention, despite being identified as a key contributor to escalating costs globally. Such costs can be viewed as resulting in wastage, which is one of the main pillars of lean construction. This review has identified that while studies have highlighted mental health as a problem within the construction industry, few studies have suggested ways to improve and address the global issue. Theoretically, the results of this study highlight that further research in this area is required in order to help fill this gap; and practically, this research suggests that organisations should consider evidence-based suggestions of ways to improve (such as alternate work schedules), and the use of validated detection tools (such as the use of electroencephalogram signals), to identify early signs of stress and mental health issues in both their white-collar and blue-collar employees.

This review illustrated that there are methodological limitations in the literature exploring mental health in the construction industry to date; and this research suggested that lean construction principles can be applied to the context of the mental health problem within the construction industry. Despite mental health in construction gaining increased attention, studies into the topic are limited and have adopted similar research approaches. Mental health within the construction industry is a global issue, that affects both blue and white-collar construction workers, and from a lean construction perspective, is one that currently represents an opportunity cost. In terms of limitations of this research, the rapid review study was limited to two databases capturing high-quality journal outputs and therefore is limited in size and scope. As mental health literature continues to grow, it is recommended that a systematic literature review is undertaken for future work.

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USING STANDARDIZED WORK TO PREVENT CONSTRUCTION ACCIDENTS

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ABSTRACT

The work done on construction sites is high risk, unsafe and could result in work-related accidents. The effect of accidents often impacts the social and economic integrity of the workers and their productivity negatively. The reported study in this paper investigated 'how standardized work prevents accidents on construction sites?' A single case research design was used to collect the primary data through semi-structured interviews and focus group interviews. The collected data were analyzed thematically. From the findings, it was discovered that improper working conditions related to scaffolds often causes accidents on construction sites. In effect, the use of standardized work would help to eradicate improper working conditions that lead to accidents because it helps project supervisors/engineers to avoid errors and omissions. For standardized work to be successful, the project supervisors should actively address the behavioral problems of the workers. Therefore, it is recommended that there is a need to conduct further research that would establish the strength of the standardized work in improving health, safety and well-being (HSW) of people in the construction.

KEYWORDS

Accidents, construction, health, safety and wellbeing, standardized work

INTRODUCTION

The construction industry is one of the most dangerous industries causing a high number of accidents worldwide (Andersen et al., 2018). Accidents in construction influences production output negatively. This is because construction work is labor-intensive in nature and the workers are valued resources that makes significant contributions to the performance and quality of the projects (Ghodrati et al., 2018). The construction site is a workplace where most of the accidents experienced on sites are linked to the workers' decisions and actions (Durdyev et al., 2017).

However, the outcomes of the accident's causations in the workplace does not only affect the victims negatively but also the society, including the family, community,

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organization and clients (Hallowell, 2010). According to González et al. (2016), the processes of investigating accidents reduce productivity because of stoppages or interruption of activities. Thus, accidents on construction sites reduce productivity, and increase project costs through medical care, delays, lost working days, and other penalties (Forteza et al., 2017).

Therefore, to solve these reported problems of accidents in the construction industry, standardized work is recommended by Micklewright (2010). The purpose of standardized work is to help organizations to improve quality and eliminate waste to achieve the continuous improvement that adds value to the clients (Saggin et al., 2017). Standardized work can be adopted to help construction managers to improve safety on construction sites (Fireman et al., 2018). Thus, the objective of this paper is to report on research that investigated 'how standardized work prevents accidents on construction sites?' According to Forbes and Ahmed (2011), the philosophy of standardized work is to help project supervisors to identify problems so that they can continue to improve the situations.

STANDARDIZED WORK PRACTICE

Standardized work is a philosophy in the Toyota Production System (TPS), which sets a baseline for 'Kaizen' known as 'continuous improvement' in the workplace (Fireman et al., 2018). Standardized work is described as a working procedure that helps to develop the best working methods and sequences for each trade of work and each worker to be tasked (Fin et al., 2017). During the implementation of standardized work, it is important for management or project supervisors to standardize or regulate the working procedures in order to stabilize the process before continuous improvement can be applied (Pereira et al., 2016). According to Gomez and Hamid (2018), continuous improvements is described as a process that helps organizations to achieve high performance by eliminating defects, reducing process and product waste, managing efficient production and thus improving productivity.

It is reported that the adoption of standardized work is to help managers to eliminate waste while exploiting performance in the workplace and the operation of each worker (Pereira et al., 2016). Therefore, it can be argued that standardized work is a suitable method to prevent construction accident. Also, in a lean practice accident is described as a type of waste (Aziz and Hafez, 2013). For instance, the impact of construction accidents usually causes lots of negative consequences relating to nonappearance of workers, delays, permanent disability of the victims, and cost of accident investigations (Shao et al., 2019). These highlighted factors by Shao et al., (2019) contribute to waste because they do not add value to the organizations.

Essentially, standardized work consists of three elements, namely; takt time, standard work sequence, and standard work in process (Micklewright, 2010). The description of these three elements of standardized work shows that:

- Takt time is defined as the rate or speed of time needed to produce items or units of a product in the workplace, and it is issued based on the ratio between time and production demand for the product (Fin et al., 2017). However, takt time is not measured or observed, but it is calculated based on the percentage of the available time by the output required (Pereira et al., 2016).

- Standard work sequence is defined as an adopted working procedure in which a set of items or units are produced in the safest manner using the best methods. However, the work sequence is different from the order of processes and product flow (Fireman et al., 2018).
- Standard work in process inventory is defined as a systematic model that provides the minimum measure of work needed to maintain the pace of production in a continuous flow, without idle times (Fireman et al., 2018).

The indicate that standardized work sets assist in achieving high levels of productivity, quality and safety in the workplace (Fin et al., 2017). Micklewright (2010: 202) quoted a statement by Henry Ford in 1988, that '*today's standardization is the necessary foundation on which tomorrows improvement will be based. If you think of standardization as the best you know today, but which is to be improved tomorrow, you get somewhere. But if you think of standards a confining, then progress stops.*'

RESEARCH METHODOLOGY

As indicated in the previous sections, the reported study investigated 'how standardized work prevents accidents on construction sites?' To meet this objective, a construction site project in Bloemfontein, South Africa was selected. Thus, this study adopted a single case design (Yin, 2014), which helped the researcher to determine whether standardized work can be adapted to prevent accidents in the construction industry. The research design provided a platform to refocus future research investigation regarding how to improve the health, safety, and well-being (HSW) of people in construction using standardized work in the construction industry.

The primary data of this single case study were collected using semi-structured interviews and focus group interviews. To be precise, nine participants were interviewed for this case study (Table 1). These nine participants were selected purposeful as recommended by Miles et al. (2014). The reason to select the participants purposeful is that the researcher was seeking to collect the data from construction professions with lived experiences. The participants were working on the same construction project.

Thus, open-ended research questions were used as a guideline to help the researcher to collect the data using a face-to-face interview mode (Miles et al., 2014). There were two interview sessions, the first session was between the researcher and the project leaders, namely a construction manager, site engineer, safety manager, and foreman. The aim of this first interview session was to identify the causes of the accidents on construction sites. The second interview session was conducted through focus group and there were two focus groups. The first focus interview was between the researcher and the project leaders and the second focus group interview was between the researcher and the artisans. The aim of the second interview sessions was to determine how standardized work can be adapted to prevent accidents on construction sites.

The use of focus group helped the researcher to understand the reported problems and to provide solutions, as it gathered different opinions from the construction professions as suggested by Krueger and Casey (2015). During the focus group interviews, each participant was encouraged to share their perception and point of view without interference. The collected data were analyzed thematically as demonstrated by Miles et al., (2014). The interviews were held at the site office and the duration of each interview was between 30 – 60 minutes. The research data were collected between September and November 2018.

Table 1: Research sample

Participants		Number	Percentage
	Construction manager	1	
	Site engineer	1	
Project leaders	Safety manager	1	56%
	Senior foreman	1	
	Junior foreman	1	
Artisans	Bricklayers	3	
	Plaster	1	44%
Total participants		**9**	**100%**

RESULTS AND DISCUSSION

The subsequent sessions present and discuss the research findings. The first session investigates the first research questions '*what contribute to accidents on construction sites?*' and the second asks '*how standardized work could prevent accidents?*. However, during the first interview sessions, the background of the study was introduced to the interviewees, particularly on standardized work in the construction industry.

WHAT CONTRIBUTE TO ACCIDENTS ON CONSTRUCTION SITES?

Most of the interviewees reported that the working conditions and working on scaffolds are the contributing factors of accidents on construction sites. The term working conditions refer to the working environment and all the present conditions influencing the workers in the workplace, such as working hours, physical aspects, legal rights and responsibility organizational culture workload and training (Ali et al., 2013). From the findings, it is discovered that working conditions are often enthused by the desire of the workers to reach a high level of productivity. For instance, a safety manager is quoted as follows:

'There are reported cases about our workers complaining that often their supervisors prioritize productivity over their safety. For instance, often they are given instruction to deliver tasks in an unreasonable period and they are restricted from diverting one of their colleagues to clean and pack the working space they are working in. They argue that their supervisors would tell them that their priorities are to deliver their task as quickly as possible.'

A construction manager had a similar response to a site engineer. They argued that the employees of their subcontractors are responsible for creating a poor working environment. In their opinions, the employees of subcontractors create non-value adding activities, which result in poor housekeeping. For instance, the results of poor housekeeping are observed as the unpacked broken bricks laying all over the site, tools and equipment that are not stored properly, personal items that are not stored and machines that are not packed correctly. Therefore, poor housekeeping might cause errors and violations which might result in unintended injuries or accidents in the workplace. However, a safety manager disputed the statement of the construction manager and the site engineer, blaming poor housekeeping on the subcontractors' employees. In his arguments, he mentioned that the construction managers and supervisors are to be blamed for poor housekeeping because they ignore the factors causing poor housekeeping while focusing on a high level of productivity from their team members.

A senior foreman stated that the results of poor working conditions are influenced by numerous factors such as limited working space on the sites. The impact of little spaces on sites forces construction managers to design a complex site layout, especially for projects in the urban areas. Also, the weather conditions are another factor contributing to poor working conditions, especially during the summer periods. This is because, during the summer periods, it rains in South Africa and the wet surface influences the working environment. The perception reinforced the report by Winge et al. (2019) that the working condition is influenced by numerous factors which include wet conditions, thermal stresses, light, noise and other physical and climate factors causing hazards and risks in the workplace.

In terms of working on scaffolds. From the findings, it was discovered that there are various risks and hazards which are experienced by the workers while working on scaffolds. For instance, a construction manager is quoted as follows:

'It is important for management to calculate the impact which might result from the accidents should a scaffold collapse or an employee fall off while working on a scaffold. It is critical that management must be able to understand how they are going to deal with such situations because one can never be able to predict the effect of human failure in the industries.'

Furthermore, a site engineer explained that scaffold erectors must always check and test the resilience of scaffold equipment upon erecting the scaffolds. This is important because a scaffold could only support a limited amount of weight, which includes materials and the workers. According to a junior foreman, failure to control the working conditions of the workers at height, especially those who are working on a scaffold is hazardous to the workers at the lower levels. He is quoted as follows:

'I once witnessed an incident whereby a worker was hit by a piece of brick, which was falling from the fourth floor, approximately 4 meters above ground level. Luckily, the brick only hit a worker on his right shoulder and the impact of the incident was not severe. After the incident, the worker was rushed to a hospital for medical examination and it was confirmed by a doctor that the worker is not seriously hurt and was put on special leave for a month to recover from home.'

Furthermore, it was also reported that it is important for construction organizations to have the medical screening of the workers before the start of the project. A safety manager explained that the results of the worker's medical fitness help them to know the health status of individuals and those who will be able to work at height. He further explained that working on a scaffold is a high risk and there are other external factors which increase risks, such as the hot temperature during the summer period (the sun temperature increases close to 38 Degrees Celsius in summer). Therefore, the challenges which individuals are working at on the scaffold and the issues of fatigue is better imagined than witnessed. The conditions, in turn, occurs due to high productivity demand by the supervisors. In addition, a senior foreman stated that the actions and behaviors of the workers are a contributing factor to risks created when working on scaffolds. He further explained that often the workers working at height on scaffolds tend to become tired and try to take shortcuts, which results with accidents. For instance, a senior foreman says*, 'it is known that when you're working on scaffolds you are not supposed to throw your tools or equipment or waste materials to the ground, but you find workers who are still throwing their equipment to the ground especially when knocking off.*'

HOW STANDARDIZED WORK COULD PREVENT ACCIDENTS?

In the previous section, the researcher identified causal factors causing construction accidents. A major identified accident factor to be solved include working on scaffolds. To solve the problem, standardized work is adopted as recommended by Micklewright (2010).

To solve the problem of working conditions, a researcher asked the interviewees to distinguish the causes of working conditions. From the previous section, it was discovered that poor housekeeping is a major factor causing poor working conditions on construction sites. It was discovered that poor housekeeping is a waste that creates non-value adding activity and hazards that might cause errors and violations on the sites. For instance, it was reasoned by one the artisan from the 2nd focus group interviews that their supervisors do not allocate period or time for housekeeping activities on sites such as cleaning the site and storing the used equipment and tools.

In addition, it is reported by some member of the project leaders from the 1st focus group interviews, that 'Takt Time (which is an element of standardized work)' can be related to a critical path method. Takt time relates to a critical path method because it determines the time needed by the workers or management to complete a task. Failure by management or the workers to keep up with the time programmed to complete a task often lead to failure which might cause defects or accidents on sites. From the 1st focus group interviews, a construction manager is quoted as follows:

'By studying the definition of 'Takt Time' I can now conclude that it is like the critical path method because 'Takt Time' is the rate at which a person needs to complete a product

in order to meet the client's needs, and while the critical path helps to identify the activities that must be completed on time in order to deliver the entire projects to the client's needs.'

It is reported by a safety manager from the 1st focus group interviews that the construction manager must start to include the housekeeping as part of the task or activity plans, and the workers who will be responsible for housekeeping sequence must perform the work within the designed period of the designed task.

In terms of working on scaffolds, it was discovered that there are several risks from hazards that are experienced by the workers when working on scaffolds. For instance, a safety manager stated the actions and decisions of the workers often results with errors and violations, and there are natural events such as rain and hot weather contributing to errors and violations. The interviewees from 2nd focus group interviews said that they would recommend that their supervisors would stop giving the bricklayer working on scaffolds the same deadline to complete their task with those working on the ground floor or working on a concrete slab. This is because workers who are working on scaffolds are exposed to more risks than those who are working on the ground floor. It is further reported by a site engineer from the 2nd focus group interviews that it is critical that the managers must include the safety measure and risk control of working on scaffolds when planning and measuring the time to complete tasks which require the use of the scaffold. This is because workers who are working at a height above 2 meters are required to wear a safety harness. The use of safety harness restricts the movement of the workers and the working space on scaffolds restrict their speed of construction. Thus, it is reported that working on scaffolds reduces the speed of the workers and this influences productivity negatively.

The application of standardized work is presented in Table 2. Hence Table 2 indicates the three important steps which must be followed in the process of adopting standardized work to prevent accidents on construction sites. The use of standardized work is responsible to help site management to reduce accident by firstly identifying the root causes of accident on a project site, as indicated in Table 2, Step 1. The identification of the causes of accident would help site management to be able to prepare the appropriate safety training that would focus on helping the workers to drive down the causes of the accident, which is indicated in Step 2. In Step 3, the knowledge transfer or safety training prepared for the workers in Step 2 would help the workers to have the skills to continue with their tasks and improve productivity on a site project. The application of standardized work is developed based on the analysis of the standardized work literature and the findings presented in this reported research study.

Table 2: The application of standardized work

Important steps	Key points	Reasons
Step 1: Identify the causes of the problems.	You must breakdown the construction activities or task and identify hazards which	This will help in the discovery of the root causes of the reported problems (construction accidents).

(For instance, poor working conditions)	might cause injury or accidents in the workplace. (For instance, it is reported that poor housekeeping, limited working spaces and extreme weather conditions might cause errors and violations on site)	
Step 2: Prepare the workers to solve the problems (For instance, the workers must be taught about the safety regulations and how to identify hazards and risks when working on sites)	It is important to improve the skills and knowledge of the workers through training.	This will prepare the workers to have the skills and knowledge of the work.
Step 3: Improve the operations (For instance, allow housekeeping to form part of the job task)	The workers must be given the jobs task and be corrected if an error is experienced.	Introduce continuous improvement for the job task.

CONCLUDING REMARKS

The reported research assessed how standardized work could prevent accidents on construction sites. The process of adopting standardized work to reduce accidents in the construction industry is highlighted in Table 2, through the three important steps. From the literature and findings, it can be concluded that indeed construction accidents are a major concern in the construction industry. It is reported by the interviewees that working on scaffolds is a major concern. Poor housekeeping is identified as a contributing factor to poor working conditions. Thus, it is recommended that a construction manager must start to include housekeeping practice as part of the action plan when designing the critical path methods. This will help the workers to promote housekeeping practice while delivering the planned task without interfering with productivity. This would also help the construction team to continue to improve the working conditions without causing any construction accidents. Hence it is highlighted in Table 2 that the adaptions of standardized work to solve the reported construction accidents should follow the three important steps.

The use of standardized work could also help construction managers to set as a baseline to promote safety by eliminating errors and violations which might be produced when working on scaffolds. It is critical for management to fully understand the risks and hazards when working on scaffolds. This will help management to improve the working conditions of the workers working on scaffolds. Therefore, it is important for management to identify the causes of the problems when adopting standardized work. This will help management to set a standardization which would provide the baseline to improve the reported problem on the construction site. There is a need to conduct further research that would establish the strength of the standardized work in improving health, safety and well-being (HSW) of people in the construction.

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ANALYSIS OF VISUAL MANAGEMENT PRACTICES FOR CONSTRUCTION SAFETY

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ABSTRACT

Lean Construction's main goal is adding value to a project and minimizing waste. Accordingly, incidents that cause injuries or deaths are considered waste. This reveals the interdependent relationship between lean and safety. Here comes the importance of visual management (VM) as a way for communicating information using the right visual tools at the right time for the right situation in all construction projects. It is crucial as it improves efficiency, ensures transparency, establishes better communication and reduces safety risks. This paper highlights the importance of VM in the workplace for construction crews as well as its relation to safety. In this study, case studies and surveys conducted in Lebanon on building construction projects are presented, analyzed and discussed to show the need for VM by workers and engineers to avoid hazardous situations. Results indicate the importance of VM in maintaining safety, illustrate that poor visualization causes many accidents, and show that construction safety in Lebanon can be improved by enhancing VM practices.

KEYWORDS

Safety, Lean Construction, Visual Management, Visual Tools, Visual Orders.

INTRODUCTION

VM is a way for communicating information using different visual tools for collaborative and integrated planning and control. Liff (2007) stresses on the importance of VM. As described by him, an open organization that encourages sharing information, celebrates achievements as well as failures, supports the employees and strives for a better performance is an organization that uses VM. VM had been attracting research interest for many years. It is one of the most important approaches, simplest and easiest way to share and communicate information ensuring clarity and good understanding (Liker 2004). One

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of the reasons for using VM is safety management where many papers and studies have investigated its importance (Enshassi et al., 2014, Awada et al., 2016). This paper analyzes VM practices for construction safety in Lebanon. Here, so many questions arise. How effective are safety visuals in a construction project? Is it possible to mitigate the risks being faced in the Lebanese Construction Industry using good VM? To which extent preventing accidents depend on good visualization? Thus, the direct impact of VM on safety will be discussed in terms of affecting conditions, direct reasons for risks and recommendations to implement a good safety program.

Construction sites are usually large and dynamic environments where different crews move around, the layout undergoes several modifications throughout the project, and the construction itself might become a visual barrier (Formoso et al., 2002). The construction industry is known as one of the most dangerous industries that witnesses hazardous and fatal accidents (Awwad, 2015). For this reason, safety should be improved in an attempt to reduce and eliminate safety accidents from occurring (Ahmed et al., 2000). Besides, as indicated by Howell et al. (2002), there is a clear relationship between lean and safety. On one hand, Lean's main principles are eliminating waste and ensuring one piece flow and continuous work. On the other, safety accidents interrupt the flow of work. Reducing these accidents by maintaining an adequate safety program will reduce waste. Many causes can lead to safety accidents. Proper VM plays a great role in ensuring a safe workplace whereas the lack of VM and poor visualization leads to unsafe situations which cause accidents (Shrestha et al., 2011).

The main objective behind proper visualization is to effectively communicate information using visuals. These visuals may be signs, labels, etc. that are basically displayed all over the construction site transferring certain messages and information that are needed to prevent safety accidents (Saurin, et al., 2001). VM, which is exchanging data using visual tools, has a historical background. In Japan, the different approaches and tools for Lean Construction such as VM including visual orders that are known as the 5S (sort, stabilize, shine, standardize and sustain) started developing in the mid-1950s (Fabrizio and Tapping, 2006). However, many companies adopted 6S rather than 5S; 6S being the known 5S plus an additional S referring to safety. This is to focus on its importance to avoid hazardous situations in the construction workplace. Moreover, a number of previous studies indicated that there is a clear relationship between applying the 5S, whether in the workplace or any other, and maintaining safety performance (Saari, 1989).

This paper presents an investigation on the significance of implementing VM in construction projects in Lebanon and how it enhances safety. A part of this paper covers VM tools and their importance regarding safety. Whereas, another part presents different case studies that are briefly described. Moreover, surveys conducted on construction projects show quantitative and qualitative data indicating the extent and effectiveness of using safety visuals in Lebanon.

BACKGROUND ON VISUAL MANAGEMENT

Effective communication is important for learning and improving. VM can ensure communication between different parties and employees to achieve lean construction goals.

VM is the managerial strategy (neither a technique nor a tool) of consciously integrating visual (sensory) information into processes to increase process transparency and self-management capabilities at a workplace (Grief, 1991). Rather than relying on the workers' reporting of incidents deviating from safe norms (Aslesen et al., 2014), VM is mainly shaped through the reliance on visual tools and orders which are the first steps on the VM ladder.

VISUAL TOOLS

As identified by Galsworth (1997), visual tools are divided into four categories which are essential for implementing VM. These four categories are: visual indicators, visual signals, visual controls and visual guarantees. The aforementioned visual tools are crucial to achieve safety management, and as the saying goes, a picture is worth a thousand words. First, *visual indicators* pass crucial information from management to operational level intending to affect human's behaviour. Examples of visual indicators are charts, photos, value stream maps, etc. Secondly, *visual signals* are used to provoke a response to the eyesight and interpret the surrounding environment enforcing high human control and directing human's behaviour. They tend to grab attention for some essential points such as traffic light or and on boards. The third category is *visual controls* that show deviations and help people see how they do their jobs. They enforce full human control by limiting the response to a specific height, width, length, quantity etc. Some examples of visual controls are road lines, maintenance, Kanban, colour coding, display of safety regulations. Last but not least, *visual guarantees* ensure that everything is done in the right way enabling only the correct outcome. They are known as mistake proof or Poka-yoke striving to eliminate human errors such as machines that stop operating at an identified time or pumps that stop when tanks are filled.

Figure 1 shows the four different types of visual tools used on different sites in Lebanon

Figure 42- The four types of Visual Tools inspired from (Tezel, 2015)

VISUAL ORDER-6S

When applying VM, 5S is a key essential. It's the first step to a visual workplace. In this paper, as mentioned before, safety is added to attain the 6S. By taking safety into account along with 5S, the aim is not only to keep the workplace neat and organized but to ensure that it is safe at all times. The 6S are classified into: (1) Sort is removing all unnecessary items from the workplace. (2) Stabilize is assigning a place for every item or material to be returned to after each use. (3) Shine is cleaning the workplace before and after the work is done. (4) Standardize is following the same steps for the same process and maintaining the level of organization and readiness in the workplace. (5) Sustain is maintaining a correct procedure to build a culture of continuous improvement. (6) Safety is eliminating all hazards and verifying that suitable control measures are in place (Sukdeo 2007).

Figure 2 shows a framework for VM implementation. It illustrates that by implementing visual orders then going up to implement all layers reaching visual guarantees, a visual workplace is achieved.

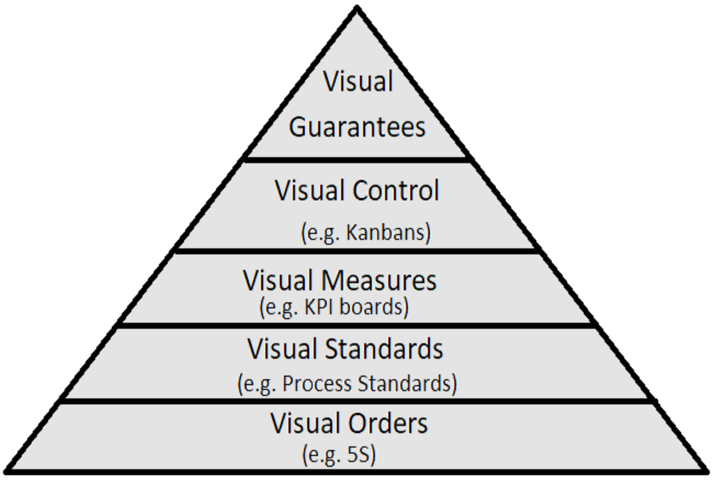

Figure 2- VM Implementation Framework inspired from (Galsworth, 2005)

METHODOLOGY AND METHODS

The methodology of this paper presents a mixed approach of case studies' analysis performed in Lebanon and results' analysis based on conducted surveys with construction professionals.

First, the case studies' analysis presents 12 building construction sites in Lebanon that differ by type and total built area.

Furthermore, a well-defined procedure for data collection on the mentioned case studies is adopted to analyse the availability and usage of VM and its tools in Lebanon. This procedure consists of the following steps: (1) visiting different projects, (2) meeting multi-disciplinary engineers and project managers, (3) interviewing 31 of them and (4) filling the surveys which include questions answered by the interviewed parties. Data collection lasted for over 20 days and the respondents completed the surveys during our meetings to ensure full understanding of the surveys' statements. A 5 point Likert scale was used to grade the statements. The scale ranges from 1 which corresponds to strongly disagree to 5 which is strongly agree. However, the last question was an open-ended one.

In order to develop the questions of the conducted surveys, a literature review was conducted to indicate factors of good VM. These factors are mainly related to visual orders and visual tools. (Enshassi et al., 2014). Once ideal VM strategies, tools and practices are well identified and once large number of accidents caused by poor VM on construction sites are detected, surveys' questions were prepared to investigate the conditions of construction safety in Lebanon.

Then, survey results including the mean and standard deviation of all responses are analyzed in the following section in order to get detailed information about safety management in the country, investigate whether or not projects in Lebanon efficiently use visual tools, know how engineers involve their workers in safety, and get an overview on the importance of right design and utilization of visual tools in decreasing the number of accidents and thus decreasing the number of injuries and deaths. The discussion of the results revealed the importance of VM, visual tools and visual orders in construction sites to ensure safety. It also shows the strong relationship between good VM and safety.

Prior to the conclusion, barriers of VM are revealed based on the engineers'/project managers' responses on questions and on specific observations during site visits. Finally, this study investigates the importance of implementing VM in different projects in the Lebanese construction industry and how it affects safety.

CASE STUDIES

Table 1 presents a brief description of the case studies that were considered in the surveys. Concerning construction case studies, they differ by their size according to the shown total built area in table (1), where some of them are considered as small scale projects, others are considered as medium scale and large scale projects. Also, the mentioned case studies differ by their type whether commercial or residential. Extent of VM usage varies between slight usage where some visual tools are used and no usage where sites lack any VM tool.

Table 1: Construction Sites' Case Studies

Case Study	Type	Total Area (m^2)	Extent of VM Usage
A	Residential	2940	No usage
B	Residential	4500	Slight usage
C	Commercial	22400	Slight usage
D	Residential	3750	No usage
E	Residential	3900	Slight usage
F	Commercial	7000	No usage
G	Residential	1350	No usage
H	Residential	1820	No usage
I	Residential	2040	No usage
J	Residential	2760	No usage
K	Commercial	15000	Slight usage
L	Residential	2880	No usage

RESULTS

BUILDING CONSTRUCTION SITES

Table (2) summarizes the results of the surveys conducted to investigate the current situation of Lebanon regarding safety in construction sites. The mean $\overline{x}$ and standard deviation σ are calculated based on the response of the interviewed engineers/project managers whom their answers were given according to Likert scale.

Table 2: Conducted Surveys related to Construction Sites

	Statement	Mean $\bar{x}$	Standard Deviation σ
1	The construction site is kept clean	3.92	1.44
2	Every material/tool in its place	3.17	1.27
3	Safety nets are available	3.50	1.81
4	PPE are clearly displayed	2.1	1.44
5	Workers wear hard hats	2.00	1.81
6	Workers wear hard and closed shoes	2.33	1.67
7	Workers often face accidents on site	4.17	1.11
8	First aid tools location is known & accessible	2.83	1.34
9	Slab openings and shafts are marked & closed	4.50	0.90
10	All exits are clearly marked	2.75	1.29
11	All walkways are unobstructed	3.50	1.57
12	Emergency evacuation indicators are available	2.00	1.28
13	Disposal procedures are visually displayed	2.50	1.00
14	Visual tools are used to make waste apparent	2.42	1.00
15	Caution signs to indicate newly casted areas	1.75	1.14
16	Safety mistakes are regularly reflected	3.25	1.22
17	Meetings held to increase safety awareness	1.67	1.07
18	Major barriers of VM implementation	Open-Ended	

DISCUSSION OF THE RESULTS

This section presents an analytical discussion of the conducted surveys and the mentioned case studies.

BUILDING CONSTRUCTION SITES

The study results reveal a significant difference between the visited sites. After a thorough investigation, survey analysis, and results' interpretation, a notable variability was detected where few sites use visual tools and follow safety regulations and many others do not use visual tools neglecting safety measures. Based on what have been seen during site visits, large scale projects are found to show more commitment to VM where workers stick to safety measures shown by visual orders on site more than medium and small scale projects where workers show less or even no commitment. Moreover, results indicated that most engineers/project managers are concerned about reducing waste mainly time and cost, increasing projects value and ensuring a safe workplace but they don't focus on VM techniques as statement (14) in table 2 shows. In the aforementioned statement, the mean is equal to 2.42 illustrating the limited usage of visuals that makes waste apparent.

Results also reveal that many incidents related to safety occurred in those sites that lack VM. Statement (7) in table 2 shows a very high mean (4.17) revealing the high number of these safety accidents on sites. The site engineers responsible for the later projects stated a number of these safety accidents that they have faced. As mentioned by the engineers, these accidents include falling from heights (scaffolding, roofs, etc.), tools and equipment accidents (cranes, trucks, vibrators etc.), falling objects, eye injuries and injuries caused by nails. So, these studies proved that lack of safety is mainly caused by lack of VM. Regarding the sites where VM is slightly used, the interviews with the engineers showed that accidents rarely occur and if they do, they would not be fatal such as injuries caused by nails. Although many sites don't use visual tools, almost all sites care for having a clean and neat workplace as represented by the mean (3.92) in statement (1).

Another crucial point was mentioned by the engineers/project managers where VM is slightly used is that location of first aid tools is well displayed by using different visual signs, for this reason even when simple accidents occur, these accidents are directly mitigated because first aid tools are easily reached and accessed by everyone. However, the mean (2.83) of statement (8) shows that even the simplest things related to safety are not considered in most of the sites in Lebanon. If there's a little knowledge about VM and its importance, by only using few effective, well displayed and organised signs, the location of first aid kits will be known and accessible by everyone. Likewise, statement (12) also shows a low value of the mean (2.00) indicating the lack of emergency evacuation indicators on site. As a result, this absence of visual tools may cause severe accidents to large number of workers in case of fire.

The mean (1.75) of statement (15) is another low value demonstrating the poor usage of visuals such as caution signs for newly casted areas which leads to unexpected damage, excess work, and more money to fix and repair thus causing waste. The interviewed engineers agreed that a clean site prevents some accidents from occurring, such as slips, trips, and nail wounds. They also confirmed that many accidents resulted from wastes and chaos in the workplace (Awada et al., 2016). However, when asking about organising materials/tools and having everything in its place, the response from most of the interviewed parties was that they do care for organising their tools, but this is neither their priority nor the job of the workers. They answered that there is a person who is in charge of organising the workplace, that's why the average answer of this question is neutral as shown in statement (2).

Figures 3, 4 and 5 show pictures taken during different site visits in Lebanon. These pictures demonstrate the difference witnessed between the visited sites. Figures (3) and (4) were taken from the same site. The 1st figure shows the visual indicators are used to display PPE. Workers in this site adhere to them as illustrated in figure (4) where all workers are wearing the safety hard hat and the high visibility vest. In contrast, figure (5) shows workers not taking safety regulations into account as commitment to PPE due to the absence of indicators. It is to be noted here that some companies force workers to wear PPE by imposing certain measures and regulations. Based on this, another key point should be mentioned which is the lack of indicators, signs and labels such as those related to commitment to PPE on construction sites as indicated by most of the respondents. As the table shows in statement (4), the mean is 2.1 which reveals poor visualization. This confirms the importance of having visual tools on construction sites to encourage workers to follow safety regulations and thus reduce accidents. Furthermore, both statements (5) and (6) show very low means, 2 and 2.33 respectively, and this is due to the absence of visual indicators and regulations that force, encourage, and remind the workers of the PPE whenever they are on site, whether inspecting or performing the work.

Figure 3- PPE clearly displayed

Figure 4-Workers commitment to PPE visual indicators

Figure 5- Workers not committed to PPE

Moreover, companies often use visual tools to define the project, project's name, owner, contractor, etc. As displayed in table (2), communication to spread safety awareness between workforces was very limited due to the poor usage of visual tools in the project sites as the mean for statement (17) in the aforementioned table shows. Most of the answers concerning VM on sites reflect the lack of using visual tools, excluding statement (9) that addresses shafts and openings where most of the engineers ensured that shafts and openings should be marked by visual tools and closed by visual barriers. It is the statement with the highest mean (4.5) where it indicates the importance of visual barriers in preventing safety accidents. Also, statements (3) and (11) ended up with an equal mean (3.5) showing that almost all sites use safety nets and keep walkways unobstructed which are major practices on site to avoid fatal accidents such as falling down from high levels or clashing with obstructing objects or materials onto walkways. Confirming to the importance of VM in safety, results align with a previous case study in Lebanon that showed the need for using visual tools to communicating important safety instructions as a key for maintaining a safe environment on construction sites (Awada et al., 2016).

BARRIERS OF VM ON CONSTRUCTION SITES

After interviewing more than 12 construction specialists (project managers, site supervisors, etc.) and based on their responses on the open-ended statement which is "major barriers of VM implementation", we can conclude that workers on construction sites have a poor background about VM tools and safety measures. When asked about the major barriers of VM implementation as mentioned in statement (18) in table (2), the interviewed parties mentioned the following barriers: (1) resistance to change, (2) overconfidence, (3) cost, (4) time, (5) lack of governmental regulations, and (6) culture. Traditional contractors, engineers, and workers stick to old methods and resist change, which prevents learning new improvement techniques. Also, those with long experience are overconfident about their work so that they don't obey rules to enhance safety. Besides, they think that it is costly and time consuming to have extra training hours to understand VM tools and orders. Moreover, there are no governmental regulations that encourage workers and managers to implement VM. Last but not least, culture is a major barrier where workers are not educated enough to follow certain safety procedures using VM tools.

CONCLUSION

This paper investigates the extent of using VM tools on construction building sites in Lebanon. It is clearly shown that VM is an integral part of lean construction, and that better VM leads to better outcomes. So, lean construction emphasizes on using VM to ensure construction safety, thus reducing waste and adding value. Results of the studied cases show that VM needs further improvement in Lebanon and highlight the importance of implementing VM to reduce accidents. After discussing the results, the difference was clear between sites that slightly use visual tools where accidents are limited and not fatal, and sites that never use VM where severe accidents occur frequently.

To conclude, a visual place is an environment that speaks for itself. So, as a recommendation, visuals should be utilized everywhere to direct actions/behaviour and enhance safety for workers, engineers, and the public. In addition, engineers and contractors should dedicate enough time and spend more money on training workers to efficiently use VM tools and reduce accidents. Finally, a lean culture should be cultivated to enhance utilization of VM. Further research is recommended to determine strategies for implementing VM in construction sites so that invested efforts will pay off in more effective results.

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LEAN CONSTRUCTION AND MATURITY MODELS: APPLYING FIVE METHODS

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ABSTRACT

The purpose of this paper is comparing five Maturity Models (MM) developed to measure the company's adherence to Lean Construction (LC) principles. Methods were applied to the same project and results show that project classification was equivalent in the five systems for LC principles adherence. This MM have differences between origins, scope, application and results presentation, showing the diversity existent in LC philosophy. For this case study, all five methods showed adherence to lean principles and the results are graphically presented to easily compare the obtained results from the application of them.

KEYWORDS

Lean Construction, Maturity Models, Continuous Improvement, Action Learning/Research.

INTRODUCTION

Throughout history, civil construction has been following the technological development of different generations, adapting advances to basic construction concepts. Among these advances, Lean Construction (LC) can be mention as one important development that was conceived by Koskela (1992) applying the principles of Lean Thinking (LT), established in the automobile industry, to construction industry.

From the Koskela (1992) the study, lean practices had been disseminated among companies and construction professionals, bringing benefits to them and others involved. It is estimated that 90% of professionals how to work with LC in Chile, consider crucial apply this philosophy to get the company growth (Salvatierra et al. 2015). The measurement of improvements results from the application of lean construction is necessary just like any other management systems, after all, "what gets measured gets managed".

The civil construction has different Performance Measurers Systems (PMS), based on results such as Kay Performance Indicators (KPI) and Balanced Scorecard (BSC). PMS is support tools to ensure goals through manage performance, human resources and company strategy (Yu et al. 2007). PMS is a set of indicators that measure the efficiency and effectiveness of organization actions to assess whether goals are met, for Wettstein and

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Kueng (2002), is a system that follows company performance, supporting results communicating, tactical and strategic decisions and organizational learning. However, Measurement Model (MM) enable implement change in a systematic and directed approach (Nesensohn 2014). After the revelation of the eleven principles proposed by Koskela (1992) and the five guidelines of lean the thinking presented by Womack and Jones (1997), were necessary to invest in MM development focused on LC.

Models based on lean principles can be divided between those that focus on the evaluation of some premises but non-full LC application and those that have extended evaluation of this philosophy. In the first group are the systems based on the Last Planner System (PLS) (Ballard 2000); the parameters suggested by Alarcón et al. (2001), focusing on waste quantification, cycle time and rework; and the evaluation process proposed by Moon et al. (2007) based on Transformation-Flow-Value (TFV).

Among the MM range that gives global LC evaluation, five had been selected in this paper for case study application. Among several models that analyze maturity level focused on LC concepts application, five of them use case study through field visit and interview approach. In addition, selected models were studied in congresses of LC, which led the authors to seek a comparison between them to be used in a construction company study. Two of these are Brazilians, one English, one Chilean and one binational (Brazil and Germany). They have in common the application method through questions and answers tool that allow compeer current state and the goals to be reached along the evolution philosophy journey.

The selected methods for this paper have a semi-qualitative approach. They evaluate the LC principles adhesion in a flexible manner (qualitative) and pointed out the current maturity level (quantitative). As a disadvantage, they are subjective because evaluate a wide range of factors (Sarhan and Fox 2013).

Thus, this work aims to draw a comparison between the evaluation methods proposed by Hofacker et al. (2008), Arantes (2010), Nesensohn (2014), Soto (2016) and Carvalho and Scheer (2017) through a case study of Brazil countryside construction site, located in the state of São Paulo, and presented the advantages and disadvantages of each method and the suited method to this case study.

MATERIALS AND METHODS

At the first moment, a bibliographic review was carried out in scientific databases searching for “evaluation lean construction”, “performance measurement systems lean construction”, “maturity model lean construction” were several documents were found. The selected sources are from 2000 to 2018 by different parts of the world, cover case studies, bibliography reviews, proposition and comparison between MM focused on LC.

The verified methodologies used to evaluate maturity in LC, those presented by Hofacker et al. (2008), Arantes (2010), Nesensohn (2014), Soto (2016) and Carvalho and Scheer (2017) were selected for this paper. The choice was given by these models being more embracing about LC and LT among the authors correlated to IGLC. Even with differences in evaluation methodology, way of use and graphic results scale, as will be presented below, the foundations and proposal are similar, allowing compare results obtained in the same construction site.

The project of this case study is a residential enterprise composed of fifty houses. The construction company has a small size and was founded in 2015 from a project company joined with a residential construction company, both together ads twelve years of experience in the city of Sorocaba-SP-BR. The project was conceived by shareholders who were the main customer of this enterprise and had been the financing of a public Brazilian house program. When the evaluations was made, the construction was in the finishing phase, with the construction site being reduced, as well as stock, workers and material flow.

The company and the project do not use LC principles in a formal way, even though some interviewees and external suppliers know this philosophy. In the construction site visit, the interviewer observed LC use in an unreasonable way and with limitations to the adoption of some LC principles due to the project nature and requirements of the fomented federal program.

Table 1 present methods specifications used in this work. The research occurred during the professional performance of one of the authors with the project. Below will be presented application details of each system, the application of methods was done as well as proposed by each author.

LEAN CONSTRUCTION-QUALITY RATING MODEL (LCR)

The authors of this method suggest that the application should be done by two external researchers who have knowledge of LC and about the questionnaire proposed. On this case study, this MM was applied by one of the authors and another professional who works in the project and know LC. As indicated by Hofacker et al. (2008), the construction site was visited and the principles use could be verified on that. After that, each evaluator completed the same questionnaire evaluating the project and answers were discussed and results analyzed. In the next chapter, the results will be presented in a radar chart according to the proposition of the method author. One site was visited, so the results represent LC maturity in this project.

LEAN CONSTRUCTION DIAGNOSTIC MODEL (MDCE)

Arantes (2010) does not present a name for the developed tool, in this paper will be used MDCE (Modelo de Diagnóstico da Construção Enxuta, in Portuguese), the title of the work that presents it. The authors of the present paper completed the proposed questionnaire after a site visit and dialogues with professional's workers of this project, evaluating just this project.

Table 1: Comparison between models applied in the same project (own elaboration).

MODEL AUTHOR YEAR	BASED ON	EVALUATION FACTORS	EVALUATION METHOD	RESULTS SCALE	RESULTS PRESENTATION
LCR Hofaker et al. (2008)	Principles of LC developed by Koskela (1992) & principles of LT developed by Womack & Jones (1996)	1 Client focus 2 Waste consciousness 3 Quality 4 Material flow 5 Organization, planning and info-flow 6 Continuous improvement	Questionnaire with 30 questions, completed by external evaluator after a hour in a construction site visit evaluating each question in quantitative way through a Likert scale from 0 to 4. Evaluate construction	Percentage scale of 4 classes with 3 subclasses each (from "d" to "aaa"). The step of the grade gradually lower while the grade get higher	Radar chart filled out, presenting the evaluation for the 6 factors

			site, authors affirm that evaluating more than 3 projects results could be used to represent whole company.		
MDCE Arantes, F (2010)	Principles of LC developed by Koskela (1992) & principles of LT developed by Womack & Jones (1996) & concepts proposed by Rentes (2009)	1 Reduce the share of non-value-adding activities 2 Increase output value through systematic consideration of customer requirements 3 Reduce variability 4 Reduce the cycle time 5 Simplify by minimizing the number of steps and parts 6 Increase output flexibility 7 Increase process transparency 8 Focus control on the complete process 9 Build continuous improvement into the process 10 Balance flow improvement with conversion improvement 11 Benchmark	Questionnaire with 24 questions, completed by external evaluator through interviews answers from agent responsible for implementing LC philosophy in the company. Evaluate project by site visit and informal conversation with workers, authors don't extend the evaluation to whole company.	It considers whether the principle is "applied," is in "development" or "non applied" and also if the company has an interest in "implementation" and sees this as "opportunity"	Visual framework proposed by Rentes (2009), presenting the evaluation for the 24 questions
LCMM Nesensohn, C (2014)	Principles of LC developed by Koskela (1992)	1 Leadership - Lean leadership 2 Philosophy - Customer focus - Way of thinking 3 People - Culture & behavior - Competencies - Improvement Enablers 4 Processes & system - Processes & tools - Change 5 Outcomes & outputs - Work environment - Business results 6 Learning - Learning & competency development	Framework with 75 statements organized in 11 attributes classified in 6 layers, completed by external evaluator after a construction site visit and conversations with employees, evaluating each attribute in a quantitative way through a Likert scale from 0 to 4. The layers have weights which are multiplied by the lowest value of the attributes belonging to each layer. Allow project or company evaluation.	Range of absolute values of 5 categories (from 0 to 4): Uncertain; Awakening; Systematic; Integrated; Challenging	Radar chart with markers, presenting the evaluation for the 6 attributes
MMDPLC Soto, U (2016)	Principles of LC developed by Koskela (1992) & principles of LT developed by Womack & Jones (1996) & concepts proposed by Diekmann et al. (2004)	1 Waste disposal - Optimization of the production system - Optimization of the work package - Supply chain management - Optimization of production planning 2 Standardization - Visual management - Definition of work process - Organization of the workplace 3 Culture / people - Organization commitment - People's commitment - Training 4 Customer focus - Optimization of value - Flexibility of resources 5 Continuous improvement / Quality - Measurement - Organizational learning - Defect response - Error prevention	Self-assessment questionnaire applied by internal evaluator, evaluating 16 LC practices on a Likert scale from 0 to 5, organized in 6 principle. Allow project or company evaluation.	Range of absolute values of 6 categories (from 0 to 5): Sustainable; Integrated; Established; Formal; Initial; Non existent	No presentation of the results model is proposed
DOLC Carvalho, B. and SCHEER, S. (2017)	Principles of LC developed by Koskela (1992) & Carvalho (2008)	1 Reduce the share of non-value-adding activities 2 Increase output value through systematic consideration of customer requirements 3 Reduce variability 4 Reduce the cycle time 5 Simplify by minimizing the number of steps and parts 6 Increase output flexibility 7 Increase process transparency 8 Focus control on the complete process 9 Build continuous improvement into the process 10 Balance flow improvement with conversion improvement 11 Benchmark	6 questionnaire, with about 30 questions each, applied by external evaluators to internal agents (designer, engineer, worker, director, supplier) and external (client) of the company. Free answers (qualitative) that the evaluator should quantify on a Likert scale from 0 to 3. Evaluate construction site, authors affirm that evaluating more than 3 projects, results could be used to represent whole company.	Percentage scale of 4 classes with 3 subclasses each (from "D" to "AAA"). The steps are uniform except the lowest grade that is bigger than the others	Radar chart filled out, presenting the evaluation for the 11 principles of LC

LEAN CONSTRUCTION MATURITY MODEL (LCMM)

The MM developed by Nesensohn (2014) evaluate statements related to LC distributed in attributes. The statements should be evaluated after a site visit and dialogues with agents of the project by an external or internal evaluator, being possible a self-assessment. The author affirms the need of calibrating the weight proposed for every attribute by applying the tool in different projects and allow the evaluator to modify them according to the values and vision of the evaluated company (Nesensohn 2017; Nesensohn et al. 2014, 2015).

In this case study were used the author of the method proposed weights and consider just project evaluation instead of company evaluation.

MATURITY MODEL FOR DEVELOPMENT OF LEAN CONSTRUCTION PRINCIPLES (MMDPLC)

Soto (2016) model, called MMDPLC (Modelo de Madurez para el Desarrollo de los Principios Lean Construction, in Spanish), propose a self-assessment tool that verifies the company's expectation about its adherence to the LC principles and the effective adherence to LC practices. No scale is proposed either a result presentation.

The author applied the proposed model through a site visit and dialogues with professional workers of this project, assessing their expectations and the real application of lean practices just in the project instead of a whole company.

DEGREE OF LEAN CONSTRUCTION (DOLC)

Of the six questionnaires proposed by Carvalho and Scheer (2017), based on Carvalho (2008), five were applied to the following agents: designer, engineer, worker, director and client. Fill out the supplier questionnaire could not be donned because there was no supplier adherence to the research. Nevertheless, the authors believe that the data collected are representative enough to this paper propose.

Carvalho and Scheer (2017) also recommend the application of this MM through external interviewer that has knowledge of LC in order to answer doubts of the interviewees. Although interviews were carried out with actors from different departments and about company procedures, this model had been applied in one construction site, so the results are just for this project not for all firm.

RESULTS

Following are the visual tools and radar charts developed by the application of the selected methods according to the previously described methodology. Is possible identify in the charts the evaluated factors, the valuation scale proposed by each author, the project adherence of each factor (through the filleted area in the charts) and the final classification of the project (percentage shown in the legend of the chart). Figure 1 present Hofacker et al. (2008) results in a radar chart with six evaluation factors, project most adherent factor was "client focus" with 54% and the project range for this method is 45%.

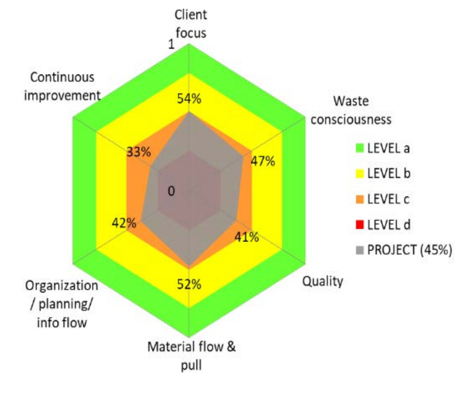

Figure 1: Project evaluation with LCR method (own elaboration).

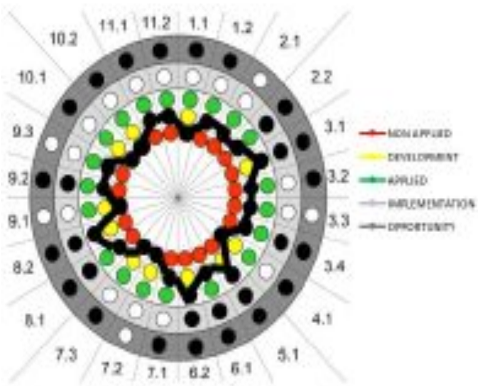

Figure 2: Project evaluation with MDCE original method (own elaboration).

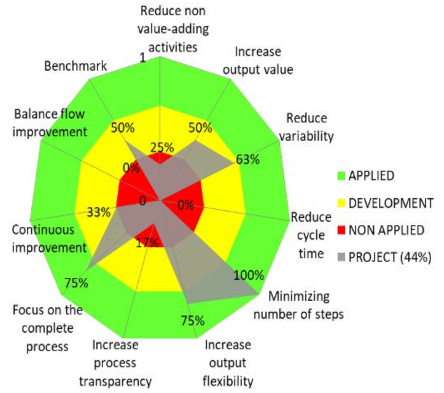

Figure 3: Project evaluation with MDCE adapted method (own elaboration).

Figure 4: Project evaluation with LCMM original method (own elaboration).

Figure 5: Project evaluation with LCMM adapted method (own elaboration).

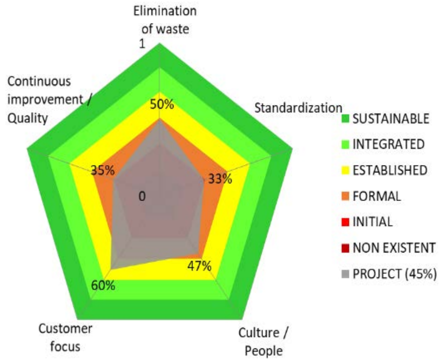

Figure 6: Project evaluation with MMDPLC method (own elaboration).

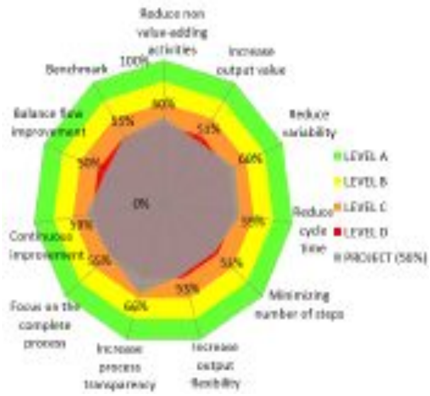

Figure 7: Project evaluation with DOLC method (own elaboration).

Figure 2 present a visual framework proposed by Arantes (2010) with 24 evaluation factors in tree scale results and with two others classifications: if the company has an interest in "implementation" and sees this as an "opportunity". Figure 3 present adapted Arantes (2010) radar char, with attributes evaluation by eleven LC principles by Koskela (1992), the value presented for each principle was the average value of statements related to them, were project had 44% adhesion.

Figure 4 present radar chart based on original Nesensohn (2014) method, considering the lowest statement value for each attribute, author propose that the project only grow to another level after filleted out all gaps of the current level, were project adhesion to evaluated principles is 20%. Figure 5 present adapted Nesensohn (2014) radar char, with attributes evaluation by statements average value, were project had 35% adhesion, shown that original the evaluation method is rough in fact. The results scale had been adapted from absolute values to a percentage scale

Figure 6 present Soto (2016) radar chart was project had 45% adhesion to LC evaluated practices. This method does not present a graphic representation, so the authors adapted the results for this radar chart with percentage scale to better compare with the other methods. Figure 7 present Carvalho (2008) model original radar chart result with 56% adhesion to LC principles.

DISCUSSION

It is observed that the five applied methods have differences and similarities, one of the main difference is the final scale results that classify project adherence to the analyzed parameters. Figure 8 presents a scale comparison of each method classification, showing the project position in each MM.

From the presented scales, those of Hofacker et al. (2008) and Carvalho and Scheer (2017) are originals from the model, the others were adapted, as previously described. Whit exception of Carvalho and Scheer (2017), the ranking levels has homogeneous ascension in lean journey.

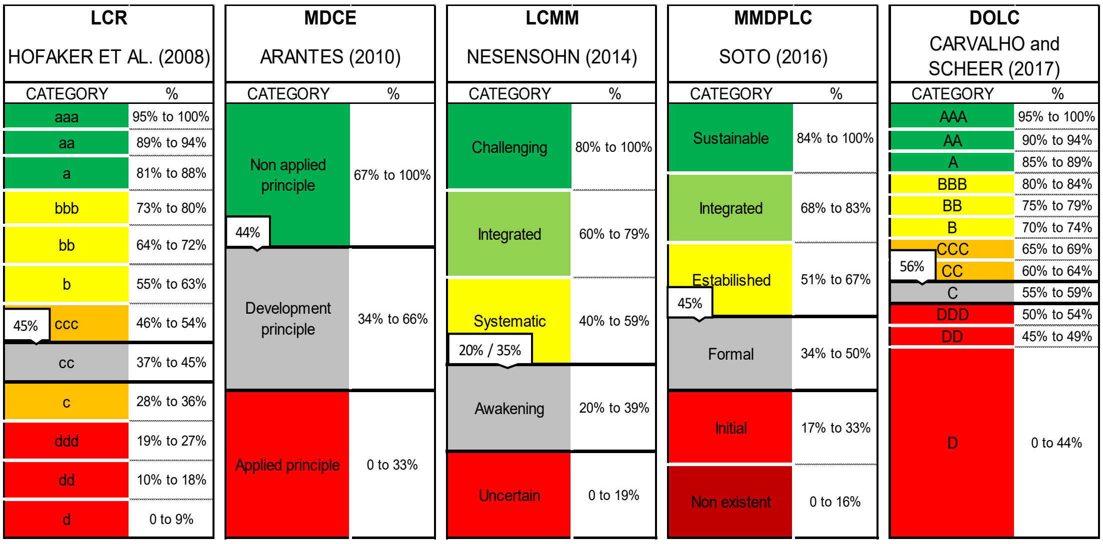

Figure 8: Comparison between the ranking scales of the models (own elaboration).

The applied MM have distant origins, this shows how different countries are concerned about assessing performance in LC philosophy and country progress in this journey. Lucena and De Mori (2018) analysed six Brazilian MM and concluded that DOLC method was an ideal application to evaluate Brazilian companies, not just each project. Carvalho and Scheer (2017) compiled papers that applied DOLC method in Brazilian projects and observed low adhesion and knowledge of the companies to LC. However, Salvatierra et al. (2015) evaluated LC awareness of Chilean companies and results confirm the Chilean pioneer in the LC application.

LCMM and MMDPLC propose self-assessment while others propose a third parties evaluation. The data collection method also differ, LCR, LCMM and MMDPLC use on-site visit and conversation with agents while DOLC and MDCE use structured interviews.

After evaluate the same project with five MM, the LC range of adherence was between 20 and 56%, below the scale average of all authors proposed range, validating the five applications on this project since it does not apply LC formally. Considering six results, because of two different applications of LCMM, the average among all methods is 41% and all classifications had been below the central level of adhesion.

More levels scales have greater sensitivity to company development in the lean journey, with this the practices to be implemented get better orientation and the answers to the advancement efforts get more directed in LC trajectory. Mainly in the initial implementation phase of this philosophy where the change resistance as huge and is difficulty assimilating lean behavior.

Researches of GEPUC presented the Lean Triangle (Salvatierra et al. 2015) on each vertices represent fundamental points for the LC application, they are: culture, technology and philosophy. The methods used in this case study evaluate all triangle vertices, but by different approaches. LCR, DOLC and MDCE focus on tool application and philosophy itself, LCMM and MMDPLC assess accurately the culture organization evolution.

CONCLUSION

Considering the data presented, are claimed about each method:

- LCR: focused on-site evaluation, restricted to a few questions and affirmations that allow a wide of answers due to the LC plurality, and the results can be distorted when different interviewers applied it or by the proposal data collection may be superficial;
- MDCE: focused only on the implementing LC agent, which can distort the results by the biased view of the interviewer, besides few classification levels can be limited the company's progress evolution in LC journey;
- LCMM: statements proposed to cover the diversity LC practices application, allows self-assessment requiring impartiality by the respondent, the classification scale is consistent with the advanced levels of LC, the attributes evaluation are rigorous;
- MMDPLC: evaluate the company's expectation about the principles and about the effective LC practices, as well as LCMM the evaluation of the practice as objective and broad at the same time, no visual results presentation but reveals project strengths and weakness and focus on what should be better applied, being a self-assessment tool request impartiality application;
- DOLC: covers internal and external project agents, demands strong adherence of the company and interviewed, may reflect the agents' expectations regarding their responses. The resulting scale with greater amplitude in the lowest level is coherent do to initial difficulty of the LC implementation, but as in the LCR responses may distort the real scenario.

After that, the authors consider LCMM the most appropriate method regards the application, results presentation and project final classification for this case study. For the Brazilian construction scenery, the maturity lake on LC application, Carvalho and Scheer (2017) reproduce the manager seizure when star the LC journey, questioning "how could I start". Nesensohn (2014) and consults experts answer that, this MM provide guidance to companies at any point in LC journey, making clear and exemplifying the plural practices of this philosophy, evaluating fundamental points of LC implementation.

LCMM method application is easily comprehended by researchers and construction site employees. Method application demand short time and adhesion of project professionals however broadly evaluate LC, embracing the plural presentation of this philosophy. The statements evaluated show examples of LC implementation and guide journey to the next level.

Nesensohn (2017) propose to each company use different attributes weight according to its values, allowing adaptation of the model to any market niche as well as increase the adhesion of employees to that. Nesensohn (2014) see the LC implementation journey as a permanent challenge without a higher level definition, because of construction processes are constant evolution and demand reinvented LC practices. This method is also best in organization culture evaluation, one of GEPUC Lean Triangle vertices, and it's the hard ascending levels used in this pepper.

The authors point out that is interesting for companies who start lean journey and use LCMM guidance's, use the average of statements to the attribute value because, in this early stage, small evolutions can be misrepresented by the use of lowest statement value for the attribute, as proposed by Nesensohn (2014).

For future work, it is proposed a tool development for specific decision-making process to be applied prior the LCMM in order to verify the vision, mission and value most correlate attributes for the company and adjust its weights. In addition is necessary to apply this method in companies or projects with different lean maturity levels to validate the scale classification sensitivity.

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STREAM 18: INFORMATION TECHNOLOGY IN CONSTRUCTION

Shou, W., Wu, P., and Wang, J. (2019). "A Survey of Simulation Modelling Techniques in Lean Construction Research." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1093–1104. DOI: https://doi.org/10.24928/2019/0142. Available at: <www.iglc.net>.

A SURVEY OF SIMULATION MODELLING TECHNIQUES IN LEAN CONSTRUCTION RESEARCH

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ABSTRACT

Over the past two decades, discrete event simulation (DES) has been increasingly employed in lean construction research as a response to the requirement of evaluating the impact of the implementation of various lean initiatives. A systematic review of DES application in lean construction research is necessary to examine how DES has been implemented in lean research. This review was conducted by reviewing 49 DES papers published in peer-reviewed journals and IGLC conference between 1997 and 2018, which aims to identify the state of the art development in this specific research area and propose future research directions. The papers are analysed in terms of publications, DES techniques, value of DES, and topic coverage. 13 types of DES techniques, 6 value of DES in lean construction research, and 8 research topics are identified and summarised. The findings of this study are expected to provide useful suggestions for the future research opportunities of DES in lean construction research.

KEYWORDS

Lean construction, discrete event simulation, review.

INTRODUCTION

Discrete event simulation (DES) has attracted increasing interest in lean construction research, which has been applied to evaluate and validate the effectiveness and efficiency of the proposed lean model as a response to the requirement of evaluating the applicability of lean principles and measuring their impact on the studied processes before to be applied in real project.

Lean construction is a management philosophy which conceptualised in three complementary dimensions: transformation, flow and value (Koskela, 1992). It is built based on Toyota production system to develop a construction workflow characterised by reduced waste, and increased value to customer through continuous improvement, in which the workflow management is improved by re-engineering construction processes based on

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lean principles (Jørgensen & Emmitt, 2008). Lean construction can be viewed as a combination of lean strategies and support lean tools to deal with variability in highly dynamic and complex systems (Thomas et al, 2002). In order to verify the benefit of changes in the complex environment, an analysis of the empirical evidence to assess the impact of the implementation of lean construction prior to real world application is needed (Shou et al, 2017). Therefore, DES is suitable for modelling complex environment and virtually simulating and assessing the efficiency and effectiveness of the lean-improved construction processes.

In response to this trend, DES was introduced into lean construction research in the 1990s and has been increasingly applied in this area because of its capability to test for the marginal contribution of each lean intervention (Agbulos et al, 2006). This method can also establish an improved construction plan to validate the results of the live experiment by overcoming its technical limitations. Sacks et al (2007) used DES to explain actual production changes in construction projects and remove the learning curve effect.

DES has been increasingly utilised as a key method to addressing issues such as the limitation of static view provided by value stream mapping (VSM) (McDonald et al, 2002), education of lean concepts (Robinson et al, 2012), and production planning and control (Bokhorst & Slomp, 2010) in lean research. Furthermore, DES has been gradually applied as functional tools to facilitate lean construction research in specific area, such as environmental management (Golzarpoor et al, 2017), capacity management (Miclo et al, 2018) and supply chain management (Zuting et al, 2014).

Mostafa et al (2016) conducted a review of lean and agile integration within offsite construction using DES. Poshdar et al (2016) proposed a conceptual modelling as an effective solution to enhance the success of a lean construction simulation study. However, these studies focus upon specific area and therefore lack detailed discussions on the development of DES application in lean construction research.

Therefore, this study aims to understand the state of the art and propose future DES applications in lean construction research by conducting a thorough review of DES assisted lean construction research. three specific objectives are proposed as follows: (1) recognise the DES software developed during the said period, (2) identify the value created from applying DES techniques, and (3) examine the evolution of topics of DES assisted lean construction research papers during the retrieved period.

RESEARCH METHOD

There are three stages of the paper retrieving process. In Stage 1, Web of Science and Scopus are the two academic databases have been selected to identify the related papers published. Keywords, such as ‘DES’, ‘discrete event simulation’, ‘simulation’ and ‘lean construction’, were used in the ‘title/abstract/keyword’ fields. The papers published in the conferences of International Group of Lean Construction (IGLC) over the years were included in the review as it is the platform to showcase all these lean construction research efforts since the initiation of lean production research in the construction sector. The stage 1 search results in a total of 167 papers.

In stage 2, a visual abstract and content review of the retrieved papers was conducted to remove less relevant or irrelevant papers from the search result in stage 1. A total of 49 articles were screened for future analysis.

In stage 3, contents analysis of the retrieved papers were conducted. The final retrieved articles were quantitatively analysed in terms of years, DES software, the value created, and lean construction research topics to determine their contributions. From Table 1, IGLC has the largest number of publications on this topic, Journal of construction engineering and management is the most utilised journal.

Table 1: number of related papers in selected journal/conference papers

Publication	No.
IGLC	22
Journal of Construction Engineering and Management	9
Automation in construction	4
Construction Management and Economics	3
Construction Innovation	2
KSCE Journal of Civil Engineering	2
Lean Construction Journal	2
Canadian Journal of Civil Engineering	1
Journal of Cleaner Production	1
Simulation	1
Sustainability (Switzerland)	1
Revista Ingenieria de Construccion	1

OVERVIEW

THE PUBLICATIONS DISTRIBUTED BY YEARS

Figure 1 demonstrates the publications on DES-based lean construction research started in 1997, with the small increase in the number of publication to 2004, followed by a soaring increase in the next 4 years, 31 papers have been published during 2005 to 2009. However, from 2010, short decreases have been observed, ranging from 13 papers between 2010 and 2014 to the 8 papers between 2015 and 2018.

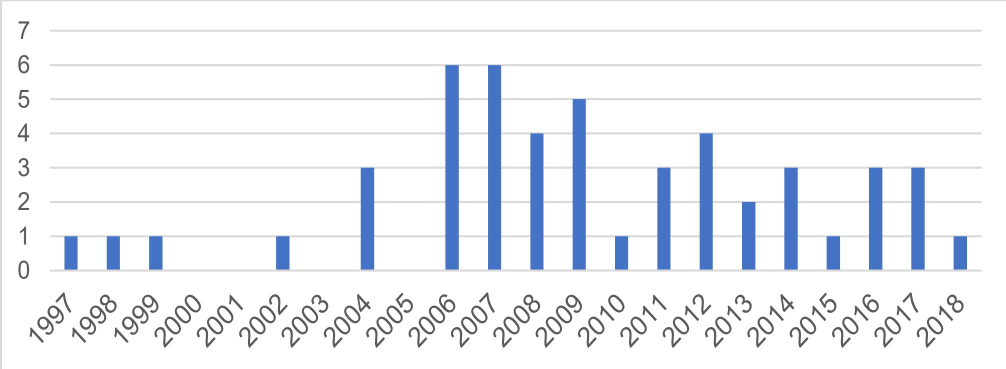

Figure 1: the publications distributed by years

DISTRIBUTION OF DES SOFTWARE

The following Table 2 shows the 13 different DES software has been used. STROBOSCOPE (State and resource-based simulation of construction processes) is the most popular simulation software used in construction sector with number of 11 references. Moreover, Simphony, Arena, CYCLONE (cyclic operations network), and ExtendSim are also popular simulation techniques in the existing articles.

Table 2: The DES software used by DES-based lean research

DES software	No.
STROBOSCOPE	11
Simphony	6
Arena	5
CYCLONE	5
ExtendSim	4
Anylogic	3
Extend	2
Extend+BPR	2
ProModel	2
EZStrobe	2
JaamSim	1
OSim (Objektsimulator)	1
SIGMA	1

THE VALUE OF DES IN LEAN CONSTRUCTION RESEARCH

Table 3 shows the distribution of articles by the value created from applying DES techniques. 6 types of value are summarised. Simulation can be used to (1) model system to create a visual view of the process. The analysis of current performance to present the need for change, which provides a better understanding of the process dynamics to engage participants; (2) assess the effectiveness of the proposed lean systems to understand the intended benefits; (3) evaluate the alternative lean scenarios to predict and evaluate change outcomes; (4) assist with the decision to replace an existing production process with a lean system by quantifying the benefits in their specific situation; (5) measure the studied impact of lean improvement on the system by comparing pre- and post-improvement performance; and (6) validate the results of live experiment by overcoming its technical limitations.

The first observation is that many of the references coved more than one type of value. Clearly, vast of the publication is in 'alternatives evaluation to design, test and improve lean systems'. Indeed, evaluate the impact of the implementation of various recommendations is at the core of the current simulation application (Sharma et al, 2006). The 'what-is' scenarios evaluation can illustrate how production choices may affect the quality of delivery of a project. Followed by 'effective assessment to understand the intended benefits of the proposed improvements' with 17 references.

Table 3: The Functionalities of DES-based Lean Construction Research

No.	Functionalities	No.
1	Visualisation of the interactions between systems to explain variations in the current process	6
2	Effective assessment to understand the intended benefits of the proposed improvements	17
3	Alternatives evaluation to design, test and improve lean systems	25
4	Benefits quantification to assist the decision to replace an existing production process	4
5	comparison of pre- and post-improvement performance to measure the studied impact of lean improvement	5
6	Validation of the results of the live experiment	4

THE TOPICS RELATED TO DES-BASED LEAN CONSTRUCTION RESEARCH

Even though a short decrease has been observed, the publication still witnessed an overall increasing trend. Thus, summarising the topic coverage of the identified DES papers is necessary. By content analysis, this study reveals that eight topics in DES-based lean construction research are categorised, namely, (1) construction operations, (2) buffering, (3) sustainable construction, (4) production systems design, (5) agile, (6) task management, (7) design management, and (8) supply chain. All the identified papers are classified according to the main research issues solved.

The Evolvement of DES-based Lean Construction Research

Table 4 presents the number of publications of identified research topics during the studied period. It indicates that the greatest research efforts on lean construction application have been made in “construction operations” but given the least attention to “supply chain”. It is notable that the research interest in “design management” and “sustainable construction” have been rising since 2009. This research can’t demonstrate all the relevant studies in this area due to the limited search scope, but the research is also able to reflect the overall development of the research trend of DES-based lean construction research.

Table 4: The Distribution of Topics Related to DES-based Lean Construction Research

Topics	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**Total**
Construction operations	1	1	1					1		5	4	2	3		1	3	1	1		2	1		27
Production systems design						1				1	1	1									1		5
Buffering								1			1		1			1							4
Design management													1	1								1	3
Sustainable construction															1		1				1		3
Task management																		2	1				3
Agile															1					1			2
Supply chain								1															1

“Construction operations” began with the application of DES to describe lean construction concepts (Tommelein, 1997). The research in this topic focused on using DES to evaluate lean principles and measure their impact on the studied operation processes. Velarde et al (2009), Han et al (2012), and Ritter et al (2017) studied lean and simulation application in modular construction. From 2012, a new hotspot was Building Information Modelling (BIM) integrated construction operation simulation (Han et al, 2012; Jeong et al, 2016).

Research on "production systems design" is an important topic that DES enabled the representation of the performance metrics in the construction process, which illustrated how production system design choices may affect the project delivery. Schramm & Formoso (2007), Schramm et al (2008), Draper & Martinez (2002), and Draper & Martinez (2002) demonstrated the usefulness of DES in improving decision making in production system design with the ability of evaluation of alternative designs. Li et al (2017) analysed production system based on the CONWIP method.

"Buffering", that may lead to the impact of productivity, was a research topic has been carried out in DES-based lean construction research. Alves & Tommelein (2004) have used DES to simulate buffering and batching practice in HVAC projects. Gonzalez et al (2009) used simulation to visualise and to design work-in-process buffer for scheduling repetitive building projects. Srisuwanrat & Ioannou (2007) investigated lead time buffer under uncertainty, Gupta et al (2012) used simulation to understand the relationship between productivity and buffers.

"Design management" is a DES-based lean construction research topic that emerged in 2009. This topic includes the study of the role of design matrix in reducing waste (Khalife et al, 2018), iteration and feedback loop in design(Hossain & Chua, 2009), scheduling models for multiple design projects (Liu et al, 2009).

DES was proposed as a quantitative method to measure the sustainable waste during the production process. Golzarpoor et al (2017) and Golzarpoor & González (2013) used simulation to assess production and environmental waste in the construction process. DES was regarded as an efficient method to demonstrate the benefits of changes in applying lean on sustainability (Song & Liang, 2011).

Hamzeh et al (2015) and Al Hattab et al (2014) used the DES to simulate task management in lookahead planning. Gurevich & Sacks (2014) examined the effects of the proposed KanBIM production control system on task selections.

The integration of lean and agile has been a new area of research. Lu et al (2011) and Mostafa et al (2016) both utilised DES to evaluate and validate the effectiveness of the proposed lean-agile model.

The application of lean and simulation in supply chain has only been discussed in one article on time study in supply chain process (Huang et al, 2004).

DISCUSSION AND CONCLUSIONS

This paper provides a systematic review of the state of the art of DES assisted lean construction research by reviewing papers published in peer-reviewed journals and IGLC conference from 1997 to 2018. 49 DES-based lean construction research papers were identified and analysed in terms of year, value of DES, DES software, and topics. The review shows the trend of studies and DES techniques for lean construction research. The number of relevant publications indicates a growing research interest in this area.

Results of the DES software identified in this study illustrated the most popular simulation techniques which have been adopted in the construction sector. STROBOSCOPE is a programming language designed for the simulation of processes common to construction engineering (Martinez & Ioannou, 1994), Simphony is unique to provide an environment that supports building simulation environment (AbouRizk et al, 2016), CYCLONE is a construction-oriented simulation technique (Senior & Halpin, 1998), and EZStrobe is a general-purpose simulation program designed for modelling construction operations (Draper & Martinez, 2002). They are the DES software designed for construction processes and have been widely applied. Anylogic is a simulation tool support DES, system dynamics, and agent-based modelling, has become a new trend of modelling tools to be applied in lean construction simulation.

The classification of DES value facilitates the application of DES. The results provide evidence that DES simulation is mainly used to investigate a wide variety of what-if scenarios about the real world system and evaluate suggested lean construction techniques to existing systems.

The eight applications of the DES-based lean construction research in the categorised topics provides evidence that DES was mainly applied in simulating lean application in general construction operations, which also indicate that lean construction contributes to planning and control in construction projects. The analysis also indicated that lean construction for sustainable construction, task management, and agile construction are the new trend of application since 2010.

Obviously, the identified 49 papers might not cover all the papers related to DES applications in lean construction research because of the retrieving rules designed. One future research direction is to conduct the review with a larger number of papers. An interesting avenue for future research is an evolutionary analysis of the simulation software applied within the topics classified, which could extent the understanding of the development of techniques as well as the interests in lean construction research.

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APPLICATION OF VIRTUAL AND AUGMENTED REALITY TECHNIQUES DURING DESIGN AND CONSTRUCTION PROCESS OF BUILDING PROJECTS

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ABSTRACT

Research regarding Virtual Reality and Augmented Reality (VR/AR) as support tools of visual managment of design and construction for building projects has increased notably in recent years. However, most of these investigations present applications that improve the management of the project in a single phase or aspect, leaving aside the generation of value throughout the entire project. This article presents a brief review of the current state of VR / AR technologies, proposes the application of the Lean philosophy trough VR / AR applications in the different phases of the life cycle of a building project, and also shows several applications in real cases in which encouraging intial results were obtained. The proposed applications proved to be efficient to improve the communication between the different stakeholders, improving the understanding of the project, giving reliability to the decision making process, foreseeing errors, decreasing negative iterations and avoiding the time delays generated by the lack of an adequate visualization of the project. Finally, some recommendations about the nomenclature and standarization of the development level of the VR/AR applications are provided.

KEYWORDS

Virtual reality, augmented reality, visual management, value, waste

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INTRODUCTION

Traditionally, the design of the buildings has been represented in 2D drawings. This type of communication hinders the transmission of information among those involved during the different phases of construction projects, due to the additional work required to interpret plans or documents. The defects and re-works produced by the misinterpretation of plans and specifications during design and construction process can be avoided with the inclusion of technologies such as Virtual Reality and Augmented Reality as complementary tools to BIM models. These technologies improve the transmission of information between the design, supply and construction team, as well as communication between the project team and non-specialists stakeholders as investors and end users, allowing them to add more value during the design of the project.

VIRTUAL AND AUGMENTED REALITY TECHNIQUES

VIRTUAL REALITY

Virtual reality (VR) is defined as the virtual simulation of environments that allows the end user to interact in realistic three-dimensional simulations (Sherman and Craig, 2018). In simple terms, it is any artificial space generated by computer in which it is possible to live experiences that are not happening at that moment or in that place.

VR technology has advanced exponentially in recent years and is being applied in different industries to improve the productivity and competitiveness (Krasnov, 2018). In the fields of architecture, engineering and construction, VR is receiving considerable attention in recent years since allows to reduce project costs, delivery time, quality problems, among others.

The development of a VR experience for a building project involves processes of modeling the architectural proposal and generating the virtual environment. Figure 1 shows the complete process summarized in three stages and presents some of the most used software in each stage of the process, as well as the selection path according to their compatibility. In the first stage, CAD drawings are simplified to only schematic references. The most used software in this stage is AutoCAD. Once the simplified architectural information has been obtained, in the second stage the model is imported into a 3D modeling program, in which the architectural information is extruded (i.e. walls, columns, beams, among others). According to a survey conducted by Unreal Engine (Unreal Engine, 2018), the most used softwares for this stage are Archicad, Rhinoceros, Revit, 3ds Max and Sketchup. Also, in this stage, preliminary textures of the materials of the building project are defined and integrated into the model, resulting in a 3D model with textures. In the third stage, the preliminary 3D model is imported to the VR software and the location coordinates of the model are defined. Also, exterior views may be included in the model which are based on real environments captured by photos or videos, or imaginary environments simulated by computer. Then the model undergoes an optimization process in which the visual features are included to improve the user experience. This stage may include lighting configuration as well as the asssignment of specific properties to the textures of the materials such as relief, reflection, transparency, etc. In this stage the animations of objects and information windows that are required within the model are also defined. Among the most used softwares for the development of virtual environments are Unreal Engine and Unity that allow the construction of sophisticated experiences. The information in Figure 1 has been connected according to system (packages) of software families considering compatibility with the system design. The proper selection of software families is an indispensable process to avoid loss of information in all the process as well as to improve the effienciency of the VR/AR development process.

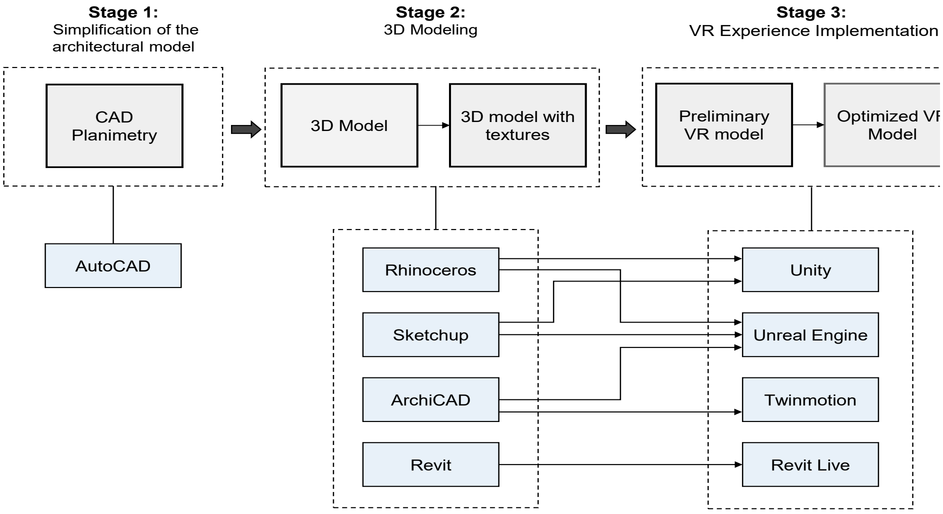


Figure 1. General outline of the implementation process of a building project using VR

AUGMENTED REALITY

Augmented Reality (AR) is a technique that enables users to interact with their physical environment through the overlay of digital information (Gruberte et al, 2017). AR can be considered a type of VR in which the real world is not replaced by a virtual one, the real world that the user observes is preserved and complemented with virtual information (Sherman and Craig, 2018). Currently, AR applications run on a wide range of devices, such as cell phones, tablets, PCs, or specific viewers for this function.

As shown in Figure 2, the developing process of a building project in AR presents three stages: the simplification of the architectural model, the 3D modeling and the development of the AR application. The first two stages are similar to those described in the generation of the VR experience. The third stage involves importing and processing the 3D model into an AR software and the creation of the AR application. Among the most popular and open-access AR softwares are Unreal Engine 4 and Unity. The use of Software Development Kits (SDK) facilitates the generation of the applications according to the platform in which they are going to be executed (Android, iOS, Windows), since they serve as an interaction channel between the graphic engine and the device to use (Amin and Govilkar 2015). The different methods to project a digital object on the device screen are based on the recognition of a target. The target can be an image, a pattern or a pre-defined object. In the case of construction projects, the design (2D) drawings or scenes from the workplace are usually used.

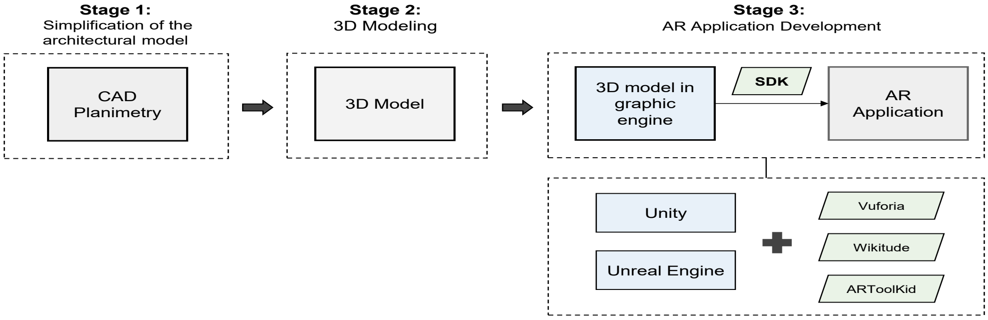


Figure 2. General outline of the implementing process of a building project using AR

VR/AR IN CONSTRUCTION PROJECTS: REVIEW OF RECENT PUBLISHED LITERATURE

In order to understand the current state of research related to VR / AR in the construction field, a thorough search was carried out in Scopus, Web of Science (WoS) and IGLC databases with the following terms: ("virtual reality" OR "augmented reality") AND construction AND building AND (LIMIT-TO (SRCTYPE, "p") OR LIMIT-TO (SRCTYPE, "j")). From this search, 498 results of articles in journals or conference proceedings were obtained, of which 494 are from the WoS and Scopus databases and 4 are from the IGLC procedures (one from 2005, one from 2012 and two from 2018). Analizing these results, a growing acceleration of scientific production was identified, in which published research in 2018 increased more than 100% with respect to 2017. With the aim of a more detailed analysis, the search was limited to publications from 2018 onwards. From this analysis, 59 occurrences were obtained which were classified as shown in Table 1.

Table 1. Classification of articles published from 2018 onwards on VR/AR in the construction industry

Type	Description	N° of Scopus and WoS articles	N° of IGLC articles
Technology	Articles focusing on the development of technological solutions and on the benefits of applying VR / AR in the construction sector.	20	0
Application	Articles presenting one or more applications of VR/AR technologies to the construction sector.	33	2
Review	Articles reviewing or criticizing publications on VR / AR in the construction sector.	4	0

The WoS and Scopus articles classified by *Application* were further selected to identify the application areas with the most publications. The results presented in Table 2 were obtained from this classification. The results show that each of the articles reviewed fits into only one of the proposed classifications, which shows that the research currently carried out focuses on only one type of application of the VR/AR technologies to the construction and commercialization sector. The integral application of VR/AR throughout the phases of Lean Project Delivery System (LPDS): Project Definition, Lean Design, Lean Supply, Lean Assembly and Use, contributes to generate value and reduce losses during the development of a construction project, which coincides with the philosophy of Lean Construction.

Table 2. Classification of articles of VR/AR Application to the construction industry

Classification	Nº of articles
Control of advance / Cost / Quality in construction project	7
Education	6
Design Review	5
Facility Management	4
Budget / Planning	3
Assignment of tasks in construction project	3
Others	5

VR/AR APPLICATIONS DURING LPDS PHASES

Some RV / RA applications were carried out in four building projects, each of the projects presenting at least one of the 5 phases of LPDS. These applications were tested, having an initial approval validation of the people involved.

DURING PROJECT DEFINITION PHASE

The Project Definition phase involves understanding and aligning the purposes of the stakeholders, especially those of the project owners and end users. In the Project Definition phase some constraints are evaluated such as site conditions, rules and regulations in order to propose the Design Concepts, which then are presented to the owner of the project (Ballard, 2008).

In the first round of meetings, the design concepts are presented which implies showing the minimum data necessary to obtain a first estimation of the economic and financial feasibility of the project, so that the project owner can validate their financial expectations. This evaluation requires defining the metrics that allow calculating the construction costs and the income from the sale of the product. Moreover, at this stage the project owner needs to understand the architectural volumetry of the design concept, in addition to the financial figures. Although pencil and paper drawings probably continue to be useful tools for presenting design concepts alternatives, virtual 3D models may play an important role (Ballard, 2008). AR can facilitate the process of understanding and visualizing using simple technological devices.

In this line, to evaluate the potential of these technologies at the definition stage, AR was used in a building project. Figure 3 shows the application of AR using a smartphone for the visualization of areas and volumes. The 2D plan drawings of the design proposal zoned by uses and costs were shown to the owner of this project. Then, the same design proposal was shown to owner using AR (Figure 3a), with an interactive color menu, which allows to turn on and off the different zoned volumes, using the 2D location plan as a target (Figure 3b). The owner of this project stated that the visualization of the project with AR was more complete, more reliable and that it would help to present the project to the other investors, who are generally not architects or engineers and therefore have limited knowledge for an adequate visualization of the projects.

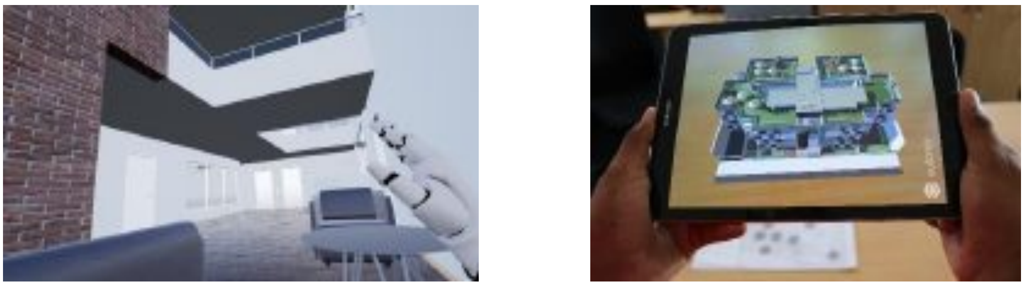
(a) (b)

Figure 3. Application of AR to evaluate a design concept: (a) volumetric model in Augmented Reality, (b) 2D plane as target.

DURING LEAN DESIGN PHASE

During design development, the approval of the project owner and end user is crucial. This approval is mainly based on the final architectural proposal and thus, the correct visualization of the spaces during the development of the project allow to corroborate the design with the owner and the end-user, generating value and avoiding the frequent time-delays and losses due to innecesary rework and negative iterations.

Figure 4a and 4b show the indoor common areas (lobby) in VR and the outdoor common areas (roof) in AR of a construction project in the design phase. For the development of the virtual models, the VR/AR development team interacted with the owner and the architecture and structural design team to acquiere information regarding the use of the spaces. The architect of this project mentioned that the VR/AR helped to confirm the proper dimensioning of the spaces, as well as to complete the textures and colors of the materials. The structural engineer mentioned that even though he knew the project, the VR improved his visualization . The owner was the one who benefited the most since the VR visualization helped him to have more security to approve the project.



(a) (b)

Figure 4. VR/AR visualization during the design process a) Visualization of interior spaces with VR b) Visualization of exterior spaces with AR

EVALUATION OF USER SATISFACTION DURING LEAN DESIGN PHASE

End user satisfaction can be validated when the design is finished. Figure 5a shows the implementation of VR of the interior of an apartment. For this, a drone was used (Figure 5b) to obtain 360° photographs of the urban surroundings at different heights according to the floor levels of the buildings. As shown, this experience allowed the end-user to observe the details and textures that the apartment will include. The end-user can also approach to the windows and balcony and observe the exterior scenery that the apartment will have in real life from the height that is located (Figure 5c). The experience also allows the user to interact with doors, lights and objects, as well as shows videos on the TV screen.

(a) (b) (c)

Figure 5. a) VR Department view b) Use of the drone to obtain 360° photographs c) Incorporation of the 360° photograph inside the model

The use of VR adds the experience of the end-user as an input for design, being an innovative approach that goes beyond the traditional resources such as the experience of the designer and the corresponding regulations (Ventura et al, 2018). These evaluations can be done interactively during the design process and also after completion, both to validate the quality of the design before the construction, and to support real estate pre-sales with less cost compared to a pilot apartment. Figure 7 shows the results of a survey of 20 potential buyers of an apartment, during a real state fair. The results evidence that VR significantly improved the end-user experience regaring the proper visualization and understanding of the project.

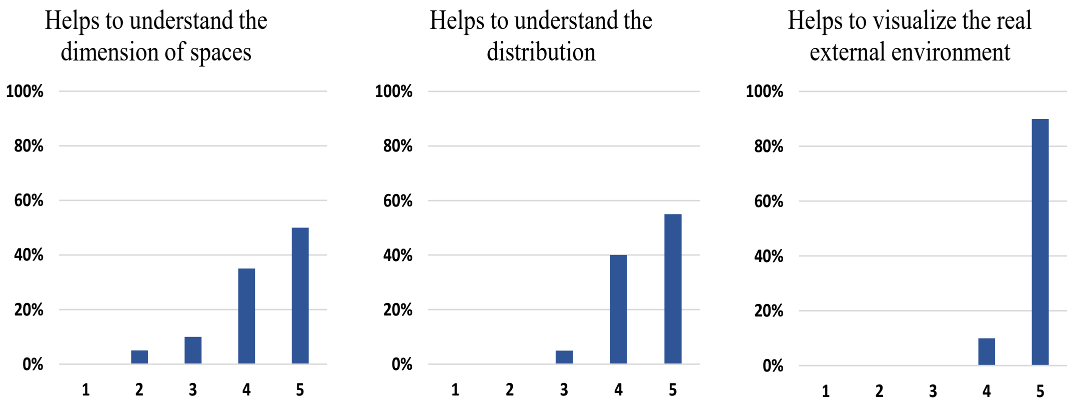


Figure 7. Results of the interview with potential end-users (20 people interviewed)

The end-user satisfaction is determined by three aspects: a) the location in the city, b) the urban environment and c) the building features (Orihuela and Orihuela, 2014). If the designers of housing programs could count on this verification in earlier stages of the project, the adjustments could be made according to reality and with the requirements of the buyers, avoiding future problems (Silva et al, 2019). For the evaluation of the third aspect referring to the building features, there are 15 attributes valued by end users. The most appreciated attributes apart from safety are architectural distribution, lighting and internal and external visual comfort (Orihuela and Orihuela, 2014) (Silva et al, 2018). These attributes can be measured effectively using Virtual Reality.

Another advantage is the possibility of showing a pilot apartment at any time and place as opposed to a real models that needs a fixed space and constant maintainance. It also offers some technical advantages such as showing an outside view, offering the buyer a safer purchase decision.

During Lean Supply and Lean Assembly phase

In the Supply phase, VR model is useful for visualizing the information contained in the detailed drawings, especially in the areas of services and kitchens and also in the finishing specifications, which is used for budgeting and purchasing issues. Figure 8a shows an VR application that displays a windows with the specifications of some finishes which are activated when the handle is positioned over the objects.

During the Construction phase, the Weekly Schedule as a part of the Last Planner System, specifies the tasks that have been released from their restrictions and that must be executed day by day, so their communication to the last planners must be very effective and friendly (Orihuela et al, 2015). Figure 5b shows an application of AR, where the target is constituted by an A4 sheet with the plant of the level under construction and the crew leaders or any worker with a cell phone can select any of the 6 days of the week and see which are the work fronts and the tasks that have to be delivered at the end of each day.

(a) (b)

Figure 8. VR/AR applications (a) VR to visualize specifications during the supply (b) AR to visualize the weekly work plan during construction

LEAN PRINCIPLES AND VR/AR APPLICATION BENEFITS

Table 3 shows a correlational matrix between the Lean Constructions Principles (Sacks et al., 2010) and the 5 phases of the LPDS, in which the VR/AR proposed applications are placed. The evaluation of other applications is an ongoing study. In future research work, the matrix could be completed.

During the Project Definition phase, the visualization of the volumes of the design concepts improves the communication between the project owner and the architect, which allows a quick validation of the design concepts. With these results, the principles in the matrix are checked.
During Lean Design phase, the visualization of the complete volume and the interior and exteriors spaces, allows to improve the communication inside, the design team and, between this team and the project owner. Also it allows having feedback from the potential users, other designers and the project owner. In more advanced stages of the design, these technoclogies may also allow evaluating the satisfaction of the potential clients.
In the Lean Supply phase, VR / AR technologies assist in the transmission of design information to the responsible supply team. In this way, the total understanding of the requirements and the acceleration and improvement of the quality of the budget and the offer is ensured.
Also, during the Lean Assembly phase, these technologies allows to understand the project and to comprehend the details of the design that influences the construction process, avoiding delays and additional work during construction. The AR allows to communicate in a visual way the scheduling of the building site to the ones involved in the project and to better understand the work to be done.

Table 3. Interaction of the Lean Principles and the phases of the project with the VR / AR applications

Lean Principles	Project Definition	Lean Design	Lean Supply	Lean Assembly	Use
Reduce variability					
Reduce cycle times					
Reduce batch sizes					
Increase flexibility	√	√			
Select an appropriete production control approach					
Standardize					
Institute continuous improvement	√	√	√	√	
Use visual management	√	√	√	√	
Design the production system for flow and value				√	
Ensure comprehensive requirements capture	√	√	√	√	
Focus on concept selection	√	√			
Ensure requirements flow down		√	√		
Verify and validate	√	√			
Go and see yourself					
Decide by consensus, consider all options	√	√	√	√	
Cultivate an extended network of partners					

RECOMMENDATIONS

From the review of the existing literature, it has been noted that the different authors do not use a standardized nomenclature to refer to the different visualization techniques. For example, the term VR is sometimes used to refer to any interaction with a 3D model, without differentiating it from the immersive VR. For this reason, it is necessary to create a glossary that standardizes the terms related to VR/AR aiming at facilitating the communication and diffusion of these techniques between researchers, designers, constructors and project owners. The authors propose the use of the concept of Levels of Detail (LoD) for dealing with VR or AR techniques in construction projects. Table 3 presents a summary of this proposal.

Table 3. Levels of Development (LoD) in Virtual or Augmented Reality projects

LoDs	Description
LoD 100	Basic level of visual information, such as areas, heights, volumes, location and orientation, applicable to interior and exterior spaces.
LoD 200	Same as LoD 100 but including textures, lighting, reflection and transparency.
LoD 300	Same as LoD 200, but includes other elements that improve the interaction with virtual reality (e.g. turn on and off lights, open doors, open taps and move objects).

CONCLUSIONS

The combination of VR and AR for the visualization of building projects, during their different phases of the life cycle, contribute significantly to avoid waste and to generate value. Its use in each of the project phases and in early stages can provide transparency and reliability in the decision making of those involved, avoiding future problems, such as negative iterations, waste, delays and rework. The use of each technique depends on the context in which it is to be applied. For desktop works such as the Project Definition phase and the initial part of the Design phase, VR is totally applicable. However, for field work such as the Construction phase, AR can be applied as its use only requires a target and a Smartphone or Tablet. The sudden increase in research into these new technologies, demonstrate that their application will radically change the traditional forms of visual management of building projects; the research in this area will certainly contribute to the development of the construction sector.

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LEAN AND BIM IMPLEMENTATION IN COLOMBIA; INTERACTIONS AND LESSONS LEARNED

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ABSTRACT

Construction projects are afflicted by cost and time overruns, primarily due to inadequate information sharing among the project participants that causes productivity reductions in the Architectural, Engineering, and Construction (AEC) industry. Therefore, by working on different areas of its value chain, it is possible to increase the construction process productivity. Building Information Modelling (BIM) emerged as a digital platform through which project teams can share and manage project information efficiently, and Lean construction practices address the issue of improving coordination within a project team, smoothing workflow in construction projects through features that reduce waste and increase value.

The present research is an applied study that comprises the analysis of the integration of Lean practices and BIM through a real-life implementation in a residential project. This paper contributes to knowledge on BIM and Lean adoption by showing how lean practices reduce coordination-related issues within the project construction, and BIM adoption makes the benefits of Lean principles more visible. Additionally, the literature still lacks specific examples of simultaneous implementation of BIM and Lean for the first time in medium-sized construction companies. The purpose is to report the experiences, opportunities for improvement, and lessons learned from the implementation. Findings show that independent implementation only solves a part of the problem. However, simultaneous implementation exposed the team to more exceptional experiences and opportunities for improvement.

KEYWORDS

Lean construction and BIM Interaction, case study

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INTRODUCTION

At the global level, a pattern of low productivity in the construction sector has become evident. The period between 1995 and 2015, evidences that the compound rate of growth of value added per worker in the sector was just 1.0%, while the economy was 2.7%, the gap is even more significant if compared to the industry manufacturing, where growth reached a rate of around 3.6% per year in this same period (McKinsey, 2017). It fits highlight that at the regional level and even within of the companies that make up the sector finds quite a heterogeneity. In fact, Colombia is not an exception. In Colombia, disruptive production delivery methods and technologies can increase construction productivity between 50% and 60%. For example, BIM has been reported to be in its experimentation stage for most AEC companies, but its adoption is continuously growing (Gómez-Sánchez et al., 2016). However, it is expected to grow even faster in the coming years due to the launching of the institutional platform for the articulation of actors around the digitization of the construction sector, *BIM Forum Colombia*, which seeks to standardize and disseminate BIM adoption nationally.

Additionally, according to Mossman (2018), Lean Construction would be more helpful to define Lean concerning its purpose than in its meaning. He concluded 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." Many different Lean principles are beneficial to the overall construction project's life cycle. On the other hand, BIM has been massively recognized as a platform which is related to improve the design-construction process through digitalization and has been defined as "not just a technology change, but also a process change" (Eastman et al., 2012).

Although these approaches are different initiatives, there exists a synergy between Lean and BIM that brings better results when implemented together than independently (Sacks et al., 2010). While BIM tackles the trustworthiness of information, Lean tackles the reliability of processes (Fosse et al., 2017). However, concerning the use of multi-disciplinary performance models (BIM) of design-construction projects that includes work processes and organization of the design-construction team, a new concept was pioneered by the CIFE (Khanzode et al., 2006) at Stanford University: Virtual Design and Construction (VDC). VDC focuses on aligning new technology related to BIM with Lean Thinking and practices (Kunz & Fischer, 2012) and VDC tools can be applied very effectively to accomplish the objectives of the Lean Production Delivery System (LPDS).

In this research, the authors proposed that the pursued value added could be achieved not only through the digitalization of the company's pilot's project traditional workflow because the current full potential for improvement of construction projects "can be achieved when the adoption of Lean and BIM adoption is integrated" (Sacks et al., 2010). Therefore, this paper discusses the lessons learned from the simultaneous implementation of Lean and BIM approaches in a case study in Colombia. The pilot project's owner wanted to generate the maximum possible amount of value added to their customers: provide a higher quality living unit, better customer service, reduce post-sales issues and brand recognition as an innovative company that highlights from other traditional construction companies. However, the methods to be applied to achieve the objective were not clear.

RESEARCH BACKGROUND

In terms of the scope of the implementation, although (Khanzode et al., 2006) and (Sacks et al., 2010) found and identified a high number of interactions between BIM and Lean, the pilot project's objectives were carefully set in order to experience parallel benefits and to avoid overwhelming the staff with many new concepts, working processes and tools. Additionally, the authors also considered the probability of underutilizing the tools and the interoperability limitations for the definition of the scope of the BIM implementation. BIM and Lean execution were made from the general manager perspective, and the objective of the implementation was to learn, plan and use both approaches in the entire project; however, this paper concentrates in the experiences of the excavation, foundation and structural construction phases.

Finally, by reviewing literature, examples of client's integration of Lean and BIM in real projects have been documented, measured and compared through different Lean and BIM maturity matrixes (e.g., Mahalingam et al., 2015; Fosse et al., 2017; Hamdi & Leite, 2012; Bolpagni et al., 2017; Khan & Tzortzopoulos, 2014). However, the literature still lacks specific examples of client's simultaneous implementation of BIM and Lean for the first time in a medium-sized construction company.

METHODOLOGY

The present research is an applied study that comprises the analysis of the integration of Lean practices and BIM tools through a real-life implementation in a construction company. The authors analyzed the 18 BIM functionalities interacting with the 24 Lean construction principles under the ***Interaction Matrix*** developed by Sacks et al. (2010), which proposes a conceptual framework for analyzing the interaction of the two transformative methodologies, Lean Construction, and BIM. In the current paper, the authors focused on a limited number of interactions applying them in a case study based on the exploration of a real-life project that is used to depict the relationships between BIM and Lean to report experiences specifically, opportunities for improvement and lessons learned from the implementation.

CASE STUDY

A medium-sized company, whose principal activities are fostering, marketing and constructing civil and real estate projects, had been planning to incorporate BIM and Lean management to their company. They decided to start the long journey with a pilot project in a residential building that consists of 25 stories, 3 basements, and 281 living units with a gross built-up area of 20.900 m2 in a lot of 1.500 m2 approximately. For accomplish this goal, the company hired as a consultant the Research Group of Engineering and Construction Management (INGECO) of Universidad de Los Andes, whose main goal was to kick-off the Lean and BIM implementation using the pilot project, so the company could learn and acquire the capabilities and skills to continue it. For this, the team worked in three levels of hierarchy: a.) owners, b.) project managers and c.) designers/contractors.

From the design point of view, the project has 23 different apartment types. Although each of these units is standard, the significant variability of the project imposes great challenges for its production planning, production control, and logistics. The building also contemplates commercial uses in its ground floors. The procurement method was Design and Build (D-B) for the electric and hydraulic systems, and Design Bid and Build (D-B-B) for the other disciplines.

Although the company knew something about BIM tools, it had no experience with the application of VDC or Lean concepts in practice. The company is aiming to gain a benefit from being early adopters of Lean and BIM to directly reduce construction costs and obtain value added from their activity. Actually, according to theory, early adopters can be hugely benefited because a company can develop and maintain a significant competitive edge until the rest of the industry catches up (Sacks, Korb, & Barak, 2018).

A description of the BIM planning, execution, and information management process are outlined below, as well as the Lean Culture dissemination in the project team and selected Lean tools that the team implemented. Nevertheless, the next section presents an analysis of the simultaneous implementation experiences of both Lean and BIM.

BIM Planning

According to Ramírez-Sáenz et al. (2018), the development of a BIM Execution Plan (BEP) is crucial for better planning and understanding in the management of BIM in a project. It should be the previous activity to the project's BIM modeling. Consequently, the team collaboratively created the BEP. For the pilot project, it had no contractual links with the designers or contractors yet. In the project's modeling process there were no more than three stakeholders involved directly. The team identified that the expected results of the VDC implementation were: to minimize field conflicts, to increase in productivity in the field, to anticipate material orders to keep workflow, to speed up verification of design and installed quantities and to follow up the construction process.

Additionally, breaking down project information has been a successful way of managing and controlling construction projects efficiently in the past decades. A variation of the Work Breakdown Structure (WBS) concept, a Model Breakdown Structure (MBS) was manually[4] carried in this project although an automated method proposal exists in recent literature (Rischmoller et al., 2017). The MBS was defined in the BEP as well. The main objectives of the MBS were to:

- Structure information to aid comprehension trying to adapt the BIM model to the project's WBS to facilitate Quantity Take-off (QTO)
- Assign work responsibilities related to the BIM activity
- Create flexible models to be easily navigated by on-site personnel
- Facilitate automated design coordination by allowing to have small and manageable groups of parametric objects

[4] Due to limitations in the software

Maintain virtual files of a manageable size to use them on ordinary laptop computers located on site

BIM Execution

As stated above, once the implementation objectives and scope were collaboratively defined, the implementation was carefully planned to ensure a paced adoption that matched the employee's gradual change in their mindset and their technical capabilities. Therefore, the first step toward implementing VDC was to introduce BIM as a coordination tool where conceptual and detailed designs were 2D-CAD based. The coordination was automated using Autodesk Navisworks and weekly construction detailing, and coordination meetings were conducted at the site office to discuss important design clashes with the aim of correcting the construction plans, being Navisworks the pivot point in each meeting. Nevertheless, coordination BIM models were provided to builders, but they were not required to use them. Because of this reason, there was an inevitable interruption in the flow of information (as well as in the traditional workflow) that could be addressed in the next step of the implementation (in a future project), by adopting BIM in design and construction and by having a Common Data Environment (CDE). The company should seek to ensure a unique database of information and that all information delivered to the construction site comes directly from the coordinated model.

The Architectural, Structural, Mechanical, Electrical, Plumbing (MEP) and Furniture design drawings were prepared using 2D CAD. The MEP contractors did not have the maturity to properly model their systems themselves nor their design were hired to be BIM-based. Therefore, the company's architect and the Research Group's[5] engineers developed the 3D model of all of them with a maturity level that ranged from LOD 300 to 350 (BIMForum, 2018) based on 2D CAD design drawings and an A360 federated model was then used to build and share a Virtual Reality (VR) model.

Apart from the automated clash checking, the project obtained great benefits from virtual walkthroughs. They were carried out in the federated model with rendered textures and were a valuable help in the process of design checking and construction planning. Referring to design checking, they drastically facilitated the understanding of the interaction of the different systems. Additionally, walkthroughs allowed the team to detect errors that were not geometric clashes but helped to rethink design specifications regarding its functionality during operation, aesthetics, ease of installation, etc. By contrast, for construction planning, they enabled the team to plan logistics, prevent irrelevant crew motions, placement of equipment and materials, and evaluate labor at the site to improve safety.

BIM Information Management

Once the parametric building's model culminated, the idea was to start building the model. We refer exactly to raising the dimension of the 3D model. Information management refers to the Bill of Quantities (BOQ) preparation through the extraction of coordinated material quantities (5D) and building schedules simulations to evaluate constructability (4D). However, the project's team tried to begin with the end in mind, and the BEP had each use

[5] Research Group of Engineering and Construction Management (INGECO) of Universidad de Los Andes

that the BIM models will have; otherwise, raising the dimension without having planned future BIM uses would involve much rework.

As for the 5D, material quantities were extracted directly from the coordinated Revit models and exported to an excel file to prepare Bill of Quantities (BOQ). Subsequently, each quantity extracted from the model was compared with those calculated from 2D drawings and analyzed, until we obtained a reliable result.

Finally, for 4D simulations, we followed a procedure that was hindered by interoperability because we created the schedule in Plexos but later converted to excel in order to import it on Navisworks Manage, which was synchronized with previously imported models to perform real-time simulations for construction sequencing. The most profitable part of this process was to evaluate different excavation alternatives, validate the construction process of the structure, and standardize the production in the typical floors.

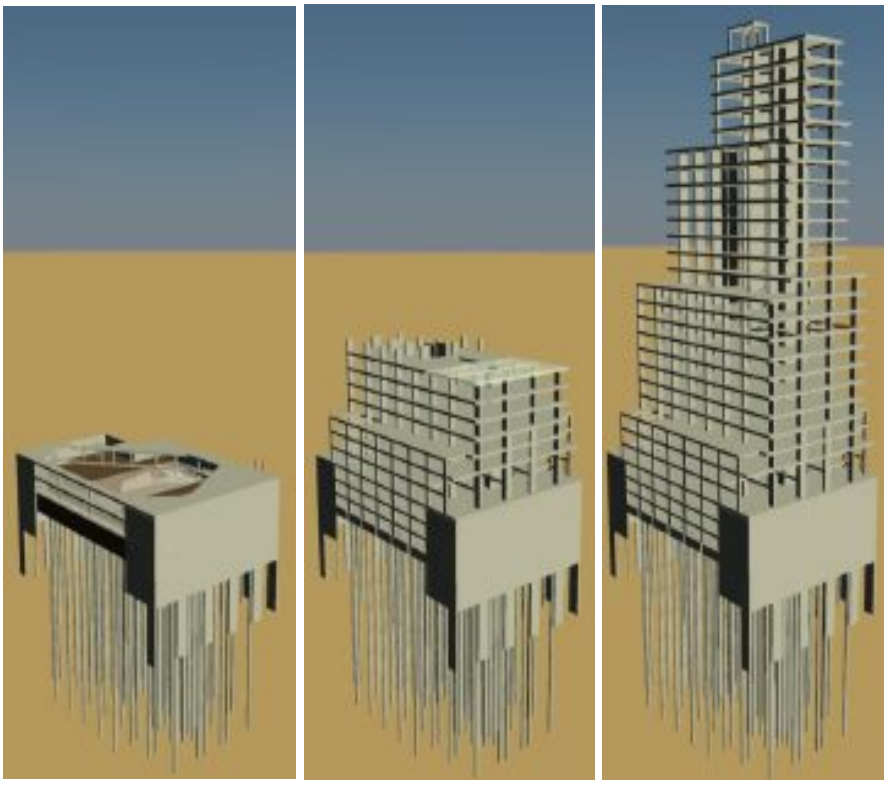

Figure 2: Autodesk Navisworks' 4D simulation

Lean Culture

While the parametric modeling of the building was in process, a Lean training strategy pretended to build a Lean culture in the organization and the project's participant's mindset. First, Sacks et al. (2010) and Hackler et al. (2017) concluded from their case study that although training on Lean tools is necessary, it is more important to create a culture based on the understanding of the Lean vocabulary, principles, and goals. Therefore, company's owners, management team and contractors started to learn the fundamentals ideas of Lean and then, the company focused on making the training interactive and on encouraging people to enhance collaboration, to express their concerns and to make reflections on how the learning experiences connected with the daily situations in the field.

Lean Tools

The main Lean tools that have been used in the project are the Last Planner System (LPS), Location Based Management (LBM), root cause analysis, 5S, Plus-Delta, and some other tools to promote visual management and establish the Lean principles in the project's team.

The scheduling process was carried out using an integration of Location-Based Management (LBM) and Last Planner System (LPS) because we were looking to benefit from this integration due to the combination of the social process of LPS with the technical tools of LBMS (Seppänen et al., 2015). Master schedule belongs to the domain of LBMS, and it was carried out using *Plexos Project* ("Plexos Project," 2019), a collaborative and flow-centered software (figure 1) capable to schedule production using Lines of Balance. Furthermore, a weekly planning and production control are clearly within the domain of LPS. The LPS and Lines of Balance work well together. From the beginning, a general Location Breakdown Structure was collaboratively defined. Additionally, LBM set additional modeling requirements to the BIM modeling team so that it allowed further BIM-based project and production control.

The Lookahead and Weekly Work Programs (WWP) were directly supported by the BIM models, and *Senda Matrix* Excel's extension was used (Gutierrez-Bucheli et al., 2017). Lean implementation was always framed by the concept that construction is a social activity, and the indicator that measured the fulfillment of commitments was established and became common understanding within the team was the PPC (Percent of Promises Completed). Once the implementation process of the WWP meetings for production control had started, autonomously, the project management team concluded that the PPC as key performance indicator was right, but it could be part of a more holistic project's performance indicator. The team realized that although the PPC considered the social process of collaborative planning, there was the possibility of weighting with each contractor's payment compliance to their employees, compliance to industrial safety requirements and cleanliness on the job site. In other words, we understood that the company was starting to adopt continuous improvement as part of the organizational culture.

LEAN AND BIM; INTERACTIONS AND LESSONS LEARNED

According to the Lean-BIM interaction matrix (Sacks et al., 2010), the project team experienced ten synergies between Lean-BIM and concluded that there are a few more with a high potential of application that the team can pursue with a little more maturity of the project team and additional minimum investment.

Restriction assessment: regarding the different experiences, the modeling process revealed additional constraints to the project planners due to the lack of rigor that existed in the detailed design drawings. As a result, the project team was able to discuss constraints well in advance of Lookahead or WWP meetings and day-to-day execution. "Early bad news are always good news" (Mossman, 2015). Also, the ease of creation of different detailed additional views of the project allowed more information to be available to make decisions and evaluate more constraints. So far, reprocessing has been avoided, and it is expected almost to eliminate rework in the future. In other words, it is related to the interaction two of the matrix.

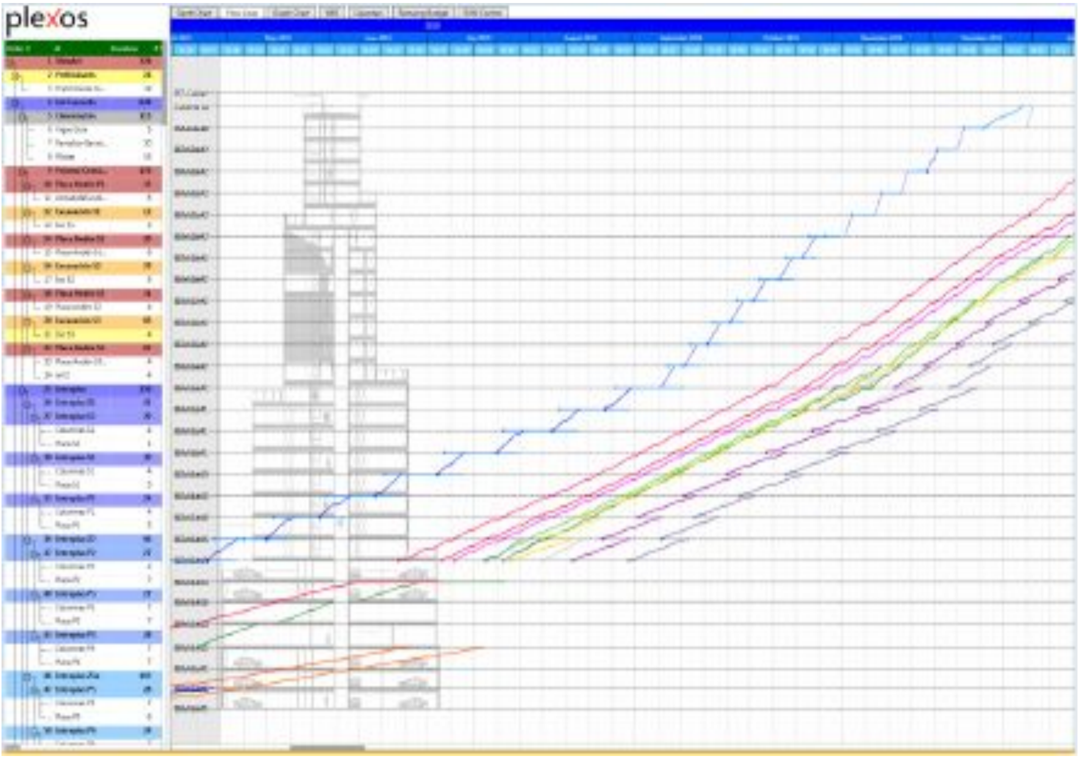

Figure 1: Project's Lines of Balance in Plexos Project (2019)

Team empowering: although designers did not work based on BIM, parametric models simplified design comprehension process to all contractors in a way that made planning more realistic, especially on behalf of project management (interactions 3 and 4 of the matrix). For example, the basement's water storage tank design presented some constructability issues that were discovered using the model and allowed the team to decide by consensus about the solution. Besides, interactions among the excavation process, concrete slabs, MEP systems, and the foundations were crucial to have a smooth flow of production. Additionally, although BIM was implemented in the project when the architectural design was utterly defined, the model's different options of visualization and management empowered the other stakeholders to propose minor or medium modifications that would improve their client's requirements (the next in line in the production process).

Virtual Gemba walks: virtual walkthroughs of integrated models (A360) helped stakeholders connect dots in design revisions. Because it does not require advanced BIM technical knowledge and does not require any software licenses (Navisworks Freedom), it can be a high-priced tool in low mature implementation projects. Apart from doing it in real life, it is beneficial to be able to virtually walk around the building in the different phases of the construction to potentiate the decision making of design and execution. The implementation has always sought to include visual management as a principle, permanently looking to positively impact system one of the human brain, which "operates quickly and automatically, without much effort, to make simple decisions" (Koskela et al., 2018). Interactions 6 and 12 of the matrix depicts them.

Design alternatives and construction simulation: as part of the evaluation of different design-execution options, the team developed a simulation of the excavation process alternatives because it had a restrictive constructive process due to particular soil characteristics. Similarly, we also created animations of the production sequences of foundations, structure, façade and interior walls in the same way (4D modeling) to evaluate constructability and guide the contractors on how to carry out activities in each project's zone and area. Interactions 7, 17, 40 of the matrix highlights these synergies.

Visual and automatic clash detection: the process of clash detection (interactions 12 and 24) performed in this project was considerably quick since test creation and execution followed a clear clash detection protocol, defined in the initial stages of the BEP. However, the design correction process was very time-consuming and took much effort. The result was practical, but it was not efficient at all because the contractors did not manipulate the models directly. The experience from this project shows that each designer should make the corrections of their disciplines so that there is a smooth flow of coordination in the pre-construction phase and the expert of each discipline conceives each solution alternative. Additionally, in some cases where time or BIM-trained personnel was available, contractors made 2D-based coordination due to fear and lack of full knowledge of BIM tools.

Automatic quantity take-off: undoubtedly, the automation of quantity extraction based on a BIM model (interaction 10) is one of the most significant benefits found in this synergy since it seeks to save time spent in unproductive tasks while reducing the subjectivity associated with this process (reduce variability). Not only was it used to validate budgeted quantities in the preconstruction phase, but also it was possible to calculate approximately 70% of the quantities executed on site. Additionally, after clash detection meetings, designs were adjusted. Estimated quantities kept updated because they maintained the original link to the quantity files. It is fundamental that the constructive process has been defined from the beginning of the project so that the model reflects the reality of execution and progress control quantification does not require additional effort. One experience from this project is that in Colombian industry there is an evident lack of standardization of quantity estimation criteria, which is why BIM tools are still inefficient due to this variability. However, BIM estimation tool's customization is possible with APIs, but they require advanced technical BIM capabilities.

BIM base scheduling and controlling: Last Planner System's meetings relied visually on BIM models. Besides, each weekly report contains a graphic preview of the project's current status, where visual information flows through all the project stakeholders, as well as the current restrictions and commitments. LPS and BIM require a minimum level of team collaboration. No matter the level of BIM implementation, it is a collaborative process. The more mature is the process, the more collaboration between professionals is required, and BIM allowed each planning meeting to be more comprehensible for the entire team. In this project, BIM modeling started one month before construction. Therefore, the lookahead plan subordinated the detailed modeling process (increasing the LOD). Keeping detailed modeling ahead of execution according to the needs of medium-term planning had a positive result in this project.

CONCLUSIONS

Each (BIM and Lean) implementation only solves a part of the problem. However, simultaneous implementation exposed the team to more exceptional experiences, frustrations, opportunities for improvement and lessons learned.

First, Lean requires sharp facilitator leadership and other "soft" skills that will allow motivation and encouragement to change the team's mindset towards new ways of working. Apart from that, the reverse phase scheduling (pull system) that has come to be closely associated with lean production is not always the best alternative, especially in lean construction pilot projects. On the contrary, the selection of the best method should depend on each stage of production, so the applied methods are mixed push-pull systems, as it happened in the present case study.

Second, if BIM tools are not properly implemented and managed, they can make a process more difficult and unstable. The availability of technical expertise will encourage BIM adoption in construction companies. Additionally, many BIM functionalities improved the flow of planning construction processes. In fact, as described by Sacks et al. (2018), the project underwent that BIM makes construction leaner even when lean was not the explicit intent in a certain activity. Additionally, from the client perspective, the BIM based design requires more caution and meticulousness from the designer, obtaining a better result in the project's earlier phases. For this reason, the authors consider that is justified the design prices increment due to the use of this methodology.

Third, the contracts and the BEP were aimed to gain the best results for the pilot project; however, to have these results, it is was important to consider the designs/contractors' skills and capabilities and not just the owners' and project managers'. Taking into account that the designers/contractors group were external to the company and had a low maturity level, assuring their participation in the training process would have had the expected outcome. As well, the learning experiences regarding Lean and BIM could have been translated into other projects.

Finally, regarding lessons for construction companies starting the implementation, companies should develop a maturity assessment before the implementation in order to benchmark their present capabilities and allow them to plan for the future, and achievements can be measured and controlled. Although it is better to implement simultaneously, the level of training, frustrations, and risks of failure are much higher. Moreover, the project team must prepare to cope in the best possible way these possibilities.

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METRICS IN VDC PROJECTS

Matilde Reinholdt Belsvik[1], Ola Lædre[2], and Eilif Hjelseth[3]

ABSTRACT

The Norwegian construction industry is far behind other industries when it comes to productivity. To improve productivity several contractors take advantage of methodologies such as Virtual Design and Construction (VDC). VDC is about streamlining projects in a Lean context with tools like Last Planner, ICE, BIM and metrics. Although few studies have been found on metrics in VDC projects, it appears evident that metrics are important for continuous improvement. However, selecting adequate metrics is challenging, as they can require more than they give in return.

The study answers three research questions; (1) "How are building design processes measured?" (2) "Which main design phase challenges can be resolved with metrics?" and (3) "Which metrics should be used in future VDC projects?"

The methods used have been a qualitative case study of a Norwegian contractor's first implementation of VDC, as well as personal interviews with experienced design managers.

The implication of the study is a list with six basic metrics for the building design processes of VDC projects, based on challenges in Norwegian construction projects. Seven additional metrics for continuous project improvement are also presented.

KEYWORDS

VDC, Metrics, Design management, Continuous improvement, Lean construction

INTRODUCTION

The Norwegian construction industry has seen a decrease in productivity of 10 % since year 2000 (Thodesen 2018). In response, several methodologies have been introduced to solve this issue.

VDC and metrics are two of these and many Norwegian contractors have begun implementing VDC in their projects to improve project efficiency (Fosse et al. 2017; Knotten and Svalestuen 2014). VDC is defined as "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives" (Kunz and Fischer 2009). Metrics is also suggested as a methodology to improve productivity. Not only are metrics important to evaluate project success but can be utilized for continuous improvement (Fischer et al. 2017).

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In the literature, there is a large amount of published material on metrics and measurements of construction projects (Chan and Chan 2004; Costa et al. 2006; Haponava and Al-Jibouri 2011; Hughes et al. 2004; Kang et al. 2014; Yeung et al. 2012). There is also a decent amount on VDC (Alarcón et al. 2013; Fosse et al. 2017; Garcia et al. 2004; Kam et al. 2013; Khanzode 2010; Khanzode et al. 2006; Kunz and Fischer 2009). However, an apparent knowledge gap exists on the topic of metrics and VDC combined. Within VDC, metrics is one of the main tools yet only a few papers have been published about it.

Contractors want to effectively include metrics in their implementation of VDC and need a list of standard metrics applicable to all VDC projects. A case study of a Norwegian contractor has therefore been conducted with the purpose of making a list of recommended metrics, based on the main design phase challenges of construction projects as well as suggested metrics from published literature.

In order to find metrics that can be used to continuously improve design processes in VDC projects, the following three research questions were developed and answered:

- RQ1: How are building design processes measured?
- RQ2: Which main design phase challenges can be resolved with metrics?
- RQ3: Which metrics should be used in future VDC projects?

Due to the limited time frame, this research has been limited to one Norwegian contractor, Betonmast, and their experiences with VDC and metrics. The focus has been on finding metrics for the design phase of construction projects.

METHOD

The research design of this report has been a qualitative case study of Norwegian contractor Betonmast and their implementation of VDC.

First a pilot case study was conducted, involving Drammen station Business Center (DBC), to document Betonmast's first implementation of VDC. Data was collected through five personal interviews and an observation in an ICE-meeting to get an understanding of the different elements of VDC and typical challenges with the implementation. Informants were selected from the design group, as they had the most hands-on experience with VDC from the DBC project. During the pilot case study, it was found that one of the biggest challenges in VDC projects is defining meaningful metrics, which laid the foundation for further research on metrics and VDC.

Following the pilot case study, six design managers of the same contractor were interviewed to identify challenges in the design phase of more traditional construction projects and to review a list of suggested metrics for future VDC projects. These suggested metrics were obtained through a literature review about metrics and VDC. The interviews were personal semi-structured interviews, with a goal of understanding how metrics are used today and how a Norwegian contractor can use metrics in their future projects. The informants were chosen for their involvement in Betonmast's VDC development work and also for their interest in learning and testing out new ideas and methodologies.

THEORETICAL FRAMEWORK

The theoretical framework is presented in three parts. The first part is about Virtual Design and Construction, with a paragraph about its relation to Lean Construction and common tools within VDC. The second part is about metrics, with general theory on metrics in construction projects followed by the third part, on metrics in VDC projects.

VIRTUAL DESIGN AND CONSTRUCTION

Virtual Design and Construction (VDC) was first introduced in 2001 by John Kunz and Martin Fischer through the Center for Integrated Facility Engineering (CIFE) at Stanford University. The framework is about project optimization by taking advantage of different time-efficient tools to achieve project goals and objectives (Jovik 2012). Kunz and Fischer (2009) define VDC as "the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives." The goal of VDC in the building design phase is to use these models to understand the complexity of a project and predict potential challenges before a large commitment of time or money is made to the project (Khanzode et al. 2006).

With the implementation of VDC a project can achieve Lean principles, and Lean as a framework can increase the effectiveness of VDC projects. Thus VDC and Lean have been argued by several researchers to go well together (Alarcón et al. 2013; Gerber et al. 2010; Khanzode 2010; Khanzode et al. 2006; Mandujano et al. 2015). Lean Construction with its background in Toyota's Lean Production is about adding value, reducing wasteful activities, improving flow and focusing on continuous improvement through benchmarking and metrics (Fosse et al. 2017).

Common tools used within and in combination with VDC include The Last Planner System of Production Control (hereafter Last Planner), Integrated Concurrent Engineering (ICE), Building Information Modelling (BIM), Model Maturity Index (MMI) and Metrics. Last Planner is a planning tool for project control with focus on stakeholder involvement, work flow control and value adding activities through pull planning and lookahead processes (Ballard 2000). ICE sessions are integrated and co-located meeting processes where different disciplines collaborate and make decisions as a team (Fischer et al. 2017), while BIM is the digital and visual representation of what the team is working on with information tied to each building object. BIM is important in ICE sessions to create communication and collaboration between stakeholders, and maturity indexes can be used to attach status to areas or objects in a BIM-model (Svalestuen et al. 2018).

METRICS

According to Bassioni et al. (2004) there are many performance measurement methods coexisting in the construction industry, such as Balanced Scorecard, just-in-time (JIT), benchmarking and activity-based management. Several studies have suggested parameters and models for performance indicators and benchmarking (Beatham et al. 2004; Chan and Chan 2004; Haponava and Al-Jibouri 2011; Hughes et al. 2004; Yeung et al. 2012). Based on a comprehensive literature review and three case studies Chan and Chan (2004) presented Key Performance Indicators (KPIs) for project success. The KPIs included objective measures like time, cost and accidents but also subjective measures like quality and satisfaction. Subjective attributes are important to avoid limiting a projects' success assessment to objective metrics (Hughes et al. 2004). A major challenge of KPIs is their product oriented focus, and that most KPIs are "lagging" indicators (Beatham et al. 2004), meaning they are used for post-project evaluation and comparison. Haponava and Al-Jibouri (2011) have proposed a generic system for more process-oriented KPIs in an attempt to address the existing KPIs' main shortcomings. Yeung et al. (2012) have compiled leading and lagging KPIs into a composite performance index (CPI) for benchmarking of construction projects in Hong Kong.

METRICS IN VDC PROJECTS

Metrics in VDC projects should not only be used to measure project outcome, but should be utilized throughout the whole project duration for continuous improvement of project processes (Knotten and Svalestuen 2014). According to Ahmad et al. (2016) lagging KPIs "are of no or limited use to the concurrent construction projects". Thus the metrics for VDC projects should mainly be active, or "leading", indicators.

Although metrics are more commonly seen in the construction phase, they can also be used to manage projects during the building design phase. Knotten et al. (2015) argue that metrics should be set up to control the quality of design and exchange of information. In a study by Hamzeh et al. (2009), on the Last Planner System metrics in design, it is shown how important it is to have "standardized production planning and control practices as proxies for performance measurement and process improvement". Using simple metrics in the design phase is effective to show the status of a project and can give an indication of where a project needs to pay attention (Knotten and Svalestuen 2014).

Fischer et al. (2017) claim that it is through metrics a project can achieve the project objectives. If put in a Lean framework, for example by the use of PDCA (Plan, Do, Check, Act), metrics can be used to continuously improve project performance. Typical metrics in VDC projects have been PPC (Percentage Plan Complete), meeting satisfaction, decision latency and amount of changes, as well as the project results in terms of cost and duration. However, the challenge is to define meaningful metrics that relate to the project goals and objectives (Fischer et al. 2017).

Several studies have reported on the advantages and limitations of VDC (Gilligan and Kunz 2007; Grindland 2017; Husby 2017; Kam et al. 2013; Olofsson et al. 2007; Redman 2017), yet few have suggested or discussed the most relevant metrics for continuous improvement in VDC projects. The main focus in previous reports has been on metrics for evaluation of the VDC implementation.

The existing literature on metrics in VDC projects is limited, but a small literature review has been conducted of sources related to metrics and VDC combined (Fischer et al. 2017; Fosse et al. 2017; Hamzeh and Aridi 2013; Knotten and Svalestuen 2014; Kunz and Fischer 2009). This paper assumes that the implementation of VDC includes modelling in 3D BIM, some sort of concurrent, co-located design process and a planning tool of the design process similar to Last Planner. The result is a list of suggested metrics for the building design phase of VDC projects, as presented in Table 19. This list is used for the analysis of the empirical results gathered in this study.

Table 19: Design phase metrics from the literature

Metric	Kunz and Fischer (2009)	Hamzeh and Aridi (2013)	Knotten and Svalestuen (2014)	Fischer et al. (2017)	(Fosse et al. 2017)
Percentage Plan Complete (PPC)	X	X	X	X	X
Tasks Anticipated (TA)		X		X	
Tasks Made Ready (TMR)		X		X	
Root causes			X	X	X
Response latency	X			X	
Decision latency	X				
Evaluation of meetings	X		X		X
Amount of quantity take-off (QTO) done in 3D-model vs drawings			X	X	
How many times the BIM was used to review alternative solutions			X		
QTO from 3D-model vs spent materials			X	X	
Meeting participation	X			X	
Clashes identified using 3D-model/clash trends				X	X
Amount of rework	X			X	
Requests for information (RFIs) on site due to design clashes	X			X	

RESULTS AND DISCUSSION

METRICS IN THE PILOT CASE STUDY

The case studied has implemented VDC in four elements; Last Planner, ICE, BIM with MMI and metrics, however the metrics were generally only apparent during the ICE sessions. These sessions were held every other week and involved all relevant stakeholders for the agenda. Usually this would include the contractor (Betonmast), client, architect and MEP-engineers. A representative from the contractor functioned as the facilitator.

During the ICE sessions the metrics used were PPC, meeting agenda achieved and root causes of absent or delayed design deliveries/tasks. The root causes were generally lack of capacity, priorities or unfinished tasks upstream that affected the present task. At the end of each session the design team would participate in a "plus/delta" discussion of positive elements of the meeting as well as "elements that could be improved". They would also answer an anonymous survey about their own and other stakeholders' preparation for the session, meeting effectiveness and relevance of the agenda.

The metrics were logged, but with varying effort. As a result, it was hard to find apparent trends to the measurements and to use them for future improvements. It would be more interesting to analyze the metrics if more results existed. The informants had different opinions on the value and purpose of metrics, as it was something new to most of them.

Project participants reported that metrics was one of the most challenging aspects of VDC, and selecting the correct metrics for continuous improvement of design processes was difficult. They were skeptical of metrics in general, as they feared the metrics could potentially be ineffective or require too much resources. Having too many and too complex metrics have been shown to potentially be time- and resource-consuming (Chan and Chan 2004). A further analysis on metrics in VDC projects was therefore requested.

METRICS IN BETONMAST

RQ1: How are the building design processes measured?

The building design processes have generally not been measured in Betonmast and consequently their experience with measurements is limited. Most measurements that have been done are focused on the construction phase and general project results. This includes measuring cost, schedule and HSE (Health, Safety and Environment), and finding solutions for occurring delays or expenses that exceed the budgeted cost. Thus they are mainly measuring product, not process.

Some informants have participated in other measurements, such as the counting of quality deviations, evaluation of meetings and time spent on meetings, and the use of simple actions like color-coding to emphasize lack of decisions.

Building design meetings have traditionally been conducted based on the report from each previous meeting, with no clear agenda other than to go through the bullet points on the report. This has led to little or no development on each task during meetings.

Several informants expressed that they lack the right tools to measure the building design processes. Presently they have "delivery plans" and "decision plans". These are plans for the last possible moment to deliver or decide something, and can mainly be used to measure whether or not the design process is on schedule. As seen in the theoretical framework there is a lot of literature on measurements. It is therefore unclear whether the informants lack the time to read published literature or the tools are not the kind of tools they are looking for.

Some of the informants also express that the Betonmast employees to an extent lack experience and understanding of the building design management and design processes. This could be related to many employees being more focused on production than design. However, to produce good design deliveries their understanding of the buildability and what is to be constructed is crucial. They emphasize the importance of managing the design process in an order that corresponds to the construction phase. If they are to use metrics in the design processes, they want simple metrics that contribute to continuous improvement.

RQ2: Which main design phase challenges can be resolved with metrics?
Based on several interviews the following challenges have been identified as the main challenges in the building design phase for the contractor:

- Lack of decisions, prerequisites or clarifications
- Designing with low buildability or low quality
- "Loops" in the design process with unnecessary rework because of lack of, late or changes in decisions, or unidentified interdependencies
- Stakeholders are not prepared for meetings
- Delayed design deliveries which delay construction
- Minimal understanding of, and respect for other stakeholders needs and/or interdependencies between disciplines
- Communication through email, and sometimes lacking responses
- Tasks at meetings are just discussed, not solved
- Designers prioritizing other projects
- Hard to make schedules for the building design process

These challenges are per now usually solved over time in Betonmast. They let time pass and find solutions as new challenges appear. Some challenges are solved by giving consequences to the stakeholder responsible for a delay or cost overrun, for example to the client for late or changed decisions. Other challenges have been met by following the delivery and decision plans, but it is hard to control and manage the quality of the design work before deadlines.

Most of the challenges are challenges that lead to rework. If designers are asked to start designing without the correct prerequisites they will have to make their own assumptions, which often leads to rework for themselves and other stakeholders. Additionally, if the designers are not communicating with the construction teams, they will potentially design with low buildability and cause loops in the design process.

Other challenges are related to meeting efficiency. Through the implementation of VDC there will be ICE-meetings (or something similar) where stakeholders make decisions and work to develop solutions together. These meetings can be measured, for example by looking at the amount of decisions made or tasks solved. Additionally, one can evaluate each stakeholder's participation, preparation and efficient time spent in the meeting.

When asked about which of the challenges can be solved through metrics, the informants often expressed a lack of belief in the effect of metrics. They were also worried that metrics would be very time consuming. However, if systems could automatically make measurements it would be beneficial. According to the informants, any implemented metric should contribute to making sure that all necessary design is decided before construction begins, to avoid rework on site and save both time and resources.

If metrics are to be used it is important that they are used diligently, and that they are in some ways standardized within the company so that projects can be compared.

RQ3: Which metrics should be used in future VDC projects?

The informants expressed different expectations for metrics in the building design phase. Some said they would not use metrics unless they were forced to or had been convinced of the advantages of metrics. Others already saw metrics as very necessary to continuously improve design processes.

From the assumption that Betonmast is interested in a standardized list of metrics for their future VDC projects, the informants produced suggestions of what they considered to be possible metrics. The most frequent suggestions were:

- PPC, Percentage Plan Complete
- TA, Tasks Anticipated
    - How many upcoming tasks were already anticipated and scheduled for the next week on the previous work plan?
- Metrics related to maturity levels of the BIM
    - Number of drawing revisions after maturity levels
    - Whether or not BIM is coordinated across trades
    - % of design that actually corresponds with the construction phase
- Root causes of delays or lack of deliveries
- Consequence (cost or time) of rework/loops
- Amount of changes or rework during building design
- Cost of meetings
    - Could the agenda have been solved differently or for less money?
- Evaluation of meetings
    - Questionnaire to evaluate stakeholder preparation and relevance of agenda
    - Plus/Delta
    - Time spent efficiently/inefficiently
- Cost of solutions vs budgeted cost
- Decision and response latency and decision stickiness

PPC and metrics related to maturity levels can all contribute to keep the project on track and visualize which stakeholders are delaying the project. Improving these metrics will increase design schedule control and delivery reliability. Evaluating TA will improve look ahead planning, by forcing stakeholders to anticipate their needs and interdependencies before upcoming tasks. Root causes are important to identify the trends in delays and loops, and each meeting should be evaluated on cost, relevance and efficiency.

Decisions from the client seems to be a reoccurring challenge and a bottle neck in many projects, thus decision latency and decision stickiness were suggested as metrics to evaluate client decisions.

Several of the suggested metrics correspond to metrics presented in the literature. The informants have suggested a few additional metrics to the ones found in the literature, such as Plus/Delta in meetings and decision stickiness. At the same time some metrics are missing, especially related to the BIM. QTO from 3D-models, using BIM to review alternative solutions and identifying clashes in BIM will all lead to fewer RFIs on site.

A challenging aspect of metrics is to encourage high quality solutions at the same time as metrics are visualizing each stakeholder's performance. Metrics will be a negative if the stakeholders compromise with quality of their work to achieve good metrics results. Nearly all the suggested metrics are related to productivity or efficiency of process, and do not directly take into account quality of the product. Therefore, it is important to align the metrics with client and project objectives.

CONCLUSION

Although only experiences from Betonmast have been researched, the results should be transferable to other contractors implementing VDC in their projects.

The recommended metrics for VDC projects are shown in Table 20. The metrics should correspond to project goals and objectives. Most of the VDC projects will be interested in simple metrics that continuously improve their project. These are listed in the column "Basic metrics for all VDC projects". Seven additional metrics are recommended for projects that have the resources to extend their evaluation and further project improvement, listed in the "Suggestions for supplementary metrics". The recommended metrics are based on the literature review ("L") and interviews ("I") with design managers from the contractor Betonmast.

The use of a model maturity index on the BIM is a prerequisite for some of the metrics. However, if a maturity index is not implemented, these metrics can relate to milestones in the design schedule and BIM based information exchange.

Table 20: Recommended Metrics

Basic metrics for all VDC projects	Suggestions for supplementary metrics
PPC, TA and TMR in meetings [%] (L+I)	Time spent doing QTO [hours] (L)
PPC for each maturity level [%] (L+I)	Cost of design loops [$] (I)
Number of clashes in BIM after reaching each maturity level [#] (L+I)	Construction cost due to design rework or delay [$] (I)
Evaluation of meetings [scale 1-4]	Cost of meetings [$] (I)
Root causes [#] (L+I)	Cost of solutions vs budgeted cost [$] (I)
Decision latency [hours] and stickiness [#] (L+I)	Correlation between decision stickiness and number and impact of design loops [%] (I)
	Amount of rework per discipline [hours] (L+I)

PPC (Percentage Plan Complete) should be measured for tasks at each meeting and for planned deliveries at each maturity level. As a continuation of PPC, **TA** (Tasks Anticipated) and **TMR** (Tasks Made Ready) should be measured, to improve control of the scheduling process and provide a more detailed look ahead plan. TA is the percentage of planned tasks for the next week that were already on the previous work plan, while TMR is the amount of planned tasks that are ready for the next week (Fischer et al. 2017). PPC and TA should be measured in correspondence to the formulas shown in Figure 43.

$$PPC = \frac{Completed\ tasks}{Planned\ tasks} * 100\% \qquad TMR = \frac{Tasks\ ready\ for\ next\ week}{Total\ tasks\ for\ next\ week} * 100\%$$

$$TA = \frac{Tasks\ planned\ for\ next\ week\ on\ previous\ work\ plan}{Total\ tasks\ for\ next\ week} * 100\%$$

Figure 43: Formulas for PPC, TMR and TA

Number of clashes in BIM after reaching each maturity level should be measured to indicate and control the quality of the design. This number will visualize the importance of designing in correct order and doing proper controls before each maturity level.

Evaluation of meetings should be done after each ICE session to evaluate the stakeholders' perceived efficiency of the meeting, their preparation and the relevance of the agenda. This could be done using an anonymous questionnaire rating each question on a scale from 1-4, with 4 being the best score. Additionally, a discussion should be conducted of "plus/delta". Pluses are positive aspects of the meeting and deltas are areas of improvement. This metric can be used to improve meetings.

Root causes for lack of or delayed deliveries or decisions, as well as clashes in BIM should be tracked. The number of appearances of each root cause should also be tracked. Typical root causes could be lack of prerequisites or work capacity.

Decision latency (the time from a decision is requested until the client or relevant stakeholder makes a decision) and **decision stickiness** (the number of changes on the same decision) commit the client to making efficient decisions. These metrics require the client to be involved in design processes and evaluations of design. Decision stickiness is also a metric to avoid ambiguity in decisions.

Other suggested metrics include time spent doing QTO (Quantity Take-Off), cost of design loops, construction cost due to design rework or delay, cost of meetings, cost of solutions vs budgeted cost, correlation between decision stickiness and number and impact of design loops and amount of rework per discipline. These metrics are more difficult to measure and require more resources. It is uncertain whether the benefits are worth the effort, but these metrics are believed to be beneficial for continuous improvement. Many of them, such as cost due to design rework and cost of design loops visualize the economic potential of having good design processes.

The empirical results come from researching one Norwegian contractor's experiences with the building design phase and one VDC project. To make the list of suggested metrics more generalizable, more contractors and more projects can be studied. A study of metrics used in the following phases of construction projects can be done to identify metrics suitable for the full VDC project duration.

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INTEGRATING INDOOR POSITIONING SYSTEMS AND BIM TO IMPROVE SITUATIONAL AWARENESS

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ABSTRACT

This paper presents the concept for the integration of Indoor Positioning System (IPS) and Building Information Model (BIM), and hypothesizes about the possible benefits of this integration to situational awareness and visual management in construction projects.

Literature review shows that the volume and quality of data enabling situational awareness during construction projects is increasing with the use of new technologies, such as indoor positioning systems and other applications of Internet of Things (IoT). However, these information streams have been used individually so far.

BIM as the interface integrating different streams of situational awareness information can result in better data-driven construction management and production. This study suggests that using BIM in 3D visualization of the indoor positioning of construction resources (workers, material, and equipment) enables visual management based on situation awareness on construction project activities. Better situational awareness of construction resources on-site based on visualization in BIM can improve the identification and elimination of waste and the identification of workflow interruptions, potentially permitting better planning and increasing productivity.

The study suggests further steps for empirical research to prototype the concept and validate it with industry partners and practitioners.

KEYWORDS

Lean construction, BIM, visual management, indoor positioning systems, information integration.

INTRODUCTION

Construction problems are often tackled using outdated information. The lack of situational awareness in construction projects is related to information bottlenecks and the cost and time needed to collect and update data (Akinci, 2014). This situation leads to poor efficiency of the actions taken, waste of time and money to collect the information when it is needed, decision

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making about resources and time made within inappropriate timing and the reactive problem solve culture, so common during the construction phase (Dave et al 2008, Akinci, 2014).

Technology development is increasing the possibility to collect data automatically in the architecture, engineering and construction industry (AEC) through 3D laser scanning and photogrammetry, indoor positioning systems (IPS) and other applications of Internet of Things (IoT). These developments are increasing the volume and quality of data collected, but the different data streams have been used individually so far. This maintains the information silos which have been commonly identified in the construction industry (Dave et al. 2008).

Building Information Modelling (BIM) tools are increasingly used in the AEC industry to manage the design and construction phases of projects. Studies of the synergies between lean construction and BIM revealed that high quality information provided by information models can improve the flow of work on site (Sacks et al. 2010) and that building model-based interfaces for visual representations of the construction project status can be applied effectively (Sacks et al. 2010).

Previous research on the integration of activities' status information and BIM for visual representation of the construction flow have been conducted with the test and implementation of the system called 'KANBIM' (Sacks et al. 2012) and with the creation and implementation of the commercial system VisiLean® (Dave 2013). Both systems were able to measure benefits of utilizing BIM as the interface to visualize activities' status.

A particularly interesting new technical tool from the perspective of lean construction are Indoor Positioning Systems (IPS). IPSs automate data collection on production resources and status using sensor technologies, and different types of sensors are being explored as Radio-frequency Identification (RFID) (Costin et al. 2012), Magnetic Field (Park et al. 2016), ZigBee (Lin et al. 2013), and Bluetooth Low Energy (BLE) (Olivieri et al. 2017; Dror et al. 2018). These technologies can enable real-time tracking and positioning of labour, material and equipment, and the information can be used to evaluate and visualize the flows of construction projects, improving the decision-making process at the operational, tactical, and strategic levels (Vasenev et al. 2014).

Visualised real time data collected from IPS have potential to increase the situational awareness in construction projects and enable pro-active management regarding resources placement. The development and research of systems to enable such visualization is ongoing (Park et al 2016, Dror 2018) and have been applied for first responders in accidents situations (Lee, 2009) integrating BIM and Global Positioning Systems (GPS). However, the use of IPS during production phase decision making in construction sites remains unexplored. This research focuses on the concept of integrating and visualizing data collected from IPS during construction projects in a BIM environment. Possible benefits to production control of construction projects are explored. The research method consists of the review of existing literature on IPS, BIM, visual management and situational awareness to propose the integration and following empirical studies to implement and validate the concept.

SITUATIONAL SWARENESS AND BIM

SITUATIONAL AWARENESS AND VISUAL MANAGEMENT

The definition of Situational Awareness (SA) originated from the military operations and was defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley 1995). SA is categorized into three hierarchical phases: Perception of elements in current situation; Comprehension of current situation; Projection of future status.

The term was first applied to construction projects focusing on safety management (Gheisari et al. 2010) but can also be applied to construction projects as a whole. Increasing the situation awareness during the production phase has the potential to allow better and more pro-active decisions about control actions both from the project managers and the workers.

Important tools to increase the situation awareness include improving communication and increasing the transparency of the processes in the construction sites. To achieve this, the use of visual communication and visual management (VM) tools has increased and successful cases of implementation have been documented (Tezel et al. 2011). Visual Management is an element of the Toyota Production System (Liker 1997; Formoso et al. 2002) and due to this, often associated with Lean Construction (Koskela 1992).

With the increasing dissemination and use of BIM technologies during construction projects, and these becoming the platforms to create and share 2D and 3D drawings, and other visual representations, like quantities sheets, structure details, and project planning, the integration of VM with BIM appears to be a logical development.

The lack of updated information in construction projects and the information silos are problems that could be solved by using BIM for integrating information connecting the real world and internet of things (IoT). This enables system-system, system-human and human-system communication. These multiple channels have as their objective capturing data at the right time and delivering it to the right person at the right time (Dave et al. 2015).

This potential has also been perceived by other industries and users from outside the construction industry. Development of the integration between BIM and GPS for use by first responders (fire brigades and rescue teams) in case of accidents, has already been explored (Lee et al. 2009) showing benefits to the situational awareness of the team when applying tracking in combination with visualization.

Visual Management applications aim to provide easy access to information, enabling the process participants to take the necessary actions with the correct timing (Liker, 1995; Koskela, 2001). BIM has the potential to be the platform used for VM in construction, and this potential has already been noticed by researchers and practitioners. Two researches aiming to develop this integration and understand how BIM based VM could improve construction management have been published, namely the KanBIM™ Workflow Management System (Sacks et al. (2012) and VisiLean Dave et al. (2011). These systems were reviewed during this study to understand how the integrations have previously been executed and which results were measured.

The work from Park et al. (2016) integrated BLE and motion sensors with visualization applying BIM. The research was focused in the accuracy and the feasibility aspects of the implementation and it did not cover aspects such as the benefits of implementation in construction or the impact on the situational awareness of the ones using the application.

The existing systems integrating VM and BIM are presented next, listing and describing the ones involving manual input information first followed by the one involving IPS data collection but is not integrated with BIM

EXISTING SYSTEMS

KanBIM™

The research of Sacks et al. (2012) started from the perception of the potential of BIM visualisation capabilities and the effectiveness of information systems in supporting the monitoring and changing of workflows. From the hypothesis that a BIM based workflow information system could be applied by construction crews for pull workflow strategies, the research developed and tested a prototype management information system to support lean workflow in construction sites.

The system is based on the Kanban cards as visual tools to pull work flow. It consists of cards with colour codes symbolizing the work status. The worker places the cards in a visible area to inform the workers from previous tasks if the work flow can continue, and the next workers if the task is concluded (green card), or was interrupted (red card), for example. The objectives are that all the workers involved in the workflow can visualise the cards and communicate efficiently any interruptions of flow and work status among themselves and to the supervisors.

VisiLean

Dave (2013) discussed that while lean construction concepts tackle the problems of construction processes, BIM presents solutions to model the construction projects and overcome the limitations of the 2D Computer Aided Design (CAD) representations. Based on these and the positive results of implementing BIM and Lean simultaneously, the author proposed "VisiLean", which is a management system that uses BIM as a visual platform together with lean concept of pull flow scheduling in construction projects.

The integration with the BIM model enables the representation of operations in an identified location and their progress. A series of visual management tools is applied to enable the easy identification of the current status of the operations. The task status, for example, can be marked as started or stopped, and colours are used to highlight this status. Also a poka-yoke, mistake-proof, approach was integrated in VisiLean by making it impossible to change the status of operations that have not yet started.

The researches from Dave (2013) and Sacks et al. (2012) were able to present the positive results of integrating data collection about production and planning with BIM technologies by integrating visual management tools and real time visualisation through the building models. However, both products, KanBIM™ and VisiLean rely on manual input of information, the first one on the input of the production teams about tasks progress and constraints and the second one on the input of the planning and controlling teams about tasks status. Manual input is required because at the time of these systems, the automated methods of data collection, such as IPS, were not yet mature enough from implementation.

bKan

The research of Dror (2018) proposed a different approach for visualizing project status and improving situational awareness. The research focused on creating a complete solution for information flow by creating data regarding resource location, and analysing and visualizing it.

Using BLE sensors and a developed application, project resources such as labour and material were monitored automatically. The data collected was transferred to a cloud based data analysis engine that then returned a visual status of resource location using a mobile interface heat map. The heat map was continuously updated automatically.

The researchers found that in a mobile interface it was difficult to visualize the project status using a 3D BIM model due to resolution issues, and therefore decided to visualize the information using 2D presentation: Building view (elevation) and in floor plan view.

After testing the platform created in real construction sites it was found that location monitoring using BLE beacons is a feasible solution that enables automatic project status update and analysis of movement patterns in order to assess wastes in the construction process. It was also noticed that even raw data that is presented to construction site managers can be very beneficial to their decision making process and save them a great amount of time.

The first systems have gaps related to the data collection that is not automated and depends on human input, which can present issues that goes from the simple human error to the costs of human data entry. The third system would eliminate the manual data entry, automating the data collection through the application of BLE's but this system does not include an integration with BIM models and the visualization using such tools. It utilizes 2D floor plans and elevations in the visualization of the BLE data.

Our research aim to cover the presented gaps, collecting data from the BLE systems in an automated manner and enabling the use of BIM to visualize the resources locations inside the construction site.

INTEGRATING BIM AND IPS

We propose the integration of automatically collected indoor positioning data of construction resources with BIM models as visual management tool to increase situational awareness in construction projects.

The technological advances in collecting real time data in construction projects are increasing the quantity and quality of data available. The IPS technologies, enable the tracking of construction resources in real time.

With the use of these sensors it is possible to collect in real time data regarding the location of resources in the construction site, the movement of workers and materials during production and the total time a worker spent in a certain location. It is possible to collect data about different resources locations using the IPS. However, just based on the position information it is not possible to infer which tasks the resources were working on or to ensure that all the needed for executing a task are in the right place at the right time. The association of the IPS data collection with other technologies, such as monitoring cameras can tackle this deficiencies, but they are not the scope of this BIM and IPS integration.

Linking the data with planning information will make it possible to visualize if the workers and material are in the planned position where required by their next task, and to detect any deviations faster than when using status update data produced weekly or at the end of day. Thus, the availability of data regarding materials and workers in real time can provide the construction team with more reliable information on the project status during the production.

Although massive data collection is now feasible, the different data streams and repositories continue to have poor connections and use different platforms to retrieve the information, contributing to the maintenance of information silos and multiplicity of information systems that are not connected or interoperable.

This research proposes that the BIM platforms could play a key role in forming situational awareness in construction projects, centralizing the different streams of data and becoming the reliable source of information during construction projects as depicted in Figure 1.

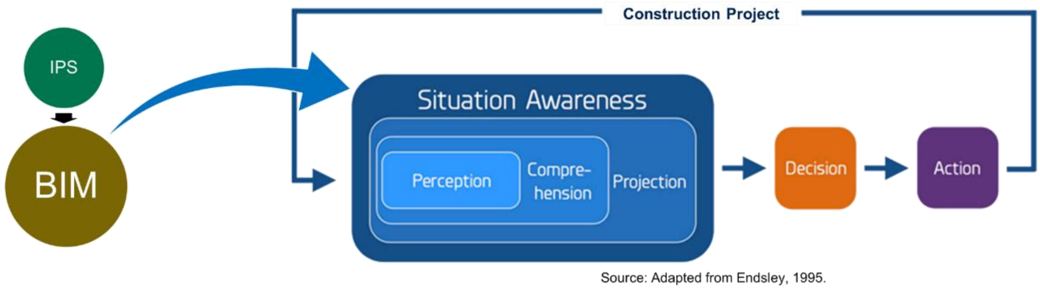

Figure 1: BIM as the Key Interface for Situational Awareness in Construction Projects

The integration of BLE data with BIM aiming a real time visualisation of workers, materials and equipment in construction can constitute a situational awareness tool to leverage the decision making for the construction project teams. It can enable:

- Visualization of planned locations of resources and their actual location, supporting the identification of plan deviations;
- Tracking of resources availability (workers, materials and tools) in the location of the task, enabling to take corrections regarding lack of resources in real time;

- Identification of work-in-progress locations, and comparing it with the planned and agreed work to be in progress;
- Analysis of frequency and intensity of workers and materials movements, which can allow a better understanding of the causes of waste and non-value adding activities.

The concept map of the integration is presented in Figure 2.

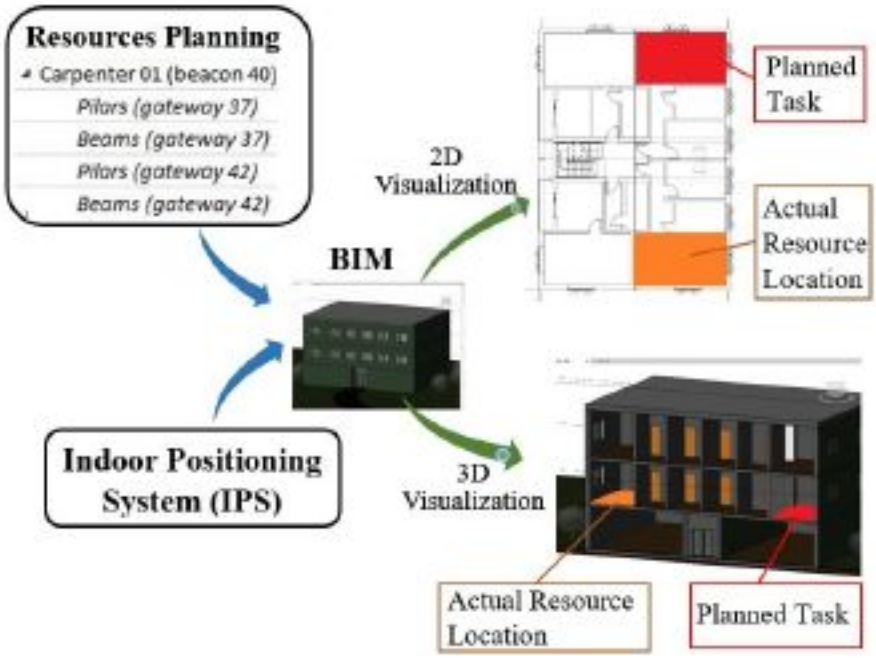

Figure 2: Concept Map of integrating BIM and IPS

ETHICAL ISSUES RELATED TO LABOUR TRACKING

Tracking and monitoring the movements of human resources arises important ethical issues that are aligned with the information technology ethical issues framework created by Manson (1986) with the categories of privacy, accuracy, property and accessibility. The integration of IPS data and possible visualizations with BIM must ensure to the tracked resources that their data will be handled maintaining their privacy and dignity and that the data is used for productivity improvement purposes and will not be misused or applied in detrimental actions against the employees.

The early involvement of the workers in development should be targeted and fully clarification on how workers will be tracked and which information will be collected must be made available. Early involvement of trade unions in the research can be an important tool to avoid any misunderstandings and assure the human resources participation. Informed consent should be given by the human resources to be tracked and the data ownership and the freedom to stop the tracking at any moment have to be clearly expressed. Uninformed tracking or tracking without consent is against ethical guidelines of research and any research requiring such methods should go through an extensive IRB approval process. In commercial implementation, it is likely that a joint agreement by the employer and employee unions should be made before large scale implementation.

FURTHER STEPS FOR EMPIRICAL RESEARCH

The integration of IPS data with BIM models is a starting point when aiming to facilitate the information retrieving and visualisation by construction project teams. The early future steps concern the validation of the concept with industry partners and practitioners about how to display the information and possible interactions with BLE data, schedule and BIM model.

Since data visualisation can be executed in the 2D or 3D format and the use of dashboards to analyse worker and material movements and task production rates are possible, the feedback of industry will support the validation of the visualisation means to be adopted. The following stage is the prototyping of systems and validation, which can be conducted through a pilot project.

After the validation of the prototype, implementation in real case studies should be conducted to evaluate whether the IPS visualisation increases the situational awareness in the construction projects, and whether it enables better decision making and identification of resource and movement waste during projects. The application in case study projects should take place also to find improvement opportunities on the visualisation criteria and to measure if the availability of the IPS information and its integration with BIM impact the situational awareness in construction projects.

CONCLUSIONS

By combining IPS and BIM, this study has indicated the potential of BIM for situational awareness in construction. Improved situational awareness can enable to perceive the real time picture of the situation on the ongoing project when it comes to resources location and availability, real value adding time spent in the production processes and adherence of planning and production. This information support the project management and the workers. The first, when decisions are made regarding late tasks, mobilization or demobilization of workers, material disposition and equipment availability, for example, more actively during the production control process, and not with the after problem correction approach. The second, providing information about the process and the production flow enabling better decisions about which place have all the resources needed for the tasks and where to work next.

As a conclusion, new technological developments related to automated data collection opens up new potential to be explored related to applying BIM in construction projects as a visual tool to increase situational awareness, and as an information and knowledge sharing platform.

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STREAM 19: CHALLENGING THE PREVAILING SYSTEM

Wold, J., Lædre, O. and Lohne, J. (2019). "Questionable Practice in the Processing of Building Permits in Norway" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1151–1162. DOI: https://doi.org/10.24928/2019/0214. Available at: <www.iglc.net>.

QUESTIONABLE PRACTICE IN THE PROCESSING OF BUILDING PERMITS IN NORWAY

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ABSTRACT

In recent years, several cases of questionable practice in the processing of building permits in Norway have been revealed. Meanwhile, authorities claim the risk of corruption associated with the processing of building permits is more obvious than before.

This study investigates the size of the opportunity space for questionable practice in the processing of building permits. Questionable practice includes both illegal practice in the form of corruption and legal, but unethical practice. Further, this paper examines if the opportunity space is being exploited, before suggesting countermeasures. A greater predictability in the processing could increase the Lean Construction and reduce costs. It has been conducted a literature review and seven interviews with caseworkers and heads of departments in five municipalities in Norway. The study is limited to the examined municipalities.

The results show that the processing of building permits is based on great responsibility delegated to the caseworkers and that there is a certain opportunity space. However, this space is not being exploited in the examined municipalities. Measures, e.g. implementing a new processing system, are anyhow proposed.

KEYWORDS

Sustainability, promise, trust, building permits, questionable practice.

INTRODUCTION

Unethical and unlawful practice has been reported to have gained significant impact within the Norwegian construction industry over the last years. Based on research analyses (e.g. Lohne et al. 2019), reports from official agencies and others (e.g. Departementene 2019; Riksrevisjonen 2015-16a, 2015-16b) and industry initiated reports (e.g. Slettebøe et al. 2003; Andersen et al. 2014), there appears to be a widespread understanding that present-

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day efforts towards countering crime are failing to control what is perceived to be an escalation of criminal activities within the Norwegian AEC-industry over the last two decades.

In addition, current efforts (Engebø et al. 2016; Kjesbu et al. 2017a, 2017b; Richani et al. 2017; Lohne et al. 2015; Skovly et al. 2017) show that important criminal activity is carried out in sectors that are not within the present scope of the Norwegian control authorities. These include supply chain management issues, identity issues, and building process related challenges, such as those occurring during the design and handover phases. Considering the gravity of the challenges, the topic of felonious activity in the AEC-industry seems, however, severely under-researched within the research literature. As Walker (2014) comments, "[t]here is a dearth of papers" on unethical activity within the industry. Of particular interest to the analysis reported on in this paper, very little seems to have been done concerning corruption challenges within this context so far.

In January 2019, Transparency International (2019) published their corruption perceptions index for 2018, and with a seventh place, Norway yet again confirms its position as one of the world's least corrupt countries. Meanwhile, there are regularly investigations of public employees suspected for questionable work. One field with such disclosures over the last years is the processing of building permits. The "Drammen-case" is the latest example, where two caseworkers in the municipality of Drammen were sentenced to 3,5 and 6 years of prison for aggravated corruption. In addition, Norwegian authorities maintain that the risk of corruption in the processing of building permits has increased (Økokrim 2018).

Questionable practice includes both legal but unethical practice, and illegal practice in the form of corruption. Although there is a great deal of international research on the subject of questionable practice, especially on the occurrence of corruption, the conditions in developing countries have been given the most attention. The amount of research on questionable practice in developed countries has proven more scarce. With regards to processing of building permits in developed countries, the amount of research seems surprisingly limited when considering the economical values in play.

In the aftermath of the revealed cases characterised by questionable practice in Norway, the standard procedure has been performing an external scrutiny, including a following report. However, these reports have been specific for the involved municipality, with a limited transfer value to other municipalities. This study provides an outline of preventive measures applicable to the majority of municipalities. Side effects include increased predictability in the processing of building permits and reduced costs in the start-up phase. These are both in accordance with the principles foundational to Lean Construction. The study addresses the following research questions:

1) What is the opportunity space for questionable practice in the processing of building permits?
2) Is the opportunity space being exploited?
3) How can one prevent the opportunity space from being exploited?

The study is limited to the processing of the matters regarding the building itself, e.g. height restrictions, footprint etc. The study has been carried out with the perspective of the caseworkers, and examines the six following axes: processing system, workload, control procedures, organizational structure, size of municipality and local interests in the municipality. Each axis is stretching between extremes in each area, and the study examines whether a certain placement on the axis has an impact on the opportunity space for questionable practice.

METHODOLOGY

In the work of this study, it has been conducted a scoping literature review, a document study of relevant scrutiny reports and seven semi-structured interviews.

The literature review followed the prescriptions of Arksey and O'Malley (2005). It began with a systematic literature search. Searches were conducted in the following databases, with both Norwegian and English keywords and phrases: Google Scholar, Oria, Web of Science and Research Gate. In the selection of relevant literature, title, keywords, abstract and conclusion were considered – in the given order. If the literature still were interesting after reading the conclusion, the whole text was read and evaluated based on credibility, objectivity, accuracy and suitability. Approximately 40 articles were studied, concerning both legal, but unethical practice, and corruption.

In the document study, legal cases, scrutiny reports and newspaper articles concerning questionable practice in the processing of building permits were examined. The main documents were the judgement and the scrutiny report from the "Drammen-case", which served as a basis for the interview guide of this study. In addition, documents and surveys regarding questionable practice in the Norwegian working life in general were studied.

The main source of information was seven interviews with municipal caseworkers and heads of department processing building permits on a daily basis. The research was limited to five municipalities in Norway, anonymized and listed in table 1. The municipalities were chosen from different criteria, as number of citizens, geographic characteristics (e.g. mountain areas vs. shoreline) and availability. As this topic is sensitive, the interviewees and their municipalities have been anonymized and randomized.

Table 1: Overview of municipalities and number of interviewees

Municipality	Number of citizens	Number of interviewees
A	1000 – 5000	1
B	1000 – 5000	1
C	5000 – 10 000	1
D	15 000 – 20 000	3
E	> 25 000	1

Five of the selected interviewees were caseworkers, while two were heads of the respective department in their municipality. This approach was to obtain different perspectives on the issue. All the interviews were semi-structured and individual in accordance with the prescriptions of Yin (2003), with an interview guide that was supplemented by spontaneous follow-up questions when applicable. The interviewees were solely asked about the conditions in their own department. Due to the critical positions of the interviewees, they can adjust their explanations to their own interests. However, the general impression is that the interviewees gave unbiased answers. The interviews were recorded and transcribed, and the interviewees have approved the transcriptions of the respective interviews.

THEORETICAL FRAMEWORK

QUESTIONABLE PRACTICE

In this study, **questionable practice** in the processing of building permits is defined as *processing of building permits that are in violation of the law or considered unethical*. Illegal processing of building permits is limited to corrupt practice. Furthermore, public officials who process and issue building permits are referred to as **caseworkers**. **Opportunity space** refers to questionable practice in the processing of building permits, and is defined as the entire span of opportunities for caseworkers. This includes both legal (but unethical) opportunities given by delegated authorizations and illegal opportunities, as for example issuing permits despite lack of documentation or issuing permits that should not have been issued. **Applicants** are those who apply for a building permit.

Figure 1 illustrates different types of behaviour. Unethical, but legal behaviour is illustrated with a target. There is a clear distinction between unlawful and lawful behaviour, as this is regulated by the law. However, the distinction between ethical and unethical behaviour is more unclear and complex, illustrated with a zigzag line.

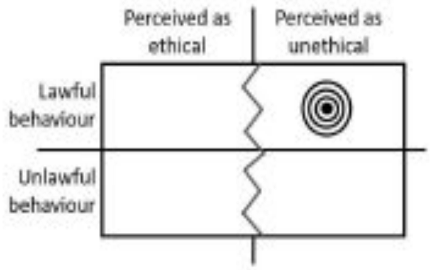

Figure 44: Different types of behaviour (Lohne et al. 2017, figure 1)

Bruce (1994) defines an ethical employee as one who works on the behalf of the public and who prioritizes the benefits of the public and the government, as well as not taking part in illegalities. She states that unethical employees are less productive and that *problem behaviour* led to costs of over 195 billion USD in 1990, only in the U.S. (Bruce 1994).

The financial consequences of corruption are immense, and IMF (2016) estimated in 2016 that bribery alone amounted for 1,5-2 trillion USD worldwide. Corruption may lead to discrimination and incorrect decisions (Transparency International Norway 2014), and a reduced trust in the public (Sedlenieks 2003; Eriksen 2014; Chiodelli & Moroni 2015). Transparency International (2011) presented numbers describing the construction industry as the most corrupted one, and earlier on, De Jong et al. (2009) estimated the cost of corruption in the construction industry to be approximately 500 billion USD worldwide. When it comes to issuing of building permits, corruption can result in illegal and hazardous buildings (Dølvik & Medalen 2017), with loss of lives as a direct consequence.

There is a gray zone of behaviour that renders corruption hard to define. Even though there is an international consensus on what actions are considered corrupt, e.g. bribery, blackmailing, fraud and embezzlement (Locatelli et al. 2017), some authorities refrain from defining the term. This may be a consequence of definitions being too narrow and thus leading to many corrupted acts not being pursued (Council of Europe 1999). In this study, the English translation of the Norwegian Penal Code's definition of corruption is used (Lovdata 2015, section 387): *A penalty of a fine or imprisonment for a term not exceeding three years shall be applied to any person who a) for himself/herself or others demands, receives or accepts an offer of an improper advantage in connection with the conduct of a position, an office or performance of an assignment, or b) gives or offers any person an improper advantage in connection with the conduct of a position, an office or performance of an assignment*. The Penal Code also operates with the term *aggravated corruption,* with a maximum sentence of ten years. In short terms, this means the corruption is of a more severe degree.

QUESTIONABLE PRACTICE IN NORWAY

Limited research of the prevalence of unethical but legal behaviour in Norway has been identified in this study. Surveys tell, however, that public officials are aware that unethical behaviour is occurring in the municipalities (Kantar TNS & Søreide 2018). These prove problematic, though, since they include both illegal and legal behaviour in the concept of unethical behaviour. In Norway, corruption is punished harder than other forms of economic crime (Ministry of Justice and Public Security 2009). Despite the deterrent effect this should have, 51 cases of corruption were revealed in Norway in the period 2006-2018 (Transparency International 2018). Meanwhile, there are surveys telling that one to four out of ten heads of departments in Norwegian municipalities have knowledge of situations involving *improper advantage* (Kantar TNS & Søreide 2018).

THE DRAMMEN-CASE

The most severe and comprehensive case of questionable issuing of building permits was the *Drammen-case.* Two caseworkers in the municipality of Drammen were sentenced to prison for 16 cases of aggravated corruption (Lovdata 2018). Caseworker 1 was sentenced for further cases of aggravated corruption and forgery, and for receiving approximately 130 000 USD in bribes. She got sentenced with six years of prison and confiscation of the money. Caseworker 2 got three years and six months of prison for conveying cases to caseworker 1 while knowing of this corruption, and a confiscation of the 13 000 USD he got for doing so. Caseworker 1 had a second job as a private architect, drawing applications on the behalf of applicants. In her job as a caseworker, she approved applications with her own drawings, and counterfeited the signature of the head of her department in the building permits. In the Drammen-case, the convicts behaved both unethical and unlawful.

THE SIX AXES

Deloitte (2018) presented a scrutiny report from the Drammen-case. Based on this report, the six axes illustrated in figure 2 were established for this study. The axes emerged as they were used to explain the opportunity space for questionable practice. This study examines whether a particular placement on the axis leads to a possible opportunity space.

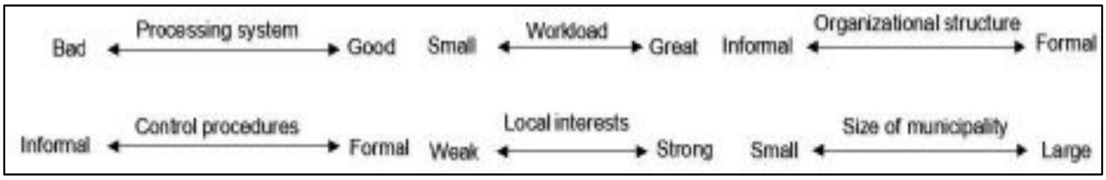

Figure 45: The six axes studied.

Description of the six axes

- Processing system: Different municipalities operate with different processing systems, and it is examined if these systems offer space for questionable procedural work.
- Workload: The study examines if heavy workload makes it easier to downgrade the control procedures and how this might affect the opportunity space.
- Organizational structure: The organizational structure in the different municipalities have been studied to see whether different structures create or limit the opportunity space.
- Control procedures: It is examined if the control procedures are more informal and verbally incorporated, or formal and embedded in governing documents, and whether this impact the opportunity space.
- Local interests: It is assumed that actors who are important for the municipality – as for example entrepreneurs or housing developers – try to take advantage of this when applying for building permits. The study examines if such actors exist and whether they try to influence the process.
- Size of the municipality: In small municipalities, the caseworkers may know the applicants on a personal level to a greater extent than in a larger municipality, and one can assume that this may create challenging situations in the procedural work.

RESULTS AND DISCUSSION

In this chapter, results and discussions from each of the above described six axes are presented in consecutive paragraphs and in relation to the three research questions formulated in the introduction.

PROCESSING SYSTEM

The systems used in the examined municipalities were either *ePhorte*, *ESA* or the recently developed *eByggesak*. In ePhorte and ESA, the caseworkers can process a building application without any external approval. However, both systems generate a list with processed building permits. This list is given to the head of the department, who uses it in meetings with the politicians, e.g. an executive council. This works as a control of irregularities. Municipality E is the only one using the new system eByggesak – under testing for two years – and here, caseworkers cannot process a building permit without external control. None of the interviewees have experienced any exploitation of their processing system in terms of questionable practice. Regarding countering measures, several of the interviewees said that even though they have not tried eByggesak, they have heard it is more customized to their work, as well as being less exposed to questionable practice. This is confirmed by the interviewee from municipality E, which earlier used ESA. Even though the high level of traceability in the processing systems does not reduce the opportunity space itself, it makes it more difficult to get away with questionable practice.

ePhorte and ESA are based on a certain degree of responsibility delegated to the caseworkers. The systems appear to have limited transparency, so without any further implemented control or quality assurance system it is hard to ensure that procedures are followed in accordance with the regulations. ESA was the processing system in the Drammen-case, but the scrutiny report does not say anything about any produced agenda of processed building permits. Almost none of the interviewees had reflected on the possibilities of exploiting the processing system for questionable practice, so there is some uncertainty regarding this matter. However, it seems that eByggesak, which reduces the opportunity space, will be commercially available for all municipalities during spring 2019.

WORKLOAD

Almost without exception, the interviewees said they have a heavy workload and that their resources do not conform with their tasks. The interviewee in municipality C says short deadlines lead to a reduced internal control, creating situations where “things can slip”. In municipality B, the head of department routinely controls and approves every approval or refusal of the application, and the interviewee says a possible consequence of the great workload is reduced quality of this control. None of the interviewees say they know about the high workload being exploited to conduct questionable practice. The interviewees in municipality D say implementation of eByggesak would free resources that could be used on supervision of built buildings – which would reduce the possibility for getting away with building something else than permitted.

It seems that no matter the size of the municipality, the workload is high, and this potentially lead to an opportunity space, for example when it comes to control of built buildings. Whether this opportunity space is exploited depends on the remaining internal control. The caseworkers seem to be more worried about that high workload could, unconsciously, lead to wrong decisions rather than questionable ones. A consequence of this could be complaints from the applicants or neighbours – resulting in an even greater workload for the caseworkers – thus creating a vicious circle.

ORGANIZATIONAL STRUCTURE

Naturally, the organizational structure in the small municipalities A, B and C is small, with a short vertical distance from bottom to top. These caseworkers cooperate with other disciplines, e.g. zoning. With few caseworkers in the municipalities, the transparency makes it difficult to hide questionable practice. The larger municipalities D and E are organized without the same interdisciplinary cooperation. An important role in the structure are politicians, that can overrule building permits partly given on administrative discretion. In municipality C, the interviewee says politicians sometimes contact caseworkers directly, demanding specific applications to be treated politically. This is more difficult in municipality E, as regulations require that politicians go through several persons with such requests. Even though none of the interviewees have experienced this as a great problem, an interviewee in municipality D says:

"That discretion, where no one can accuse (politicians) for doing something illegal, even though it's not ethically correct… that's maybe where the greatest opportunity space lies".

It seems that the informal structure in small municipalities makes it hard to hide questionable practice, as transparency seems to reduce the opportunity space. On the other hand, in large organizations, the separation of disciplines reduces the opportunity space. Whether political decisions can be tainted by personal agendas is a particularly interesting issue regarding unethical, but legal behavior. This topic is complex, and actors with unethical behaviour can hide behind the law. As this is a local democracy issue, every municipality will experience such challenges.

CONTROL PROCEDURES

Mostly, the interviewees maintain that there is no enshrined framework for control procedures for processing building permits. Instead, the quality assurance and internal control systems are based on incorporated routines, with a lot of responsibility delegated to the caseworkers. For instance, in municipality A, B and C, the caseworkers have the right to sign a building permit themselves, but there is a routine of forwarding processed applications to the head of department for control, no matter how uncontroversial the building permit is. In municipality D, the caseworkers only did this if they wanted a quality check. The exception is municipality E, where the processing system eByggesak is designed in such a way that the caseworkers are deprived the right to sign, and the building permits have to be approved at several organizational levels.

The interviewee in municipality B considers the greatest opportunity space comes with the possibility of hastening applications through the system. This saves waiting time for the applicant, and the interviewee believed this would not be detected. In municipality D, the caseworkers also have this opportunity. This is by intention, as they earlier had a queue system where they had to process the oldest case. It caused time overruns and accumulation of cases, as many applications missed documents necessary for processing.

There are municipal differences regarding secondary jobs. In municipality C, the caseworkers are not allowed to have a second job that may conflict with their work. In municipality B there are no routines concerning this. The interviewee in municipality B formerly worked with building permits for a local contractor. When she started working for municipality office, no rules prevented her from processing applications from her former employer. However, on her own initiative, she refrained from processing their applications for over one and a half year, as she felt it would be "too close".

The legitimacy in the procedural work is based on delegated responsibility to the caseworkers. The interviewees maintain that this reduces bureaucracy and shortens processing time. However, responsibility may be subject to abuse. A key precondition in the Drammen-case was the main convict's second job as an architect, and it is worryingly that most of the studied municipalities have no clear guidelines for such second jobs. Another transferable issue from the Drammen-case is the hastening of building permits.

The main convict often finished applications the same day they got registered, sometimes even in just a few minutes. At the same time, it seems too rigid to impose the caseworkers to process building permits in their inbounding order, as this create delays. A system detecting suspiciously fast building permit processing is a possible solution of this issue.

LOCAL INTERESTS

The interviewee in municipality C has felt the pressure of making "easy choices" to stop nagging from applicants. The interviewee in municipality B shares these experiences, as she has felt the pressure from applicants to practice questionable casework without being offered any personal gains. She says:

"They think it's easier for them to get an application approved, than for others".

Two of the interviewees in municipality D say they have felt such pressure several times, and that they have felt a certain discomfort after they have been invited to coffee or been given wine or flowers. One of the interviewees was once given a bag of pastry during a meeting with an applicant, which she refused to accept. She says:

"I'm very glad I refused to accept it, because later on, his application was rejected. But he built nevertheless, which was detected, and it became a terrible case".

In municipality D, the caseworkers' department receives an anonymous cake each Christmas. However, they think this is just an unknown applicant wanting to express a general gratitude. The interviewees tell such episodes were much more common 15-20 years ago, and that the frequency of such gifts has been significantly reduced the later years, in line with an increased attention on questionable behaviour in the society as a whole.

In several of the studied municipalities, there are strong local interests, but such pressure does not create an opportunity space itself. However, it can make caseworkers more prone to exploit the already existing opportunity space, mainly by hastening cases through the system. In most of the studied municipalities, there are no guidelines of how to deal with such pressure. It is up to the caseworkers to not make promises, show self-discipline and make correct judgements of right and wrong. One method to relieve the pressure in such situations could be to forward these applications to political treatment.

SIZE OF MUNICIPALITY

It seems from the interviews that living and working in a small municipality, where "everyone knows everyone", can be challenging. The interviewee in municipality C says:

"I know about people quitting as caseworkers, as certain cases have given them too much of a burden".

The caseworkers living in the same municipality as they work experience a greater pressure from acquaintances to conduct questionable practice compared to those living in another municipality. It should be noted that this type of pressure has been of a non-profitable character for the caseworkers. The interviewees living and working in the bigger municipalities have not felt the same kind of pressure. All are very aware of this issue and refrain from processing applications where they know the applicant too well, and the interviewees have never succumbed to the pressure of conducting questionable practice.

The issue of the size of the municipality can be hard to handle, as one cannot deprive caseworkers the opportunity to live where they want. One can not monitor which friends they have, neither. A solution may be an increased attention on delegating such cases to others, and to inform of what problems that may arise from not doing so. The latter may explain why the interviewee in municipality C is quick to renounce such applications.

CONCLUSION

This study has outlined measures against questionable practice in the processing of building permits. It has unveiled a certain opportunity space for questionable practice in the processing of building permits, and that whether caseworkers exploit this space or not may depend on their ethos, understood as their personal moral stance. This space is illustrated as unethical, but lawful behavior in figure 1. Unethical, but lawful behavior is possible, and municipalities have few possible sanctions against caseworkers that operate here. Unlawful behavior is possible, but will be punished according to the penal code. This opportunity space exists because the caseworkers are delegated great responsibility. In most of the examined municipalities, prominent opportunities are for example signing building permits without a required external control or forwarding applications in the application queue.

Interviewees tell that the opportunity space is not exploited in the examined municipalities, due to the self-discipline of the caseworkers and the incorporated routines in the municipalities' internal quality assurance systems. This said, caseworkers that want to, can exploit the space for questionable practice. Caseworkers are regularly pressured to conduct questionable practice. Even though it seems challenging to outdo the opportunity space, examples of preventive measures that reduce this space are listed in table 2. It should be pointed out that all measures are not relevant for all municipalities, as they are organized somewhat different.

Table 2: Preventive measures that reduce opportunity space

Number	Measure	Reason
1.	Implementing a more customized processing system, e.g. eByggesak.	Will structure the casework, and thereby reduce the opportunity space, as well as freeing up resources.
2.	Detection system at suspiciously short processing times.	A very short processing time may indicate questionable procedural work.
3.	More formalized routines and regulations regarding secondary jobs and duties outside work.	Reducing the risk of conflict of interest, while increasing the caseworker's understanding of when they are disqualified.
4.	More caseworker resources.	Increases endurance against pressure to conduct questionable practice.

This has been a study of a relatively unexplored topic. The topic should be studied from other perspectives, for example the perspectives of applicants and politicians. It is also suggested to conduct a second study of this very issue when more municipalities have implemented and used the new system eByggesak, to see the effect of this measure.

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EXPLORATORY STUDY OF 'COSTING COLLABORATIVELY' IN THE UK CONSTRUCTION INDUSTRY

Sa'id Ahmed [1], Christine Pasquire [2], and Emmanuel Manu [3]

ABSTRACT

This research study looks at how stakeholders collaborate over costing in the UK construction industry. The purpose is to define the concept of 'costing collaboratively' (CC), to widen understanding of collaboration. Post economic recession, more collaborative practices have been regarded as strategies for transforming construction challenges. However, studies have shown that these practices are fading in the UK, because of fragmentation, adversarialism and, clients preference for lowest tender, whilst cost consultants struggles to be involved in collaborative working especially, during costing activities. The primary research used a multiple case study approach, which aggregated data from interviews and documentary analysis (financial business case; costing & estimating manuals etc.). Overall, 23 interviews were captured with cost consultants, lean practitioners, main contractors among others within the building and infrastructure sectors in the UK. The results showed attributes, like target costing, optioneering and all-inclusive value engineering, as relevant constituents of CC. Accordingly, these were used to defined CC as an approach that engaged stakeholders (upstream and downstream) around wider scheme budgets creating a sense of ownership, driving positive behaviours to achieve desired cost outcomes. However, the results also show that although CC is progressing within the multidisciplinary settings, the approach is still driven by price, and a limited understanding continue to affect the wider practice of collaboration in the UK construction industry.

KEYWORDS

Collaboration, target costing, construction, costing collaboratively, target value design.

INTRODUCTION

Post-economic recession, the construction 2025 report called for partnership at all levels among stakeholders in the UK industry to reduce costs by 33%, and time by 50%. This was

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followed by the Farmer Report (2016) that called for modernization and the adoption of manufacturing advances such as lean construction, BIM, and integrated procurement strategies for improvement (Farmer, 2016; HM Government 2018). It seems as if though galvanizing these concepts to achieve the necessary improvement would require extensive collaborative working (CW) in the industry. However, despite these calls, CW in the mainstream construction remain sporadic (Aziz & Hafez, 2013). The Farmer Report (2016), added that the UK construction industry has now adopted a 'survivalist' mentality wherein commercial practices are reinforced by traditional procurement protocols, thus resisting change. This is even though it has been suggested that CW should transcend beyond the hierarchical arrangements to align commercial functions (costing, design etc.) with the production process (Sarhan *et al.,* 2017; Namadi *et al,* 2018). Consequently, as it stands, the current status quo hinders clients and cost consultants from collaborating with suppliers during early costing phase on the basis that this will limit competition (ICE, 2018). The issue is that, this creates more transactional characteristics, given that commercial practices are carried out in 'confidence' (Nicolini *et al,* 2000). Herein, costing and design activities are repeatedly viewed as separate functions, rather than integrated and part of production as advocated in the target value design (TVD) model.

This view continue to linger despite scholars arguing that collaboration especially during early costing phase can shift the customary approach (Laryea, 2010; Jung et al, 2012; Ballard & Pennanen, 2013; Love et al, 2017; Shalpegin et al, 2018). Nonetheless, professional cost consultants, particularly in the UK continue to work in isolation. This in part has taken precedence from the way the costing & design approach unfolds, i.e., based on the RIBA plan of work, which is discrete, sequential and favours competitive tendering. But also, that 'institutional' factors and cultural behaviours are engrained within the business delivery model, thus influencing project delivery (Namadi *et al*, 2018; Sarhan, 2018). Consequently, stakeholders invariably work in isolation, which in turn affects the dynamism of collaboration (Zimina et al, 2012). Therefore, this paper intends to look at 'costing collaboratively', in an attempt to provide a wider understanding on CW in the UK construction industry. The study will define CC; describe its perception and development in practice. The paper starts by describing the research context, followed by the theoretical background, and thirdly, presents and discuss the case study findings.

RESEARCH METHOD

This research adopted an exploratory qualitative approach using a multiple case study technique. This provides an opportunity to investigate real-life perspective (Pratt 2009; Yin 2009), also, it covers the 'what and how' questions and the influence of the social context in practices within human dimensions (Maxwell 2005). The primary research gathered data from interviews, open-ended questions, which provide insights from the views of participants and allowed the author to understand the concept of CC. An ascribed definition was produced, which was further examined in the cases using semi-structured interviews and the analysis of costing & estimating manuals; financial business plans and supply chain policy documents from the cases studied, to improve the quality of findings and conclusion

(Yin, 2009). The study adopts a purposive sampling method in selecting the cases. Bryman (2012) maintain that this allow researchers to choose case(s) that can answer particular question(s). For example, some criteria for the case study selection were: (a) the companies must have adopted target costing or an integrated approach during the early costing phase (b) collaborative values that cut across project teams and supply-chain groups and (c) domiciled in the UK. Thus, 23 participants participated in the interviews that lasted for 60 minutes comprising of: client, directors (commercial, alliance & procurement), designers, contractors, cost consultants, estimators, lean practitioners, and suppliers. The author focused on early costing interactions from three cases to understand the development of CC. Table 1 illustrates the characteristics of the cases studied.

Table. 1 Characteristics of the case study projects

Project Attributes	**Case study 1**	**Case study 2**	**Case study 3**
Nature of projects	Infrastructural	Infrastructural	Infrastructural
Location of projects	UK	UK	UK
Nature of works	Design & construction of water recycling treatment plants	Construction of water recycling treatment plants and sewage works	Upgrade of highway to smart motorway btw J19 & 16
Types of clients	Public	Public	Public
Mode of partners selection	Alliance, framework	JV, framework	JV, framework
Proposed duration	60 months	60 months	24 months
Procurement arrangement	Centralised procurement system	D & B	D & B
Contract sum	£1.2 billion	£200 million	£120 million
Phase examined	Costing	Costing	Costing

THEORETICAL BACKGROUND

COLLABORATIVE WORKING IN THE UK CONSTRUCTION INDUSTRY

Collaborative working (CW) is a typical term used in the construction industry to denote a mutual and beneficial working relationship among stakeholders to deliver a project to the required standard (Mattessich et al, 2001; Xue *et al.,* 2010). Although, in construction CW is often interchanged with partnering, Bresnen & Marshall (2000) argued that partnering entails commitment by organisations to co-operate and achieve common business objectives. This means that partnering is an element of CW. CW is still gaining prominence in the construction industry. It has been increasingly adopted over the last decade to underpin relationships between project participants, transparency and cooperation, instead of operating based on contractual formulations (Dagenais, 2007). It has also been argued that it brings several benefits to projects, especially when stakeholders are engaged early (Alderman and Ivory, 2007). Despite these, organisations in construction continue to use their traditional approach. Which is why Wilkinson (2005) cautioned that true collaboration cannot be easily accomplished in construction because of hierarchical arrangements and construction industry culture.

Similarly, Akintoye and Main (2007) argued that CW in construction is being overshadowed by cultural attitudes and behaviours, where contractors enter CW with the hope of financial gains. This practice is preventing the industry from realising the benefits of CW, and shows that contractors only enter such relationships if it is a viable proposition for them and not because of what their competitors are doing. In the same way, Baiden *et al.,* (2006) added that construction projects continue to witness overruns in time and cost, which are due to lack of CW. Challender et al., (2014) posits that perceptions have shifted after the austerity times, and individuals are now responding with a quest for job security, which in turn encourage the risk-averse practices that is affecting the idea of long-term relationships in construction.

It appears that CW seems to exist in principle rather than in practice. Most clients and stakeholders have acknowledged its benefits, but the propensity to inculcate it properly is still missing. This is partly because the model put in place to deliver and facilitate construction encourage 'adversarialism' through hierarchical relationships (Bennett, 2000; Pasquire *et al,* 2015). According to Erikson and Laan (2007), construction clients now place more emphasis on price and authority and very little on trust, a position that is also taken by the contractors to keep their subcontractors at arm's length. This establish a form of governance within the system that focus on price and control, despite, the suggestions that CW would help teams develop beyond the transactional perspective of 'buying behaviours'. It seems that for genuine CW to exist, trust and cooperation must thrive among stakeholders (Latham, 1994), to enable organisations restructure and manage their interrelated activities, thus improving communications and shared understanding (Challender *et al,* 2015). Accordingly, CW during conceptual processes (costing/design etc.) remain significant, but this rarely exist in practice. For instance, the study of Zimina *et al.,* (2012) observed that cost advisers and the contractors do not collaborate in this sense, especially when developing project cost. In fact, the costing model adopted in the UK pushes cost consultants to work in isolation from designers and vice versa. This not only results in developing unrealistic estimates, but compounds waste into production processes and encourage opportunistic behaviours (Pasquire *et al,* 2015). Without a genuine culture of collaboration, consistency and accuracy in costing processes will not be effective.

OVERVIEW OF COSTING IN CONSTRUCTION

It has been established that costing is an integral process for managing construction projects. For example, Michalak (2001) reported that it contributes to business and project objectives, which ensure that accurate and efficient information is available to support informed decision-making. This implies that managing project cost depends largely on the cost forecasting information and its recommendations in facilitating any action in practice. The cost management process is spread across the project lifecycle, encompassing pre-contract, cost management, contractor's estimation and post contract cost management. Eldash (2012) added that, despite it being separated into phases, it is still crucial to have continuous dialogue among stakeholders during the exercise, preferably working in tandem to achieve best options that would enhance project value. This is why Marchesan and Formoso (2004) asserts that the goal is to provide accurate estimates that would stimulate interactive dialogue feeding into the production process. However, previous studies confirm that the current costing approach has not truly achieved these purposes (Johnson & Kaplan, 1987; Howell & Ballard, 1996; Koskela & Ballard, 2000). For instance, Howell and Ballard

(1996) and Koskela (2000) reported that traditional cost management has placed much emphasis in managing contracts ahead of the overall production. This means that various professionals entrusted with costing functions work in isolation, prioritise their individual activities and thus, optimise pieces of the project (Marchesan and Formoso, 2004). Certainly, cost management in construction needs to be tailored towards improving its transparency and timeliness in terms of the information procedures, as this would help to identify and eliminate wastes in production process through strategies that support collaboration (Hanid, 2014).

CURRENT STATE OF COSTING AND COLLABORATION IN CONSTRUCTION

Costing practices have often been criticized in literature. Johnson & Kaplan (1987) identified that the information tends to be too late, aggregated and distorted to be relevant for production planning and control. This implies that the information provided are past-oriented and too aggregated to be useful in developing and controlling cost decisions. Other issues that have plagued costing process include disruptions, design liability, lack of collaboration, isolated decision-making, and limited understanding of cost management techniques (Ashworth, 2010; Hastak, 1998; Kern & Formoso, 2004; Dallas, 2006; Hanid et al., 2011). Kirkham (2007) pointed out that the classical 'cost planning' technique, which is a key process in costing, still follows the conventional process outlined by the RIBA plan of work. This approach favours competitive tendering with expensive iterative cycles of 'design-estimate-redesign'. Arguably, this is where practice focuses more on costing detailed design rather than establishing a detailed estimate. Akintoye & Fitzgerald (2000) reported that this approach lacks proper communication and feedback systems, as most times it leads to ferocious competition, lack of trust and data sharing that ultimately results in increased project cost (Eastman et al., 2011).

Accordingly, scholars continue to emphasise the need for CW, especially at conceptual stages. For example, Shalpegin et al, (2018) revealed that such approach is needed to capture suppliers at conceptual stages in order to reduce commercial friction. This was also seen in (Ballard & Pennanen, 2013), reporting that the approach fortifies the accuracy of conceptual estimating. Likewise, Jung et al, (2012) show that the strategy has the propensity to shift the customary approach in costing, adding that this kind of economic approach is expected to give more in-depth understanding of CW. On the other hand, lean thinking provide various management-based practices that pursue perfection in construction, thus inspiring CW. Among others these include concepts like integrated project delivery (IPD), which promote better commercial alignment and incentivizes stakeholders in construction (Matthews and Howell, 2005); and TVD, introduced in 2004, which steers design and construction processes to maximize the owner's value within the project constraints (Ballard and Reiser, 2004; Ballard, 2012). These enriched concepts support CW where project teams plan, manage and deliver customer value in a setting where risks and rewards are shared. It is also claimed that TVD transforms costing approaches with more predictability and transparency, thus reducing waste at conceptual stages (Rubrich, 2012). In doing so, it allow dense collaboration amongst stakeholders where clients have extensive cost interactions, which makes the final product more competitive (Do et al, 2015).

CASE STUDY FINDINGS AND ANALYSIS

In this section, empirical findings were gathered to define and describe CC in the UK construction industry. The concept was further explored in the cases to understand its progress in practice.

PERCEPTIONS OF 'COSTING COLLABORATIVELY'

The overview of collaboration in the literature has set the context for CC to be explored. Therefore, the researcher started by probing the constituents of CC. The participant's responses were: '*transparency during costing*', '*collective value engineering'*, '*reliable cost planning approach'* as seen in table 2. Similarly, other respondents cited attributes like, '*pain/gain sharing', 'cost visibility*' which is reference to open book estimating, while others mentioned '*optioneering*' in search of efficient & reliable cost outcomes, hence through collaboration. These statements described CC as an approach with potentials to achieve a 'win-win' situation by the project team - thus, in need of mutual understanding and a sense of ownership among participants. Some of these attributes are found in CW, which mean it is socially driven. This is to keep in line with Fischer *et al.,* (2017) definition of collaboration as a *'community of people working together to achieve common goal - through a deep level trust, clear understanding of project values and feeling the sense of ownership'.* This definition acknowledged the social interaction of community to mean project performers i.e., designers, constructors, trade vendors and the client all working toward a common goal.

Further attributes associated with CC derived from the participants were categorised into themes namely: 'optioneering', all-inclusive value engineering and target costing. The respondents referred CC to 'target costing' meaning collective substantiation of information that leads to the development of target price. Others suggested that CC is a progressive approach in construction. For example, a respondent with manufacturing backgrounds described it as '*an approach that steers design to achieve a desired cost solution within the boundary of what has been contracted*' [lean practitioner, CS1]. This view indicate that the approach embrace trust, shared understanding, and dialogic conversations around scheme budgets or any assumptions to develop cost solutions, hence, through CW. Similarly, all-inclusive value engineering, in this case means reciprocal dialogues on what is required, knowing where cost, time and quality stands, thereby developing trustful relationships with the project team. This underlines how teams need to collectively forecast and track cost variables, to develop eloquent cost solutions in project.

Table 2: Description of CC and attributes gathered from interviews

Themes	Attributes 1	Attributes 2
Target Costing	Open dialogue Cost certainty Open book estimating	Transparency in costing & design process Cost negotiations
Integrated Value Engineering	Well-informed discussions during costing; Shared understanding	Value creation Cost visibility
Optioneering Process	All-inclusive validation study Risk/reward sharing	Open conversations Reliable cost planning & estimation

CC was also considered to have commonalities with optioneering process. This means that it requires a collective value engineering and target costing traits to realise client's condition of requirements. A respondent with contracting background described this as '*a process that encompass extensive discussions and investigation where multiple cost and design options are distil into single solution, thus feeding into risk and value sessions'* [Main contractor, CS2]. Indeed, achieving single solution in this process is important; as this would allow stakeholders to collaborate over costing and design iterations, especially in multidisciplinary environment where stakeholders are presumed to have in-depth collaboration on costing and value matters.

Therefore, CC as gathered from these descriptions could simply means an approach that engaged stakeholders (upstream and downstream) around wider scheme budgets creating a sense of ownership, driving positive behaviours to achieve desired cost outcomes. This definition acknowledged the social interactions to mean project performers i.e., designers, constructors, quantity surveyors (QSs), supply chain and the client all working together towards a common goal with shared accountability.

COSTING COLLABORATIVELY - AS PRACTICED

After defining the concept of CC, it is equally important to understand how it is progressing in practice. Thus, the study embrace some TVD principles such as *target costing*, *set-based design*, *choosing by advantage* and *relational form of contracting* as a guiding lens to understand how CC is developing in practice.

CASE STUDY 1, 2 & 3 COSTING APPROACH

Figure 1, illustrate the process of target costing, supply chain (SC) approach and the extent of collaboration during early costing phases in multidisciplinary settings. As studied, the process normally begins with collation of historical price data from various project schemes, which are extrapolated into the client database. This revealed a highline TC that informs a new financial business plan (FBP). The FBP is continuously refreshed with historical data, where cost consultants (from client the camps) establish the TC at the end of DM5 (see figure 1). As the project approach conclusion, the final costs are then compared with that of the clients TC, an average cost is selected and the project teams are tasked to value- engineer. As such, the process is centrally coordinated by the client's team, albeit, with little interaction and input from the project and SC teams.

Most of the cases adopts top-down approach for CC, which does not overtly on-board commercial actors SC early, because the project teams are involved indirectly. This was lamented by some of the respondents stating that:

'TC are set by the client organisation independent of the project team. They use data from the 'cost capture system' (CCS) once the previous scheme costs are established; the final costs are transferred to the CCS which drives the client database. Our input is indirect and, we've only started involving the tier-2 in the last few months'.

Despite using the top-down approach, the project teams complain about underlying issues associated with commercial and SC groups, which thus, brings some tension in practice. Some of the participants interviewed lament on:

'Insufficient provision of details to the project team 'continued struggle with the SC on pain/gain share structure', and the incessant waste embedded in the scheme costs of which the new TC is based upon' [Design manager CS2; Consultant CS3].

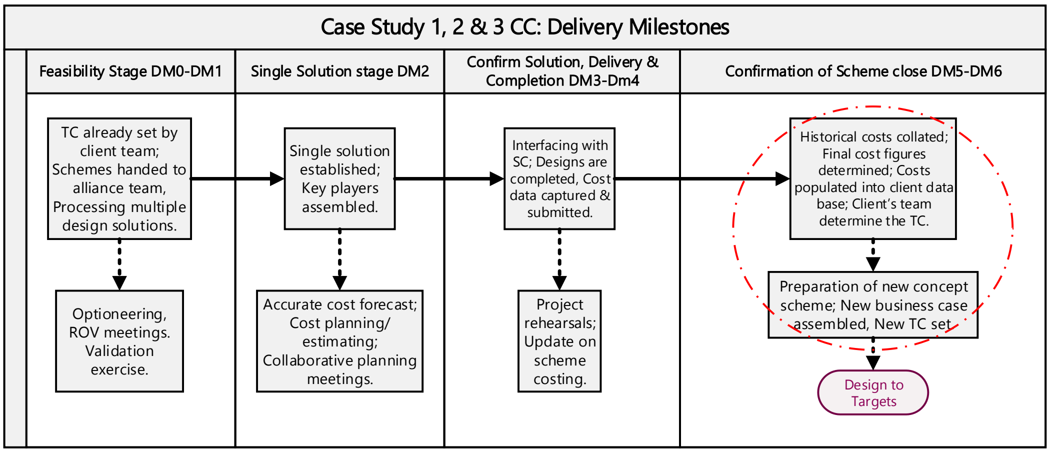

Figure 1: Example of 'Costing Collaboratively in Multidisciplinary Setting

Although, the top-down approach showed notable principles similar to those in TVD and glimpses of CW such as having integrated teams, standard process for TC development; and the owner appears to be heavily involved with the project team. However, other key principles that would intensify CC are missing. For instance, the TC is often set in isolation from the project team; there is no cross-functional team dialogue with the client to underline desirability and viability issues. It was also found that at times the TC sent to the project team is non-negotiable particularly in case study 2 (CS2), which become the final amount to spend. This means that collectively, stakeholders including SC often miss the opportunity for dialogic conversations at feasibility to enhance costing activities.
Similarly, CC and SC approach in case study 3 (CS3) appears to be disconnected. This is because the process keep alternating, where sometimes SC are engaged on framework, and other times on competitive basis. The commercial director stated that:

'For some time now, our SC are engaged in a traditional competitive basis of which we realised the enormous transactional relationship and lots of adversaries that is costing both parties where the client end-up paying'. He further affirms that they are deploying a new strategy now suggesting that: *'We adopt the ECI running our optioneering with the SC at a lower rate, so we engage contractors to help us with the scheme design and negotiate with the SC at that stage'.*

This shows a different type of CC approach, where ECI process allows the team to address buildability and constructability in designs. However, they still emphasise on cost negotiation with the SC groups. This encourage negative behavioural characteristics, as the team are still having difficult relationships with their tier-2 in costing activities. Furthermore, he stated that:

'So what we're doing differently now is getting the SC early and setting the price target with them, and we ultimately end up agreeing the right price in a collaborative way'.

Interestingly, this show that CC would indeed motivate reasonable price determination that is fair to the parties involved, returning value to the owner and stakeholders. However, this needs to start from a position of transparency and sustainability to eliminate any transactional characteristics, so that stakeholders involved would not need to chase claims or unnecessary disputes in the process.

DISCUSSION

Exploring the concepts of collaboration and costing brought some new insights and attributes that defines CC. Most of the respondents felt that collaboration offers significant benefits in practice. Although, not fully applying its attributes especially as seen in the cases examined means maximum benefit would not be realised. This also relates to the concept of CC and how it is perceived. The exploration showed partial understanding and application in practice (see figure 1 and table 3). Whilst establishing CW seems essential in practice, the study discovered that the current costing approach does not overtly integrate commercial actors and SC groups even within the multidisciplinary settings. For instance, a main contractor interviewed on CS03 stated that *'we don't involve our strategic suppliers (tier-2) when we're building these costs; we design and give them to quote'.* This can equally be interpreted as cost negotiation, a position that dominate the current practice and a challenge to CC. Besides, negotiating over cost, which is supposedly referred to as CC completely lacks trust, open dialogue, shared understanding and the wider sense of togetherness, instead it encourage the habit of 'mining for profit' from the contracting parties (Pasquire *et al,* 2015). Invariably, CC as practiced in (CS3) seems to show one-way streak for clients to negotiate or request for information when it suits them but thoroughly lack transparency and interaction. Unsurprisingly, these views are inspired by 'institutional' factors (Sarhan, 2018), which seems to compound the issue of fragmentation, cultural resistance and the poor approach in costing practices.

Table 3: Summary of TVD Principles examined across the three Case Studies

TC/TVD principles examined	CS1	CS2	CS3
Setting TC based on design, value, with cross-functional team.	Occurs partially	Occurs partially	Occurs partially
Co-located facility.	Utilised	Utilised	Utilised
Use of relational contracting.	Sporadic	Sporadic	Sporadic
Application of BIM, Set-based design & Choosing by advantage methods.	Partially Utilised	Not utilised	Not utilised

As examined, the TVD principles required to support CC are either missing or partially applied in the current approach from the cases studied (see table 3). The most apparent is the lack of dialogic conversation when developing the client's costs and the infrequent integration of cross-functional teams to explore costing and design alternatives. For instance, an interviewee stated that '*'we build our projects cost mostly reliant on the market prices and sometimes becomes the amount to spend on the overall scheme''* [Commercial Director, CS02]. According to Simonson (2016), the essence of these dialogic conversations for target price is to determine the degree of certainty on the overall costs for owners to make sure sufficient funds are available to finish the project, and assist in making informed cost-benefit analysis before construction commence. Apparently, these dialogues do not often take place or even widely understood, thus, the chances of attaining cost certainty at conceptual stage would remain slender, given that the default approach is to refer to the contingency savings. Indeed, CC needs a strategy that best aligns the interest of all involved, including commercial actors & SC groups to inspire productivity, innovation, and value addition beyond the least cost approach. (Zimina *et al.,* 2012).

CONCLUSIONS

The study explored costing approach, with a purpose of defining CC concept to widen the understanding of collaboration in the UK construction industry. In doing so, the study identified some constituents that defines CC. These include *target costing*, *all-inclusive value engineering* and *optioneering process*. Therefore, in this study CC is considered as an approach that engaged stakeholders (upstream and downstream) around wider scheme budgets creating a sense of ownership, driving positive behaviours to achieve desired cost outcomes. The concept was further explored to understand its progress in practice. The findings shows that ideal CC is required to improve on the current approach. This is because, the depth for all-inclusive and collaborative dialogues with relevant parties during costing phase is weak/lacking, thus, risks & rewards sharing strategy are not properly understood, especially among the tier-2 groups. Although, it appears to be progressing where the findings revealed customer focus, design centred and somewhat involved cross-functional teams, yet, the approach is still driven by price.

Consequently, the concept could benefit or even becomes better if principles within TVD such as set-based design, choosing by advantage, and relational contracting (eg., IPD) are all embraced when defining TC. More importantly, this would be better if the wider teams are involved early (including traditional cost consultants and tier-2) to compensate the lack of trade-specific and constructability input to inform the limited options that aren't available during costing development. Indeed, establishing this would further strengthen CW, as testament to the definition of CC, upstream & downstream players need to have a sense of ownership and starts from a position of transparency and sustainability to eliminate any transactional characteristics in practice. Although, this study focused on upfront costing (eg., through design), therefore, further research is required to take it beyond expected costs at the end of design to the end of construction using the ascribed definition of CC, as potentially this would shed more light in understanding how to set the right environment that would mitigate commercial challenges to strengthen CW.

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MANAGER PERCEPTION AND DECISION FOR MAKING-DO IN CHINA V.S. IN THE U.S.

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ABSTRACT

Making-do, a decision to start work despite knowing that preconditions are not fully ready, has been referred as a type of waste in construction projects. It will be interesting and beneficial to understand how project managers make making-do decisions when managing projects in different countries and cultures. This research conducted two surveys, one in China and one in the U.S., to study how making-do decision is made differently in two countries by project managers with various levels of experience and responsibility. The research also examined whether there is significant difference in experienced task starting time and duration variation between people with different making-do preference. Findings showed that there was a significant difference in making-do decision preference for construction managers in China vs. the U.S. However, there was no significant difference on making-do decision preference for managers at different responsibility levels. Results revealed Chinese managers who preferred making-do have experienced significantly higher duration variation while in U.S. the results are opposite. Emphasizing obedience, remaining consistency with peers and supervisors, and constantly checking labor, equipment, and materials availabilities are highly valued in the Chinese culture and management practice, which contributed to the making-do decision outcomes in China vs. the U.S. The findings help project managers to understand the difference and rationale in making-do decisions and have more efficient collaboration and communication when they work in projects located in a foreign country.

KEYWORDS

Making-do, lean construction, constraints, China, U.S.

INTRODUCTION

Making-do refers to starting a task before all preconditions are ready (Koskela 2004). Making-do is a complex phenomenon and it is very difficult to avoid, because it is both

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rational and irrational decision at the same time (Bølviken and Koskela 2016). Although making-do is a locally and momentarily rational strategy to reduce waste, reasoning that "it is better to do something than to do nothing", in a long run it can be counterproductive from the perspective of the production system and results in waste (Bølviken and Koskela 2016).

Previous literature suggests different possible reasons for making-do, including high capacity utilization (Koskela 2004), getting the job (Koskela 2004), schedule compliance (Koskela et al. 2013), profit (Pikas et al. 2012), lack of trust (Formoso et al. 2011), and the false belief that "the sooner you start the sooner you finish" (Koskela 2004). However, there may be other possible factors influencing making-do decisions. For example, do people from different countries or culture background choose to use making-do differently? Do people with more experience prefer to wait when preconditions are not ready? Are higher-level managers more cautious than crew-level managers in deciding the timing to start a task? Do managers who prefer to choose making-do tend to experience shorter overall task delay?

In order to answer the above questions, this research conducted two surveys in China and the U.S. Both focus on government projects performed by civilian contractors. The survey in China was distributed among 16 government/public projects from June to August 2018 and collected 141 usable responses. The survey for the U.S was distributed among 240 construction companies working on government/public projects from July to August 2009 and collected 119 usable responses (Wambeke et al. 2011). Using the total 260 responses, the research conducted four hypothesis tests: *H-1:* There is no association between making-do decision preferences and the country in which project managers are working. *H-2:* There is no association between making-do decision preferences and managers' level of construction experience. *H-3:* There is no association between making-do decision preferences and mangers' responsibility level. *H-4:* Project managers with different making-do preferences experience the same amount of task starting time (and duration) variation. In this research, task starting time variation is defined as the difference between the planned and actual task starting time. Task duration variation is the difference between the planned and actual task duration.

LITERATURE REVIEW

MAKING-DO

Making-do as a waste refers to a situation where a task is started without readiness of all its preconditions, or the execution of a task is continued although the readiness of at least one precondition has ceased (Koskela 2004). Preconditions included labor, material, equipment, detailed design and instructions, space, prerequisite work completion, and external condition (i.e. suitable weather) (Koskela 2000). Conceptually, making-do is the opposite of buffering. Whereas in buffering there is a positive waiting time for preconditions to get ready before starting a task, in making-do that waiting time is negative, (Koskela 2004). Koskela (2004) argued further that besides buffering, "making-do is another penalty due to variability" because it is practiced for maintaining a high utilization rate and/or for avoiding schedule slippage.

Formoso et al. (2011) stated that "making-do has a strong relationship with the concept of improvisation." This is because when people face difficult and uncertain situation, they tend to use whatever resources available to reach their objectives (Cunha 2004). Pikas et al. (2012) mentioned that making-do decisions can happen by the crew leaders (last planners) even after the crew has committed to the weekly work plan. They must decide whether to start the task at hand or to wait when conditions are different from those contemplated in the weekly work plan. There are numerous factors influence making-do decisions. For example, perception of the state of readiness, maturity of the work (Pikas et al. 2012), maintaining profitability by utilizing resources (Koskela 2004; Pikas et al. 2012), start the work just for getting the job (Koskela 2004), and lack of trust and pressure of an immediate response (Formoso et al. 2011; Koskela 2004). When choosing making-do, project managers believe that by starting early, even with lack of preconditions, the task will also be completed earlier (Koskela 2004).

By collecting data from two case studies and performing explanatory data analysis Formoso et al. (2011) found: (1) the most frequent types of making-do were related to the access and availability of working areas, temporary facilities, protection, and equipment and tools; (2) the main causes of making-do were the ineffectiveness in providing adequate temporary facilities, poor management of layout/space, and insufficient information; and (3) the main impacts were material waste, poor safety conditions, and reduced motivation. Pikas et al. (2012) collected empirical data over eleven weeks at a large residential construction project. They analysed different scenarios based on task go/no-go decisions and their outcomes and developed a flowchart of making-do decision-making process at operational level. Neve and Wandahl (2018) actively participated in weekly Last Planner System (LPS®) meetings and conducted work sampling studies on six trades for three housing refurbishment projects. They found that making-do is highly likely to be the prevailing reason for the low productivity in refurbishment projects. Furthermore, they found an apparent correlation between excessive talking and making-do, concluding that excessive talking is a valid making-do indicator (Neve and Wandahl 2018).

Although previous research has emphasized on the complexity of a making-do decision, suggested stimulating factors behind making-do decisions, and demonstrate the impact of making-do on project performance, it is still unclear whether culture background, level of experience, and responsibility have significant relationship with making-do decision. It will also be valuable to learn how making-do choice is associated with the amount of experienced task starting time and duration variation. Identifying the impacting factors will help project managers to understand how people with different culture background, responsibility level, and previous project experience react differently in the decision-making. It also will help project managers to have more efficient collaboration and communication when they work in projects located in a foreign country.

METHOD

QUESTIONNAIRE SURVEY

The survey questionnaire was first designed in English and distributed to 240 civilian contractors performing public work under a government contract in 2009 (Wambeke et al.

2011). Those contractors and projects located throughout the U.S. The survey questionnaire was adjusted and translated into Chinese. The adjustments were made to change the expression of the terminologies commonly used and understandable in Chinese. The Chinese version was then translated back to English. The final version in English matched the original version in English. The Chinese survey was distributed to 16 projects located throughout ShanDong province in China in 2018. ShanDong is the most populous and third affluent provinces located in the north-east region in China. All projects were under a government contract and performed by civilian contractors.

Each survey contains three parts. The first part asked respondents' background information such as years of experience in construction, current position, etc. The second part asked whether respondents prefer to "start" a work or "wait" when the preconditions (labor, material, equipment, etc.) are not fully ready. In the third part, respondents were asked to state on average how many hours per week they have experienced task starting time (and duration) variation in their most recently completed project, due to the 50 pre-identified causes of task variation. The 50 individual causes were listed in eight precondition categories. The eight precondition categories included Koskela's seven precondition categories (Koskela 2000) and an "information flow" category. Examples of the causes in "detailed design and instructions" precondition category are constructability issues in design, design changes, insufficient drawings before starting work, long owner's response time, long consultant's response time, vague and unclear drawings details, non-standard and complex structure, and nonspecific construction method and instructions.

SURVEY RESPONSE

The research team received 214 responds from the survey in China and 260 responses from the survey in the U.S. A two-step approach was taken to clean the data and identify the usable responses. First, responses with less than 25% of questions answered was removed. Second, the three-times interquartile range (3×IQR) was used as a cut-off point for removing outliers (Iglewicz and Hoaglin 1993). After data cleaning, 141 usable responses from China and 119 usable responses from the U.S. were identified.

ANALYSIS AND RESULTS

H-1: There is no association between making-do decision preferences and the managers' country of origin (China or the U.S).

A chi-square statistic test was conducted test the null hypothesis that the two categorical variables "Country" and "Making-do" are independent. A crosstabulation of country and making-do was created (Table1).

The chi-square (χ^2) was calculated by comparing the observed number and the expected number of using the following equation:

$$\chi^2 = \sum_{all\ cells} \frac{(\text{observed - expected})^2}{\text{expected}} \tag{1}$$

The value was $\chi^2 = 6.726$ and was significant at $\alpha = 0.05$ level with the p-value of 0.011. Therefore, the null hypothesis is rejected: there is a significant association between country and making-do.

Table 1: Crosstabulation between country and making-do

Country	Count	Making-Do		
		Yes	No	Total
China	Observed	88	53	141
	Expected	95.4	45.6	141.0
	% Row	62.4%	37.6%	100.0%
U.S.	Observed	92	27	119
	Expected	82.4	36.6	119.0
	% Row	77.3%	22.7%	100.0%
Total	Observed	180	80	260
	Expected	180.0	80.0	260.0
	% Row	69.2%	30.8%	100.0%

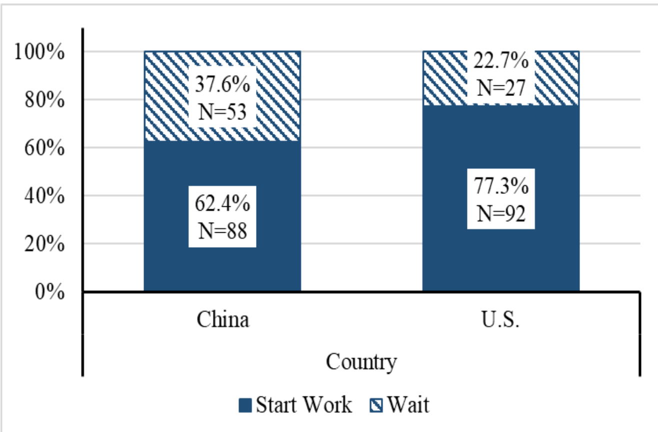


Figure 1: Making-do preference by country

Overall, as demonstrated in Figure 1, making-do is a more preferred choice for both China (62.4%) and the U.S. (77.3%). The research team interviewed five experienced project managers in China**.** They emphasized the importance of n on-time completion of public projects duo to high visibility and potential politic influence. For example, the new QingDao International Airport, Sino-German EcoPark, and HuangDao Resettlement Housing projects. Therefore, the government gave high priority and timely support when there is any problem. The contactors also utilized their best long-term partners to provide labor, equipment, and materials. Another unique phenomenon in construction projects in

China is that all workers and site managers stay on job site 24 hours per day for the entire duration of their portion of work. The workers are farmers from various regions in China. They learn construction work skills as a tradition in their villages and form groups to work on projects in cities. Labor dealers have contact with a larger number of those group leaders. Once there is a need from a construction project and an agreement on the work duration and price, labor dealers call group leaders to send workers on site. This can happen with a few phone calls or text messages and workers can show up in a few hours. Contractors provide food and board for workers and pay labor dealers directly. Labor dealers then pay group leaders after taking their profit. Site managers also stay on job site 24 hours per day for at least six days a week. Managers usually expect a short turnaround time get problems resolved when preconditions are not ready. This could be one of the reasons why managers in China are more likely decide to wait. They have the expectation that the waiting time won't be long.

H-2: There is no association between making-do decision preferences and managers' level of construction experience.

All usable responses were classified into three groups based on their experience in construction industry: (1) less than five years of experience, (2) five to ten years of experience, and (3) ten years of experience or more. The chi-square test was performed three times, for China, the U.S., and combined. None of the chi-squares were statistically significant, meaning that the null hypothesis is true: making-do decisions and the level of experience are independent (not related). Figure 2 shows that Chinese managers with various level of experience choose making-do at similar rate. In Chinese culture obedience and consistency is usually encouraged. While in the U.S., managers with 5 years or more experience choose making-do more often although there is a slight decrease in making-do choice for the group with 10 years or more experience. Also, results revealed that the biggest different in choosing making-do was observed in the group with 5-10 years of experience (62.7% in China and 82.1% in the U.S.).

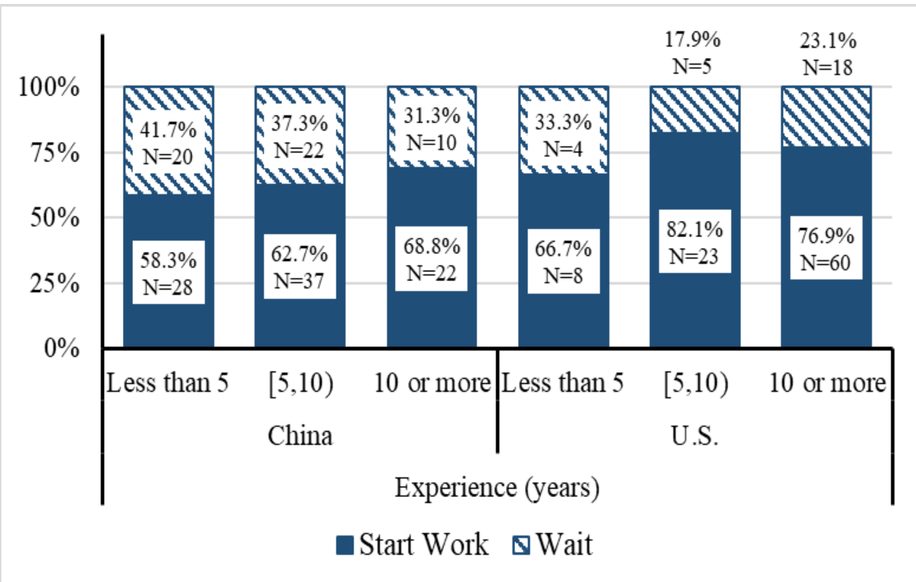


Figure 2: Making-do preference by years of work experience

H-3: There is no association between making-do decision preferences and managers' responsibility levels.

All usable responses were classified into three groups based on their position level: (1) crew/labor, (2) middle-level managers (foremen and superintendents), and (3) high-level managers (project managers). Chi-square test was conducted for each country and combined. None of the chi-squares were statistically significant, meaning that the null hypothesis is true: making-do decision and position levels are independent (not related). Figure 3 shows that in China, there is high level consistency in making-do selection percentage for all three level of managers, at 37.8%, 36.4%, and 35.7% respectively. The culture emphasize authority from higher-level commanders. Frequently asking for directions, following directions, are mimic supervisor's strategies are often encouraged and regarded as one of the criteria for promotion and career advancement. In the U.S., mid-level managers have much higher tendency choosing making-do than other level managers.

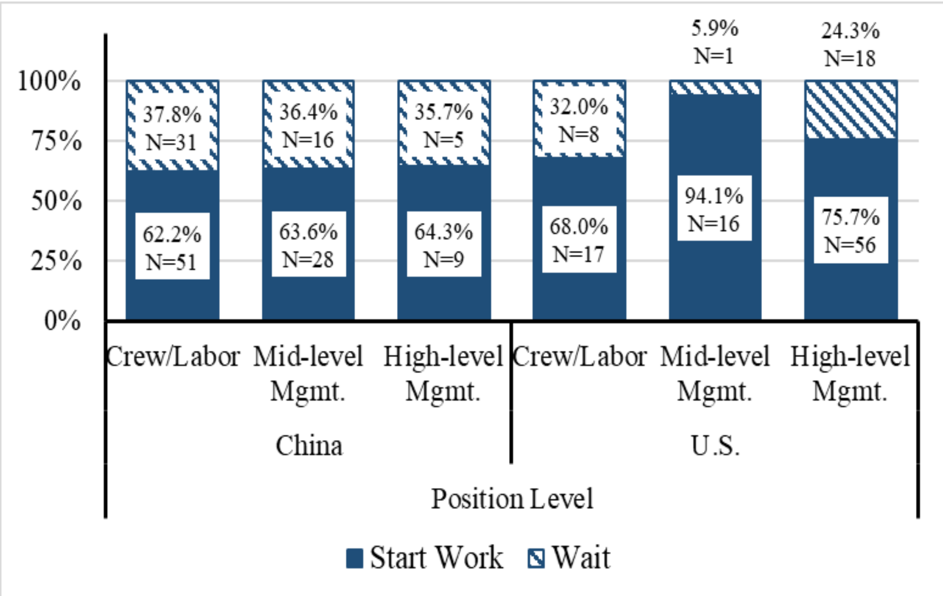


Figure 3: Percent of people start work or wait based on their position level

H-4: Project managers with different making-do preferences experience the same amount of task starting time (and duration) variation.

The average amount of starting time and duration variation (hours/week) experienced by the respondents due to the lack of readiness in the eight defined prerequisite categories were calculated (Table 2). The Mann–Whitney U test was performed using IBM SPSS Statistics V25 to examine the differences in the perceived amount of task starting time and duration variation for the making-do and none making-do group.

The Mann–Whitney U test is a nonparametric test that compares the central locations of two population with similar-shape distributions (not necessarily normal) when there are two independent random samples drawn from these populations (i.e. people who start work and people who wait). Instead of comparing the raw data directly, the Mann–Whitney U test compares the ranked data (Newbold et al., 2012; Norušis 2012). Observations from the two samples are combined and ranked on the ascending order. If there are tied observations, the average of ranks is assigned to all of them. The Mann–Whitney U null hypothesis is that there is no difference in terms of task starting time and duration variation for the making-do and none making-do groups. In order to test this null hypothesis, the Mann–Whitney U statistic were calculated using the following formulas (Newbold et al., 2012):

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1 \quad (2)$$

$$E(U) = \mu_U = \frac{n_1 n_2}{2} \quad (3)$$

$$Var(U) = \sigma_U^2 = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12} \quad (4)$$

$$Z = \frac{U - \mu_U}{\sigma_U} \quad (5)$$

where n_1 and n_2 = size of the "making-do" and "none making-do" groups; R_1 = the sum of the ranks of the "making-do" group; σ^2_U = the variance of the Mann–Whitney U; and μ_U= the mean of the Mann–Whitney U. After calculating the Z value, decision was made to whether reject or accept the null hypothesis considering significance level of $\alpha = 0.05$.

Table 2: Average experienced task starting time and duration variation (h/week)

Prerequisite Categories	**China**				**U.S.**			
	Avg. Starting Time Var. (h/week)		**Avg. Duration Var. (h/week)**		**Avg. Starting Time Var. (h/week)**		**Avg. Duration Var. (h/week)**	
	Start	**Wait**	**Start**	**Wait**	**Start**	**Wait**	**Start**	**Wait**
Prerequisite Work	1.14	0.94	1.08	1.04	1.18*	1.53*	0.92	0.80
Design & Specs	0.87	0.70	1.13	0.86	0.75*	1.71*	0.87*	1.41*
Labor	0.87	0.94	1.23*	0.91*	0.52*	0.72*	0.76*	1.11*
Equipment	0.44	0.33	0.53*	0.35*	0.32*	0.56*	0.31*	0.44*
Material	0.63	0.50	0.69*	0.40*	0.67*	1.32*	0.73	0.79
Layout & Space	0.74	0.50	0.70	0.65	0.72*	1.12*	0.72	0.92
Information Flow	0.61	0.54	0.87	0.78	0.69	0.90	0.75	0.88
External Conditions	0.78	0.80	1.04	0.82	0.65*	0.92*	0.99	1.20

Table 2 shows average of task starting time and duration variation (h/week) experienced by the respondents in China and the U.S. Respondents' experienced variations were ranked in each of the eight precondition categories and arithmetic mean scores were calculated for China and the U.S. data separately. Mean scores are plotted in Figure 4 and Figure 5. The results of the Mann–Whitney U test revealed there is a statistically significant difference (at $\alpha = 0.05$) in experienced starting time (and duration) variation by people with different making-do preference due to the lack of readiness in seven of the eight precondition categories and therefore the null hypothesis is rejected.

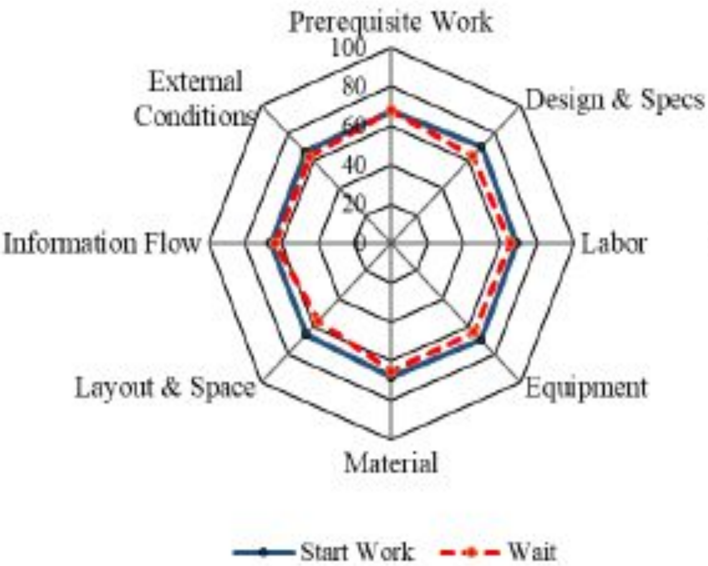
These preconditions are indicated by an asterisk (*) next to the average variation in Table 2 and next to the prerequisite category labels in Figure 4 and Figure 5. Figure 4 shows how experience task starting time variation differs between making-do and none making-do respondents. There is not much difference experienced in task starting time delay due to the eight precondition categories for Chinese managers with different making-do preferences (Figure 4a). But the U.S. managers who preferred to making-do have experienced significantly less task starting time variation due to lack of precondition readiness in all categories except "information flow" (Figure 4b). Figure 5a shows that respondents in China with making-do trait experienced higher amount of duration variation due to lack of readiness in "labor", "equipment", and "material" categories. There are also significant differences in the U.S. managers' experienced task duration variation in "design and specs", "labor", and "equipment" precondition categories for making-do and none making-do groups. Their experience is that forcing to start in the long run results in less task duration variation.

CONCLUSIONS

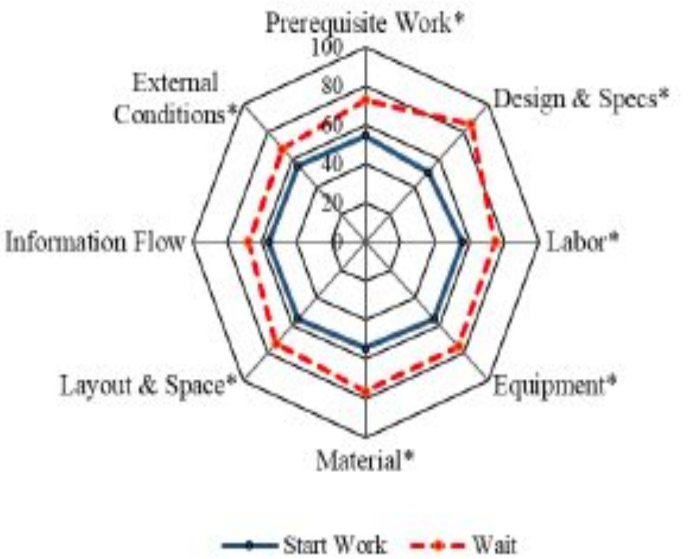
In order to understand how managers with different culture background choose making-do strategies differently and the rationale behind it, this research conducted two surveys in China and the U.S. Findings showed there was a significant difference in making-do decision preference for construction managers in China and in the U.S. However, there was no significant difference on making-do decision preference for managers with different levels of construction experience as well as with different responsibility levels. Results revealed that the U.S. managers who preferred making-do, experienced lower amount of task starting time and duration variation due to the lack of precondition readiness. On the other hand, Chinese managers who preferred making-do, experienced higher amount of duration variation due to lack of readiness in labor, equipment, and material categories. This is one reason why in China fewer making-do decisions are made because Chinese managers have experienced more making-do wastes in terms of task duration variation. Interviews with five Chinese project managers indicated that obedience and constantly checking labor, equipment, and materials availabilities are emphasized in the culture and management practices. These contribute to the differences of making-do in Figure 5.

LIMITATIONS AND FUTURE RESEARCH

Survey in China was only conducted in one province, while the survey in the US. was nationwide. However, Shandong province is the second most populous province and has the third highest GDP in China in 2017. Therefore, the results are useful and beneficial for managers. Future research can perform more in-depth analysis to find to what extend managers' experience of variation in the past contributes to their making-do decision for the future.

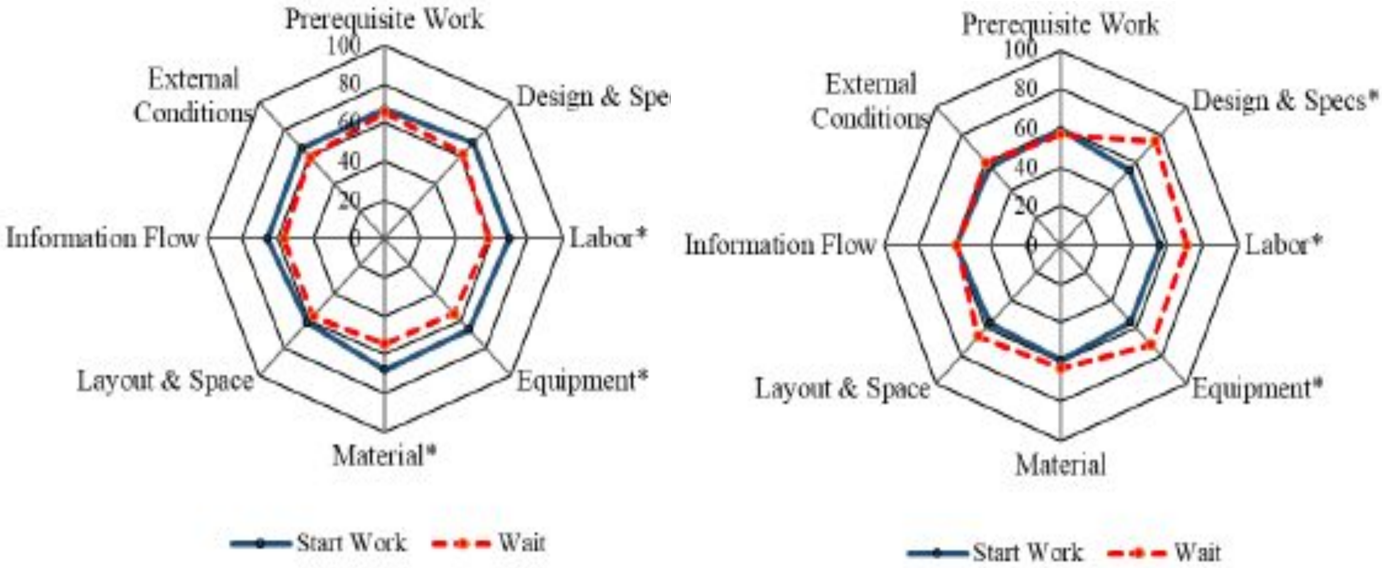


(A) CHINA



(B) US

Figure 4: Task starting time variation profiles experienced by construction practitioners



(A) CHINA (B) US

Figure 5: Task duration variation profiles experienced by construction practitioners

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INTEGRATING LEAN CONSTRUCTION AND SUSTAINABILITY VIA A SYSTEM DYNAMICS FRAMEWORK

Ann Francis[1], Albert Thomas[2]

ABSTRACT

The growth of the construction industry has been constantly challenged by issues such as low productivity, time overruns, reduced profits, and high variability. Additionally, growing emphasis on sustainable development challenges the industry to explore methods and technologies that improve the sustainability of construction and built systems. Lean construction is proposed as a solution to address many of the construction related issues by reducing wastes and improving reliability, and recent research reveals that, it has significant potential in addressing sustainability concerns as well. Therefore, the relationship between lean and sustainability warrants a deeper understanding to assimilate the trade-offs across economic, social and environmental parameters. Even though the existing studies in this domain establish the relationship between lean and sustainability, they are greatly diverse in their approaches thus creating a fragmented understanding, and does not collectively analyse the various interrelationships and the feedbacks. This mandates the need of a realm like systems thinking to capture the dynamicity and interlinkages embedded in this complex relationship. This paper proposes a conceptual framework based on system dynamics modeling approach for the integration of lean and sustainability. A systems approach provides a better understanding to the industry practitioners about the scale of lean implementation demanded to ensure sustainable development.

KEYWORDS

Lean construction (LC), Sustainability, System dynamics, Systems thinking, Waste

INTRODUCTION

Sustainable development refers to development that promotes economic growth to fulfil the needs of the present generation, and sustain resources for the future (WCED 1987). In addition, it aims at enabling a socially inclusive growth, and emphasizes on the conservation of the biodiversity and ecosystem by improving its tolerance against human activities (Hay and Mimura 2006). The

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construction industry has a major role to play in sustainable development owing to the influence it has on the natural environment, human life and the global economy. This influence can be characterised by the economic contribution of the industry that is projected to be over 15 percent by 2020, with an anticipated growth rate of about 4 percent per annum (GCP 2015). The sector also contributes to the social dimension as well, by providing security to people and through employment opportunities generated from the sector's activities. Furthermore, the construction industry significantly affects the ecosystem through large resource consumption, enormous energy use, and environmental emissions associated with its activities (Degani and Cardoso 2002). The concern towards the environment has thereby forced the construction industry to re-think its practices by adopting strategies that address environmental concerns, while promoting economic and social growth. Therefore, the need to adopt a triple bottom-line approach has promoted the concept of sustainable construction that could enable the industry to align its inherent goals with sustainable development objectives.

However, achieving overall sustainability is an added challenge to this industry that is already burdened by existing problems of low productivity levels, revenue risks, lack of skilled workforce, project delays and slow technology adoption. Lean construction (LC) that emerged in 1990's is one such philosophy that promoted a behavioral change in the industry, with potential benefits in the form of improved productivity, reduced wastage, reduced cost and inventory, improved work flows and higher profits (Koskela et al. 2002). Lean philosophy originated from Toyota's production system propagated by Ohno (1988). LC primarily focuses on elimination of wastes, satisfying customer needs, focusing on value and perfection, improving efficiency in project delivery by reducing variability, and augmenting reliability of construction processes (Koskela 1992). It provided a new definition to wastes unlike conventional thinking where wastes meant to be only physical wastes. The seven wastes categorized by traditional lean production ideologies (Ohno 1988) are transport, waiting, motion, extra-processing, overproduction inventory and defects/rework. Lean thinking hence, contrasted the conventional approach in construction by directing attention to flow and value.

Several studies have also opined that, LC has a very close relationship with sustainability (Huovila and Koskela 1998, Nahmens and Ikuma 2011, Carvalho et al. 2017). The synergies between LC and sustainability have therefore been widely researched and various authors have proposed integration of these concepts through different modes such as case studies, conceptual models and theoretical relationship frameworks. However, most of the existing studies deduce only a limited set of interdependencies between lean and sustainability. This is due to the focus on individual parameters of LC and sustainability and key interlinkages between them being overlooked (Degani, and Cardoso 2002, Peng and Pheng 2011). Furthermore, even though several studies explored the impact of lean on sustainability, the counter effects of sustainability on lean is not prominently discussed (Khodeir and Othman 2016). The diversity in approaches in the existing literature while proposing the integration of LC and sustainability necessities the need of a framework to evaluate it as an integral system. This motivates the authors to propose a conceptual elucidation to this scenario, by proposing a systems thinking approach that facilitates a qualitative and quantitative understanding of the integration between LC and sustainability. Within systems thinking perspective, system dynamics (SD) simulation enables the understanding of the behavior of complex systems over time by considering the various dynamic factors influencing the system under consideration (Sterman 2000), and therefore this study adopts a SD based conceptual framework to evaluate the interrelationship between LC and sustainability. The proposed framework intends to aid in the analysis and assessment of the interactions between LC and sustainability across the three major dimensions (social, economic and environmental), and understanding the feedback mechanisms and behavior of the resulting integrated system.

THEORETICAL BACKGROUND

As mentioned in the introduction, recent emphasis on sustainability across the globe has inspired the lean research community to explore the potential of lean to address broader concerns of sustainability. The main point of confluence between LC and sustainable construction has been on the aspect of waste reduction (Bae and Kim 2008, Nahmens 2009, Koranda et al. 2012, Johnsen and Drevland 2016).This is because, LC focuses on eliminating the non-value, adding activities and sustainable construction aims at promoting efficient resource use. Several studies have proposed relationship matrices between LC and sustainability that focused on elaborating the elements of correlation between the two concepts (Khodeir and Othman 2016, Carneiro et al. 2012). Meanwhile, few studies conducted empirical investigation into their integration (Lapinski et al. 2006, Ogunbiyi 2014, Carvalho et al. 2017) and others used case studies to demonstrate this relationship by showing the influence of lean tools of VSM (value stream mapping) and LPS (last planner system) on sustainability parameters (Koranda et al. 2012, Rosenbaum et al. 2013, Ghosh et al. 2014). Further, several authors proposed conceptual models that included frameworks integrating lean, green and six-sigma (Banawi and Bilec 2014) and lean and green conventions for evaluating delivery of green projects (Klotz et al. 2007, Martinez et al. 2011).

Even though, limited consensus is observed in the approaches of integrating LC and sustainability it can be observed that, the existing literature can be categorized into three main fragments. This division is primarily based on the mode of approach adopted to integrate these concepts. A major portion of the existing literature discusses about the interactions between lean and overall sustainability by discussing the influence of lean practices on some aspects of the social, economic, and environmental dimensions of sustainability (Bae and Kim 2008, Nahmens and Ikuma 2009, Salem et al. 2014, Ogunbiyi et al. 2014). The other major segment of existing research discusses about the merger between lean and green, primarily focusing only on the environmental aspects of sustainability (Degani and Cardoso 2002, Carneiro et al. 2012, Ghosh et al. 2014). The third portion is centered on the aspect of delivery of sustainable facilities through lean practices that help in reducing the costs and improving the ease and efficiency of delivery of such projects (Lapinski et al. 2006, Klotz et al. 2007, and Martinez et al. 2011). Overall, the fragmented approach in the understanding of LC and sustainability inhibits the evaluation of the influence of their integration on overall sustainable development. Furthermore, most of the proposed integrated frameworks lack a triple bottom line approach. Hence, it leads to biased inferences about whether LC and sustainability are complimentary or contrary in nature. This demands the need of an approach that holistically views the interlinkages between different elements of LC and sustainability and further helps in visualizing the feedback relationship involved between the two concepts.

A systems approach would be ideal in this scenario. Systems thinking helps in understanding and interpreting the interdependencies and complex interactions between various entities in a system (Anderson and Johnson 1997). System dynamics (SD) modeling that evolved from systems thinking was developed by Forrester (1958) as a method to visualize and analyze complex dynamic systems using computer based simulations. It enables in formulating policies according to the analysis of the dynamics involved, and helps in deciphering a system's core structure and comprehending its behavior over time. The construction sector is an ideal platform for the use of SD, owing to the complexity and highly dynamic nature associated with it causing numerous feedback interactions. SD is hence, widely used for decision making in the design phase of buildings as well as in assessing the building lifecycle energy performances (Thomas et al. 2016). Hao et al. (2008) used SD to develop a model to manage and forecast construction and demolition waste by modeling the waste generating factors. SD has also found applications in lean production. Few studies have been reported on the application of SD for evaluating lean performance in the manufacturing sector (Krishnamurthy and Chan 2013, Omogbai and Salonitis 2016). SD has further been used to model the causes of rework (due to design, client and contractors), which is a major lean waste in construction projects and it was used to propose policy interventions to reduce the same (Aiyetan and Das 2015). Similarly, in the area of sustainability, SD has found applications for assisting in proposing various policy interventions to reduce the environmental impact, and for assessing the sustainability of projects (Shen et al. 2005, Zhang et al. 2014). However, there have been very limited attempts on integrating the concepts of LC and sustainability under a systems thinking ideology. SD provides a suitable platform to observe the complete network of influences between various parameters of LC and sustainability and evaluate it as an integrated system. Therefore, a framework has been proposed in the subsequent sections, integrating LC and sustainability using SD.

CONCEPTUAL SD FRAMEWORK FOR INTEGRATING LEAN AND SUSTAINABILITY

In SD, causal loop diagram (CLD) is a major component that visualizes the behaviour and structure of a complex system. In the context of lean and sustainability interactions, the CLD developed in Figure 1 attempts to capture the influence of each lean tenet with the different sustainability attributes and their mutual influences on the whole system. This CLD consists of the various lean tools namely Kaizen, LPS, 5S, VSM, prefabrication, and just-in-time (JIT). Further, it depicts sustainability and the three main pillars along with the different parameters that are components of the three pillars. Lean and sustainability are primarily linked by parameters such as variability, rework, material wastes, inventory, transport etc. The interrelationship between each component is captured via causal links and the nature of the interactions is shown by link polarities. A positive sign on the causal loop link shows that, both the linked elements exhibit the same direction of change, while a negative sign shows that they exhibit an opposite cause and effect relationship (Sterman 2000).

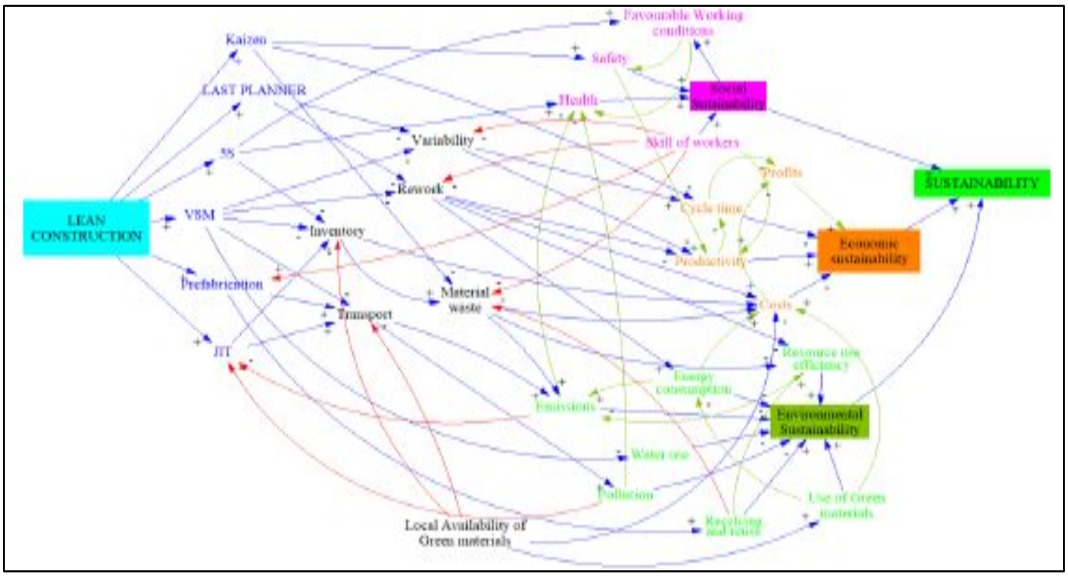

Figure 46:-Causal Loop Diagram representing the interaction between LC and Sustainability parameters

The CLD can be interpreted as follows. LC implementation increases the application of lean tools in a project, which in turn influences the reduction of lean wastes of inventory, transport, rework, material wastes and variability. This reduction influences the various parameters of social sustainability, namely safety, skill of workers, health and favorable work conditions; economic sustainability parameters namely costs, profits, cycle time and productivity; and environmental sustainability parameters such as resource use efficiency, energy consumption, emissions, water use, pollution, recycling and reuse, use of green materials and greenhouse gas emissions. It should be observed that, most of these parameters additionally influence the reduction of some of the lean wastes. The benefit of using CLD's is that it captures the interrelationships inherent between the different sustainability parameters. Hence, changes in certain environmental parameters due to lean tools could result in changes in the economic or social sustainability parameters and vice versa. These interactions within a subsystem and between subsystems can be easily captured using CLD's.

Few important feedback loops could be observed from the CLD. For example, JIT delivery reduces inventory, thus resulting in lesser material waste, and hence lesser emissions. But at the same time if the delivery distances are very large and reliability of suppliers are not ensured, then JIT will result in more frequent transportation leading to increased pollution and emissions (Bae and Kim 2008). Hence, if JIT leads to more congestion and pollution it is advisable not to implement it. Using SD, it is possible to model optimum JIT schedules to keep the harmful emissions under control. Prefabrication also exhibits similar feedback loops. It reduces a considerable amount of material waste, promotes recycling or reuse and ensures better working conditions for the labor (Peng and Pheng 2011). But then again, if the precast yards are too far, transporting elements to the site will lead to a lot of emissions and pollution. Additionally, prefabrication requires more skilled labor, which is an aspect of so cial sustainability.

Understanding different feedback loops is important to make right decisions on the implementation of various practices so that negative impacts on the overall system could be suitable controlled.

Other prominent relationships in the CLD are described as following, Kaizen (continuous improvement) is an important aspect of LC that helps in enhancing the efficiency of the processes through reduction in material wastes, improving cycle time (economic sustainability) and site safety (social sustainability) (Vieira and Cachadinha 2011). Similarly, VSM helps in identification of different lean wastes. It proposes measures for improvement of processes by reducing rework, variability, material wastes and transport that further influences the different economic parameters of sustainability. Further, as reported in a particular study, VSM could help in reducing water use and material waste, which are important parameters of environmental sustainability (Vinodh et al. 2011). Likewise, 5S helps in maintaining the workplace in a clean and orderly manner, thus keeping the place safe and accident-free (social sustainability). It reduces inventory and wastage due to spillage or leaks thus reducing emissions (environmental sustainability) (Bae and Kim 2008). Similarly, LPS reduces variability, which influences the economic parameters of cycle time and productivity. It reduces rework, thereby leading to more resource efficiency (Ghosh et al. 2014). The CLD can further capture the inverse relationship of some parameters of sustainability on certain wastes. For example, material waste can be reduced by recycling or reuse and could be a result of improved skill of the labor. Similarly, local availability of green materials influences the use of green materials and the amount of transport or inventory associated with these materials thus influencing both lean and sustainability attributes.

While Figure 1 represents a specific CLD, Figure 2 below represents a schematic system framework to model LC and sustainability based on the feedbacks and inter relationships mentioned in the CLD. Even though a fully developed SD model is outside the preview of this paper, based on this framework presented below, it is possible to model the interaction of lean and sustainability using stocks and flows, and simulating it along a specific time frame to help in decision-making. Stock flow diagram (SFD) is a powerful representation of a complex system and provides mathematical implications to the behavior of the system. Lean wastes and sustainability could be provided with measures of some form and represented as stocks and these could be controlled by flows such as rate of accumulation of lean wastes and rate of implementation of lean tools. The sustainability measure is influenced by the different economic, social and environmental parameters, and it is drained by the presence of lean wastes. However, implementation of lean tools could lead to an increase in the sustainability stocks by reducing the lean wastes. The representation in Figure 2 is purely conceptual, and provides the foundation for development of comprehensive models to explain LC and sustainability relationships

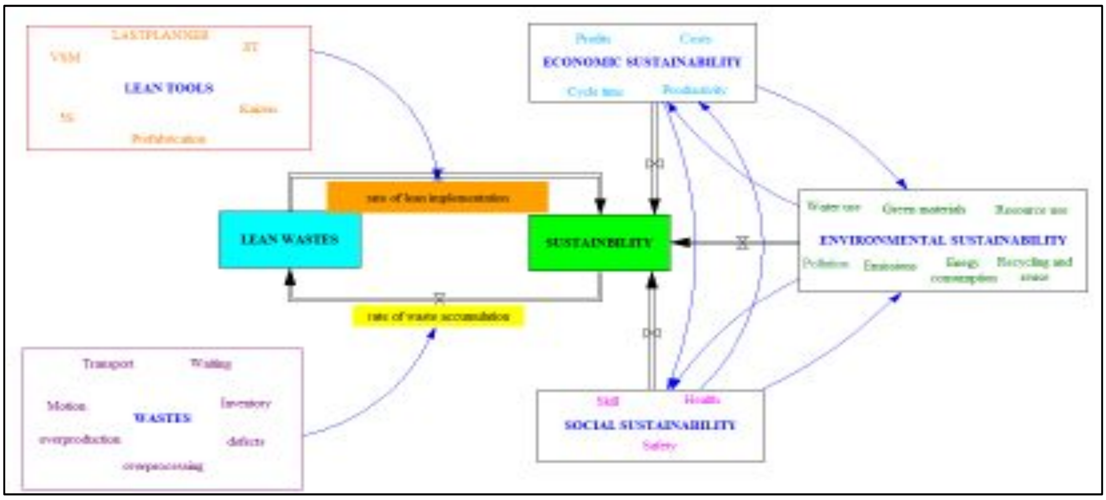

Figure 47:-Conceptual framework based on System Dynamics

DISCUSSION

Evaluating LC and sustainability under a systems thinking perspective provides comprehensive understanding of the benefits and impairments of integrating these distinct concepts through a unified framework. Developing a SD framework as discussed above helps to quantitatively measure the impact of implementing LC practices to achieve sustainability in construction sites. Hence, this approach helps in visualizing the mutual influences of integrating lean and sustainability through a triple-bottom-line approach, thus equipoising the shortcomings of the previous frameworks. Even though the framework presented is conceptual in nature, an actual implementation strategy could be by modelling each of the lean tools individually and capturing its influence on the different sustainability parameters.

For instance, to quantitatively capture the influence of the lean tool JIT on the environmental parameter of emissions, a SFD could be used. A possible approach of developing this model could be by quantifying several aspects such as the number of trips, inventory stock to be maintained, fuel consumption and material waste generated due to excessive inventory. JIT is proven to result in lesser inventory, material wastes thereby resulting in lesser emissions. However, JIT might result in increased number of trips leading to excessive emissions. This trade-off between emissions can be suitably appraised using the SD based framework. Adopting such a modeling approach in a simulation platform will thus help in optimizing the JIT delivery schedules so as to balance the goals of LC and sustainability. Similarly, other lean tools can also be modeled and their subsequent sustainability influences and feedbacks can be quantitatively measured and evaluated using SD.

Therefore, SD can help in computationally simulating the mutual influence of LC practices on sustainability parameters, and based on the suggestions from the model, suitable decisions or policies could be formulated to reap maximum benefits. Hence, adopting a systems approach could serve as a supporting tool for industry practitioners to develop a better understanding of the scale of lean implementation required to achieve sustainability in construction sites. Conversely, the impact of sustainable construction on the lean production efficiency parameters could also be evaluated using such an approach.

CONCLUSION

Encouraged to enhance the understanding of LC and its role in promoting sustainable development, the authors proposed a conceptual framework based on system dynamics. The framework aims to aid in comprehending the behaviour of the complex interrelationships between LC and sustainability in a more systemic and unified manner through a triple bottom line approach. System dynamics could assist in solving the contradictions associated with the integration of these two distinct concepts that hold sufficient concurrencies with each other. This research is part of an on-going study that is currently adopting SD as a tool to evaluate and quantify the impact of LC practices on sustainability and vice versa. This paper is limited to proposing a conceptual outline based on SD to analyse LC and sustainability as an integrated system. Future scope involves developing computational models to obtain quantitative measures for LC and sustainability integration. Based on this study, the authors propose that, future research should focus on exploring the long-term impacts and dynamic influences of lean practices on sustainability in the construction sector.

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RECONCEPTUALISING CREM ALIGNMENT TO ACCOUNT FOR WASTE

Tuuli Jylhä[1]

ABSTRACT

Every business needs a place to operate. The management of corporate operational assets is called Corporate Real Estate Management (CREM). In the era of sustainability, smart use of real estate as the second-largest asset of corporations is needed. The purpose of the paper is to reconceptualise CREM alignment to feature the waste concept in smart use of CRE resources. This research is limited to the conceptual analysis of CREM alignment.

The reasoning is based on integrative literature review. In general management theories, alignment is divided between vertical and horizontal alignments within and across organisations. In CREM literature, vertical alignment within an organisation is dominant while horizontal alignment within an organisation and across organisations has gained minimal attention.

The conceptual analysis indicates that there is plenty of waste in CREM. Lean aligns especially horizontally and offers a way for smart alignment, i.e., a smart use of CRE resources including not only the use of materials and energy but also the use of human resources with their social capital.

KEYWORDS

Corporate real estate, corporate real estate management, alignment, waste, added value.

INTRODUCTION

Every business needs a place to operate. The real estate needs of a museum, stadium, law firm, health care centre, retail chain or a car manufacturing company are unique. The management of these operational assets to house corporate's business is called Corporate Real Estate Management (CREM) (Edwards and Ellison, 2004; CoreNet Global, 2016). In corporations, real estate is often undermanaged although it is the second-largest cost of companies after human resources (Edwards and Ellison, 2004).

In CREM, real estate is seen from the user perspective, not from the investor's or service provider's perspective. During the life-cycle of a building, the CRE manager represents the user in the design and construction phases, manages the use and reuse phases of the building and is the key respondent in the reuse, recycle and redistribution of the materials in the demolition phase of owned properties.

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In the era of sustainability and smart use of resources, the smooth cooperation and value delivery during the entire building life-cycle is highlighted. To avoid excess use of resources is one of the main concepts in lean construction, but hardly known in the field of CREM. Instead, two other concepts have a dominant role in the current CREM literature: alignment and added value. Alignment is typically adapted from strategic management literature, as Heywood and Arkesteijn (2017) concluded, and the concept of added value after Porter. Both concepts are widely used and accepted in the CREM literature (e.g., Krumm et al., 2003; Jensen et al., 2012) and illustrated in the often used CREM definition:

> CREM is "the alignment of the real estate portfolio of a corporation or a public authority to the needs of the core business, in order to obtain maximum added value for the business and to contribute optimally to the overall performance of the organisation" (Dewulf et al., 2000).

In this paper, it is argued that CREM theories benefit from the adaption of the waste concept. The purpose of the paper is to reconceptualise CREM alignment to feature the waste concept in smart use of CRE resources**.** Waste in this paper is defined after Bølviken et al. (2014): "the use of more than needed and unwanted output".

To reconceptualise, the reasoning is based on integrative literature review as proposed by Torraco (2005). First a summary of alignment theories from strategic and operational management literature is presented and then CREM alignment literature is analysed with an integrative approach.

ALIGNMENT

In this section, the alignment types inside an organisation (organisational alignment) and across various organisations (cross-organisational alignment) are briefly presented.

ORGANISATIONAL ALIGNMENT

Alignment is studied in many disciplines and, consequently, the literature has matured but also siloed. The used terminology varies from field to field and other terms, such as fit, integration, harmony, coherence and linkage, are often used. In this paper, the term 'alignment' is used due to its common acceptance and use in the CREM literature.

This paper follows a model of Kathuria et al. (2007) on the hierarchy of alignment within an organisation. In the model, alignment is divided into vertical and horizontal alignment (Figure 1): vertical alignment goes through the entire organisation and horizontal alignment on two levels: functional and intra-functional. Next, the three main organisational alignment types are briefly presented.

(1) Vertical alignment, also called hierarchal alignment, refers to the consensus of "strategies, objectives, action plans and decisions throughout various levels of the organisation" (Kathuria et al. 2007). Vertical alignment is a commonly used concept between three levels – corporate, business and functional levels (1a-1b in Figure 1). In their model, Kathuria et al. (2007) presented that vertical alignment depends also on the fourth level: on the decision areas within a function (1c in Figure 1).

Horizontal alignment is explained through two forms of alignment (Kathuria et al., 2007): (2) cross-functional and (3) intra-functional alignment. Cross-functional alignment refers to the fit between different corporate functions (2 in Figure 1), such as HR, ICT, marketing, operations and real estate (RE). Intra-functional alignment refers to the fit between different decision areas and their actions within each function (3 in Figure 1). Kathuria et al. (2007) highlighted that intra-functional alignment requires also vertical alignment: the decisions and actions between decision areas are aligned with the policy documents of that function and these have a fit with the overall corporate strategy.

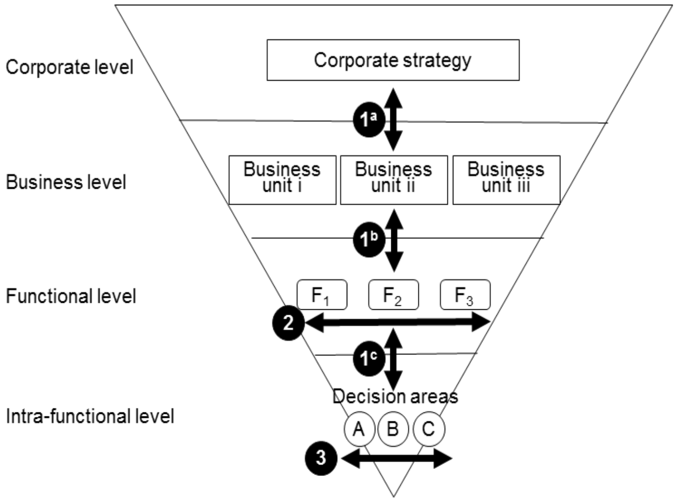

Figure 1: Summary of organisational alignment (adapted from Kathuria et al. 2017)

Vertical (strategic) alignment

Traditionally, strategy design is seen as an iterative, top-down process, where the strategy design on corporate levels leads the iteration. However, a bottom-up approach is also discussed in the literature (Kathuria et al., 2007). The early pioneer presenting the bottom-up approach was Skinner (1974), who encouraged to see manufacturing as a strategic weapon for corporations instead of as simply conforming to the corporate strategy without two-way dialogue. Hayes and Pisano (1994) stated that corporations often “focus on the form of their asset”, such the type of technology the corporation has, “rather than on their substance” such as skills and capabilities to use that technology. Wheelwright and Hayes (1985) were in line with Skinner and identified four stages in how manufacturing contributes to the strategic objectives of an organisation:

STAGE 1: By minimising the negative potential of manufacturing (internally neutral)
STAGE 2: By following industry practice to achieve parity with competitor (externally neutral)
STAGE 3: By providing internal support for the business strategy (internally supportive)
STAGE 4: By providing competitive advantage (externally supportive)

Cross-functional and intra-functional alignment

Cross-functional and intra-functional alignments as horizontal alignment types have been studied less than vertical alignment and, thus, the related research is sparse (Kathuria et al.

2007). Two of the early pioneers are Henderson and Venkatraman (1989; 1993), who proposed that in addition to strategic integration, operational integration is also needed. By operational integration they referred to horizontal alignment inside an organisation.

There are few fields where horizontal alignment is studied more. One of these fields is operations management, where terms such as 'process re-engineering', 'process redesign' and 'process improvement' (Lee and Dale, 1998) are used instead of alignment. In operations management, alignment refers to "arrangements of various parts in a company so that they work together harmoniously" (Yuan Hung et al. 2010). To work together means that organisation is not solely moving to the same direction but is also capable of minimising its internal inefficiencies (Alagaraja et al. 2015). This leads to an idea of increased value and removed rework and other types of waste when the process is streamlined (Benner and Tushman, 2003). This requires functional understanding of processes including "individual, functional, cross-functional and cross-organizational processes" (Alagaraja et al. 2015).

CROSS-ORGANISATIONAL ALIGNMENT

By continuing the idea of the previous chapter, horizontal alignment is also needed in cross-organisational processes (Alagaraja et al., 2015). For example, supply chain management (SCM) or value chain management (VCM) represent this type of cross-organisational alignment. According to Vrijhoef and Koskela (2000) and Schniederjans et al. (2010), the early traces of SCM can be traced back to JIT delivery systems in Toyota Production System (TPS) and to the quality control field pioneered by Shewhart, Deming, and Juran. Cooper and Ellram (1993) highlighted that SCM focuses on "the total flow of a distribution channel from the supplier to the ultimate user" instead of focusing on few players in that supply chain.

According to Schniederjans et al. (2010), waste and inferior results can be avoided by aligning strategies, tactics and operational plans. They continued that lean aligns especially horizontally within an organisation and across organisations. Lean contributes by improving effectiveness and efficiency of the supply chain operations. Effectiveness refers to the value proposition (i.e. doing right things) and efficiency to waste elimination (i.e. doing things right).

CREM ALIGNMENT

Next, organisational and cross-organisational alignments are presented from the CREM perspective.

ORGANISATIONAL CREM ALIGNMENT

Vertical (strategic) CREM alignment

Vertical alignment means that CRE unit is strategically aligned with the overall strategy or/and business units' strategies. In CREM literature, this strategic alignment has gained a lot of attention (e.g., Weatherhead 1997; Nourse and Roulac, 1993; Lindholm 2006). The RE strategy design process covers both approaches – top-down and bottom-up – but, according to Heywood and Arkesteijn (2017), the top-down approach is more dominant.

Similarly, the alignment between the business level (Figure 1) and the RE function on the functional level (Figure 1, level 3) is highlighted for example by Appel-Meulenbroek et al. (2010), Then and Tan (2013) and Then et al. (2014).

In CREM literature, the golden idea is that CRE can contribute to the strategic objectives of an organisation, similarly as Wheelwright and Hayes (1985) proposed it in their four stage model. In the last 20 years, CREM literature has strongly emphasised the added value perspective: CREM literature often presents the idea that CRE is no longer seen as a cost or necessary burden for corporations, but that CRE can support corporation's business objectives and add value (e.g., in Nourse and Roulac, 1993; Lindholm 2006; Appel-Meulenbroek et al., 2010). According to Van der Voordt (2017), the added value discussion in the CREM field was initiated by Hans de Jonge in his EuroFM presentation in late 1990's. After this, a strong body of knowledge has been established for example to present (e.g., Krumm et al., 1998; Lindholm and Leväinen, 2006) and to measure (e.g., Lindholm and Nenonen, 2006; Riratanaphong, 2014; Jensen and Van der Voordt, 2017) the added value of CREM.

Despite the common idea of contributing to the overall business strategy, the four-stage model of Wheelwright and Hayes (1985) is not directly used in the mainstream CREM literature. CREM alignment literature has two streams (Jylhä et al. 2019). In the first stream, the role of added value of RE is highlighted in the overall contribution to the business: RE can add value for example by promoting human resources objectives (Roulac 2001); by increasing employee satisfaction and productivity (Lindholm, 2008; Jensen, 2008; Den Heijer, 2011); by increasing and capturing the value of corporate assets (Roulac 2001; Lindholm, 2008); and by promoting marketing and sales of the corporation (Lindholm, 2008; De Jonge 1996). In the second stream, CRE is seen to contribute to the overall business by strengthening the competitive advantage of the corporation (Jylhä et al., 2019). Compared to the four-stage model of Wheelwright and Hayes (1985), these streams remind the supportive stages 3 and 4, respectively. Interestingly, stage 2 (to minimise the negative potential of CRE and to achieve parity with competitor) has received less attention.

Cross-functional and intra-functional CREM alignment

From CREM perspective, cross-functional alignment means that the performance and actions of the CRE function fit with the performance and actions of other functions on the corporation's operational level, such as HR, ICT, marketing and operations. In the literature, the importance to achieve this fit is often acknowledged (e.g., Lindholm et al., 2006; Harris and Cooke 2014), but the literature still lacks research that would further study this type of alignment (Jylhä et al 2019).

Intra-functional CREM alignment aims to find a fit between the decision areas of the CREM function. When following the model of Dewulf et al. (2000), these decision areas are called facility management, cost control and asset management. These same decision areas are found in other models. For example, Leväinen (2013) calls these, respectively, facility and workplace management, property management and asset management. Despite how the decision areas are called, there are only few remarks related to intra-functional alignment between the decision areas. One of those is the integrated resource management framework by then (2005). In his model, he highlights the two-way integration of the different decision areas. Similarly, the intra-functional alignment is touched in the model of Dewulf et al. (2000) by illustrating CREM as a linking pin between the decision areas. However, the model does not further explain how this is done.

The vertical alignment within CREM functions has been highlighted more. In many models, such as in those of Nourse and Roulac (1993), Weatherhead (1997) and then (2005), the CRE strategy gives a direction for all the decision areas to follow. There are also models for designing a RE strategy in line with the corporate strategy (e.g., Edwards and Ellison, 2004; De Jonge et al., 2009).

To summarise, in the CREM literature cross-functional and intra-functional alignments are studied less than vertical (or strategic) alignment, similarly as in the general alignment literature.

CROSS-ORGANISATIONAL CREM ALIGNMENT

The supply chains of CRE functions are manifold. CREM literature has shown that a great deal of CREM functions are outsourced, i.e., activities and tasks are done across organisations and the product and service delivery is allocated along several supply chains. For example, Sharp (2013) and McCarty and Gottschalk (2014) stated that it has been a trend to outsource especially strategically non-important activities. The spectrum of these services is wide and it also varies between organisations. For example, in the model of Heywood and Kenley (2013), procurement covers technical and user services, management services, and construction and property development services. In addition, the limited in-house capacity might require to acquire some of the CRE management tasks from an external service provider (Heywood and Kenley, 2010; 2013). This means that an external service provider, who delivers CREM services, acts on behalf of the CRE function based on the agency commitment. Heywood and Kenley (2010, 2013) named this 'the extended CRE organisation'.

Due to the heavy outsourcing and related structures, horizontal CREM alignment across organisations is needed. Unfortunately, CREM literature includes limited amount of research focusing on aligning its horizontal supply chain across organisations. It seems that horizontal alignment is more or less left at the responsibility of the other decision areas, such as facility management and maintenance management. For example, in facility management, supply chains are often discussed but the discussion is centred around sourcing strategies and related contractual responsibilities (e.g., Jensen and Van der Voordt 2017; Lehtonen and Salonen, 2006). In recent years, the focus in FM has been on the added value on strategic level (e.g., Then et al. 2014; Jensen et al. 2012), similarly as in the field of CREM, and operational excellence has gained less attention. One of the few exceptions is Jylhä (2013), who studied a selection of real estate service processes. She concluded that the separate sub-processes interrupt the value creation and that a comprehensive management of the value chain is missing.

CONCLUSIONS

Based on the conceptual analysis, the potential of waste is not yet acknowledged in the field of CREM. This paper claims that there is plenty of waste intertwined in CREM. In fact, the current CREM alignment theories have created a good environment for waste.

One explanation is the transformation view used to conceptualise the value delivery. A value delivery that is based on sub-processes with many players is a good condition for waste. In CREM, even the management responsibility of the value delivery is typically divided in the extended CRE organisation between the inner stakeholder and external agent. Another explanation that provides a good condition for waste is the heavy focus on one specific aspect of alignment, namely on strategic alignment. The CREM field is not alone with this feature. For example, recently Trevor and Varcoe (2017) stated that

> "The challenge is that executives tend to focus on one of these areas [strategies, organizational capabilities, resources, and management systems] to the exclusion of the others, but what really matters for performance is how they all fit together.

The applicability of waste in reconceptualising CREM alignment is manifold. First, being able to reduce waste in functional alignment (2 in Figure 1) means that RE-related value creation fits with the processes of the other functional units, such as HR, ICT and operations. For example, a new employee would have an easy and timely access to the needed facilities, services and equipment at her/his arrival; acquired office would meet the ICT needs of a company; and corporate operations (such as R&D and production) and their employees would not be disturbed by maintenance or renovation projects.

Second, being able to reduce waste in the intra-functional alignment (3 in Figure 1) provides synchronisation between the decision areas of CRE in terms of time, content and resources. For example, avoiding cleaning of the windows before a facade renovation; avoiding heavy workplace investments in properties with exit strategy; or avoiding rework, errors and overprocessing due to the lack of internal communication. Similarly, waste reduction in cross-functional alignment provides the same benefits but across the value chain. For example, creating a flow in the value chain would reduce waiting from the user perspective, would level the workload of the employees in the value chain and would offer higher quality service delivery.

Lean aligns especially horizontally and, thus, it offers a way for smart CREM alignment, i.e., a smart use of CRE resources including not only the use of materials and energy but also the use of human resources with their social capital. To account for waste in horizontal CREM alignment would expand the research from strategic CREM alignment into smart CREM alignment.

The analysis encourages to further study the horizontal CREM alignment within and across organisations. The resource-based CREM research would be thriven by smart use of CRE resources and operational excellence. The CREM theories and practice could also learn from other disciplines such as lean construction and lean health care.

The reconceptualisation of the CREM alignment provides a new way of thinking for academics and practitioners. It offers a resource-smartness approach to manage the second-largest assets of organisations. The CREM theories, which are still relatively young and nascent, would also benefit by using theories from more mature fields, such as lean supply chain management, process re-engineering and process redesign, outside the strategic management literature.

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STREAM 20: SKILLS AND COMMUNICATION

Taggart, M., Willis, C., and Hanahoe, J. (2019). "Not Seeing the Wood for the Trees – A Gemba Walk through a timber framed Housing Development". In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1209–1218
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NOT SEEING THE WOOD FOR THE TREES – A GEMBA WALK THROUGH A TIMBER FRAMED HOUSING DEVELOPMENT

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ABSTRACT

This applied research seeks to improve the efficiency of production planning on repetitive construction projects. Ireland currently has a pressing need for a rapid expansion of housebuilding and many projects are planned or underway. However, programming of such works has been poor historically. This research proposes approaches to make planning of such projects more efficient.

Information on a representative sample of dwellings was collected on a large timber-framed housing site over a five-month period. The main-contractor's bar chart programme for the project was analysed using the Line of Balance production planning approach. This allowed the time waste inherent in the programme to be visualised and allowed options for improvement to be considered. The results showed that a significant improvement could be made in the programme and in the efficient use of resources. This has significant benefits for contractors. The research is based on a single case study, which constrains universal claims about the results reported. However, the authors note their extensive experience of visiting similar projects, allowing them to attest to the 'typicality' of the case study in the Irish SME marketplace. The work has implications for improving lean construction practice in production planning and suggests the need for additional training in technical education.

KEYWORDS

Gemba walk, last planner system, line of balance, programming, planning.

INTRODUCTION

This research is focused on improvement in production planning on construction projects of a repetitive nature. Ireland has a very pressing social need to rapidly expand housebuilding output towards meeting a significant current shortage and to address the additional needs of an expanding population (National Planning Framework, 2018). The

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National Planning Framework (2018), foresees the need of 550,000 new dwellings by 2040, however, progress towards this target is very slow and inefficient. Irish house builders have traditionally used very simple Gantt charts as a means of programming time on their projects. Whilst they are familiar with this simple approach, it can be strongly argued that it is normally an inefficient means of programming as it provides little real-time information about what is happening on site (Seppänen et. al, 2014). Koskela (2014), suggests that such approaches, normally supported by critical path theory, have serious limitations when attempting to model the particular complexity of construction projects.

Motivation for this paper came from a Gemba walk around a housing development of 200 timber framed dwellings. The site manager professed himself happy that work was being carried out in an efficient and timely manner. However, it was immediately obvious that a large majority of the dwellings stood empty, at various stages of construction. Workers progressed only a small number of the units at any one time. The research herein, illustrates how the adoption of a Line of Balance approach could inform and improve the programme of works used on the site and also inform future projects.

APPROACHES TO PRODUCTION PLANNING

PROGRAMMING LITERATURE

Cooke and Williams (2013) detail the following common types of programming techniques which are used in construction: bar (or Gantt) charts; linked bar charts; arrow diagrams; precedence diagrams; line of balance; and time-chainage diagrams. The underlying theory associated with many of these techniques is that of the Critical Path Method (CPM). Most of the traditional methods of production control used in construction were developed in the manufacturing industries in the 1950s (Koskela et al., 2014). Koskela et al., (2014) and Kenley and Seppänen (2009) chart the pervasive dominance of CPM in the construction industry, whilst also providing a detailed critique of the many flaws associated with the CPM approach. A principal criticism by Koskela et al., (2014) is that CPM has morphed from being a potentially useful method of production control into a method of contract control. Clients have adopted it as a very useful mechanism for pinning blame for contractual delays. Seppänen et. al (2014) observes that CPM is the primary planning methodology used in construction but notes its inefficiency. When considering CPM in the lean construction paradigm, the principal intent of CPM is to optimise the technological linkages of activities. Biotto et al., (2017) categorise CPM as an activity-based planning tool. Such tools are widely criticised by lean construction researchers for their inability to deal with construction complexity, or provide a smooth, uninterrupted project work flow. Smooth work flow is both a central tenet of the lean construction philosophy and a highly desirable outcome for the sub-contractors, who physically execute most of the work on Irish construction sites.

As a response to the issues described above, the Last Planner System methodology was developed, originating from a lean philosophical approach by Ballard (1994). The Last Planner System is directly focused on construction work, whereas traditional tools have evolved from manufacturing. At its core, the Last Planner System seeks to maintain workflow in the construction process, avoiding the stop/start workflows traditionally associated with the industry. A central proposition of the Last Planner System is that the whole project team should be involved in planning and then executing the work. All other things being equal this should provide a better planning outcome, whilst avoiding the lack of ownership of production programmes seen on most construction projects (Johansen & Porter, 2003).

The development of the Last Planner System approaches has engaged significant interest from the lean community, notably, several hundred papers have been submitted to past IGLC conferences on the subject. However, the Last Planner System still requires suitable input data from project stakeholders to achieve a smooth project workflow. A typical approach to this task is to help stakeholders 'visualise' the steps of the process they are planning to undertake.

From multiple field observations made by the authors, It is clear that in Ireland, the predominant form of project programming on SME construction projects is via the use of simple bar (or Gantt) charts. There is also some evidence that on a small number of projects, efforts have been made to apply critical path analysis techniques, such as CPM, to inform the efficiency of the bar chart's contents. However, this does not appear to be widely or systematically developed in our view. The use of the Last Planner System is very rare in Ireland with the authors only having encountered a handful of projects using this approach. Biotto et al. (2017) situate Line of Balance squarely within the Lean Construction paradigm, claiming it as a valid tool for Lean Construction enquiry. Kenley and Seppänen (2009) contend that construction can benefit from taking a fresh look at some of the methods that have been discarded in the race to adopt CPM as the one best approach.

LINE OF BALANCE PLANNING

Line of Balance (LOB) is a tool for project planning and control that provides great visibility for the flows of work in a construction site (Kemmer et al., 2008). It is an established variation of linear scheduling/linear programming and time/location methods (Moura, Monteiro & Heineck, 2014). Biotto et al., (2017) note that LOB is a tool for production design, that expresses the work structure in a visual fashion. The work locations of the project are used as the unit basis for planning and control. The approach is used in the construction industry for projects that are typically of a repetitive nature. LOB diagrams visualise the planning, typically using suitable quantity units on the vertical axis and time on the horizontal axis (but can be reversed in some situations). The activity lines typically slope to the right, representing the planned rate of delivery of the units. The LOB approach is focused on improving continuity of work. A continuous flow is sought, trying to minimise trade group conflicts and ensuring interruptions are avoided. Continuous flow is created by ensuring work location spaces on site are used efficiently (Kankainen & Seppänen, 2003).

Kankainen and Seppänen (2003), suggest the use of LOB as a viable option to check the feasibility of the project master plan (bar charts) before they are executed. Schramm, Costa, and Formoso (2004), found that LOB could be used to define and simulate the workflows and the pace of each work crew. The object being to identify the interfaces between production crews, and where necessary and possible, change their pace or sequences to avoid clashes. Changes in the production resources available may also be needed to achieve this balance. Moura, Monteiro and Heineck (2014), state that LOB suggests all activities are to be performed with a single output rate, making it a parallel programme, with no wasted time between the end of one activity and the beginning of another, save for a contingency buffer. Where two or more activities occupy the same location space and are performed at the same time, a potential negative impact on productivity pertains. LOB helps visualize these potential conflicts and allow corrective actions if needed.

Lean construction researchers have noted the possibilities of LOB as an effective Lean tool (Kankainen & Seppänen, 2003). The approach has not, however, attracted much interest within the IGLC research community, with LOB attracting less than one paper per year, on average, at IGLC conferences. Mendez and Heineck (1999), similarly suggest that LOB has not engaged the interest of practitioners. They speculated that a lack of suitable LOB software (as opposed to plentiful options for CPM) may explain the dominance of CPM. They note that CPM directly identifies a critical path, but also details non-critical activities, suggesting that, the latter must surely contain some potential element of wasted time. Kemmer et al., (2008) considered some of the case studies on LOB presented in the IGLC literature to be trivial in nature, concerned with theory, but not much with practice. The authors present results of their own case study where LOB was used as a visualisation tool, enabling site management and other stakeholders to investigate their plans in terms of: determination of appropriate batch size, number of work teams, number of members of work teams and cycle times. LOB diagrams were presented for various planning scenarios that the project team could discuss and refine. Kemmer et al., (2003) noted that the approach did indeed assist greater efficiency. However, they also noted cultural barriers mitigated against acceptance of Lean construction methods. For instance: the smoother work flow led to more pressure on supervisors to keep up. Additionally, workers were concerned at how bonus payments could be lost or reduced in the newly efficient plans. Similar examples of cultural resistance are noted elsewhere where Lean interventions into programming and planning spheres were implemented (Johansen & Porter, 2003).

GEMBA WALK

Samudio, Alves and Chambers (2011) discuss the importance of 'going and seeing' to the construction process. They found that adopting this approach provided valuable insights into production cycle times; waiting time; inventory; and rework. They trace the antecedents of Gemba walks back to Ohno and Shingo in Lean manufacturing, who documented many instances where they had visited the workplace to obtain clear insights into problematic issues and associated practice. Gemba is the Japanese word for *'actual place'* – This concept was developed in the Lean manufacturing paradigm into the practice of Gemba walks. Samudio, Alves and Chambers (2011) note the essential ingredient of involving the workforce and stakeholders in developing collaborative approaches and providing their expertise and insight into the planning effort. Koskela et al. (2014), in contrast note that the typically 'top down' approach of CPM programming and centralized planning does little to support site management in their endeavors. The authors, herein, can report that their experiences show that the typical approach of the Irish SME sector is to adopt a command led programming approach, with limited input into production planning from sub-contractors or other stakeholders. This is very much a top down agenda.

AN IRISH CASE STUDY

CASE STUDY RESEARCH METHODOLOGY

A case study for one project in Ireland is presented below. Yin (2011) notes the use of exploratory case studies as a suitable method to extract both implicit and explicit data, from complex situations. In this case author two, worked on the case study project full time as part of an industrial work placement, working as assistant site manager. This allowed immersive access to contractor data as well as real time observation of what happened on site. Single cases give rise to questions of generalizability of the results, which is a limitation of this research. However, Flyvbjerg (2006) argues strongly for the possibility of recontextualising learning from case studies in other simpler contexts. Interestingly, Seppänen et al., (2014) recommend case study for investigating the complex variables involved in construction planning.

The case study project involved circa 200 dwellings, mostly semi-detached homes, constructed in phases. Some terraced houses, for social housing were also provided. The value of the project was circa 50 million euro. The construction techniques used on the site are typical in terms of the use of open panel, timber frame construction in Ireland. The production planning approach adopted by the main contractor for the project was the use of simple bar charts, without any critical path evaluation. The authors note that this approach is typical of planning approaches for SME construction companies in Ireland.

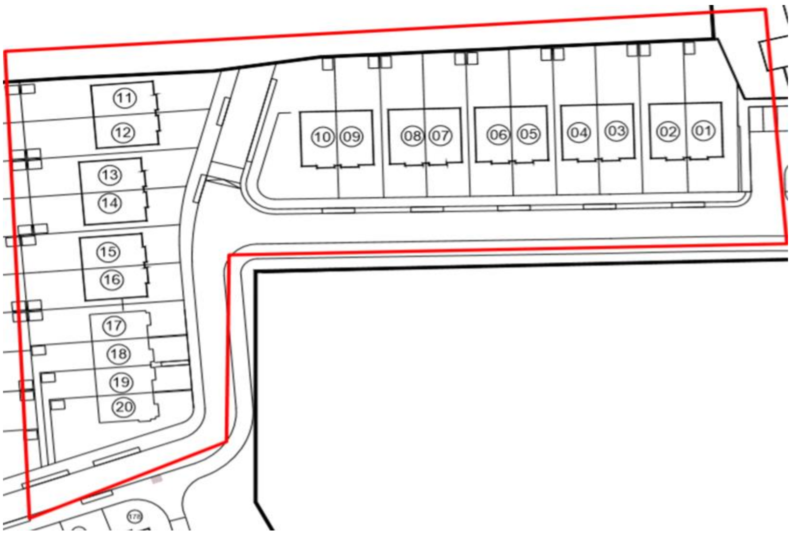

Figure 1: Partial site plan, showing sample of 20 dwellings on the case study project

The main contractor developed a simple bar chart programme for the works, which was distributed to sub-contractors as the principal means of time management on the project. The study focused on a representative sample of data from16 semi-detached and 4 terraced homes on the site (Figure 1). The main-contractor's contractual bar chart programme was compared with observational data collected from the 20 homes. This involved keeping a daily log, over a five-month period, recording the progress made/work carried out on each of the 20 homes in tabulated form. This information was compared to what was originally planned to happen on the contractors Gannt chart. The contractor's base information was then modelled using LOB techniques, to produce a more efficient, less wasteful programme of works.

ANALYSIS OF MAIN CONTRACTORS PROGRAMME

The network diagram (Figure 2) shows the sequence of the work. The work has been divided into four elements. Substructure, Timber frame erection, Superstructure and External works/finishes. These 4 elements are represented graphically throughout this section in both Gantt/bar chart and Line of Balance formats.

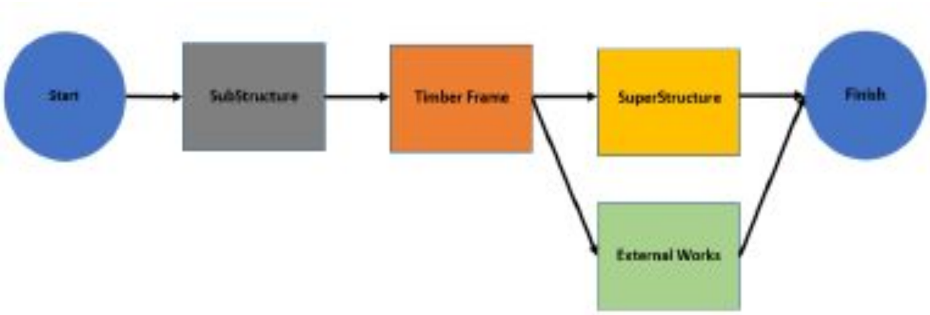

Figure 2: Sequence of activities

The primary format of scheduling used by the main contractor was a bar chart. Figure 3, below, shows the main contractors original programme intention in a simplified bar chart layout. The intention was to complete the 20 sample dwellings in a period of 37 weeks.

Figure 3: Original plan in simplified bar chart format

It was observed that the programme was not being used for reference by the sub-contractors. It was also clear from an early stage that the project was behind its original schedule. Figure 4 shows the actual durations of the elements and that this part of the project actually took 47 weeks to complete. Unfortunately, Figure 4 is not of any great assistance in understanding why this delay occurred.

Figure 4: Actual durations observed in simplified bar chart format.

Table 1 shows the actual durations of each element for each house pair. This information, while useful, is still difficult to visualise.

Table 1: Actual timings observed in tabular format

	Substructure		Timber Frame		Superstructure		Services & Ext. Works	
House	**Start**	**Finish**	**Start**	**Finish**	**Start**	**Finish**	**Start**	**Finish**
1 & 2	1	3	11	12	13	24	16	27
3 & 4	2	3	8	9	10	24	13	29
5 & 6	2	6	9	10	11	25	14	30
7 & 8	2	6	10	11	12	26	15	29
9 & 10	3	9	12	13	14	30	17	35
11 & 12	3	9	17	18	19	34	25	47
13 & 14	4	11	16	17	18	33	22	42
15 & 16	4	11	15	16	17	32	21	40
17 - 20	4	15	13	14	15	36	18	37

Figure 5 shows the same information in a Line of Balance format.

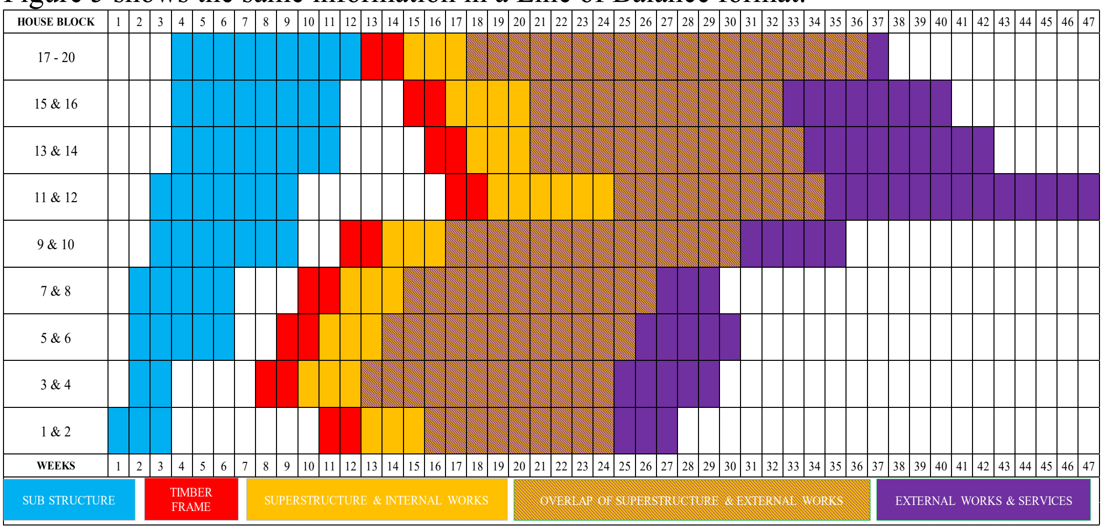

Figure 5: Actual sequence of work in Line of Balance format

When the same information is presented in this format, it gives a much better insight into the work sequence.

- The original (planned) duration was 37 weeks, but the actual duration was 47 weeks
- The substructure elements took 2 weeks for some units and up to 8 weeks for others.
- There is no logical or efficient sequence to the elements
- The timber frame element happened in a different sequence to the substructure. The timber frame element was sequenced based on the supplier's schedule rather that the onsite requirements.

Figure 6 shows a proposed improved sequence. This allows for much better continuity of work, with crews moving from unit to unit in a clear logical way. It also allows for a contingency buffer between activities. Further improvements become more evident which would benefit the programme (including speeding up the rate of timber frame erection) should resources allow.

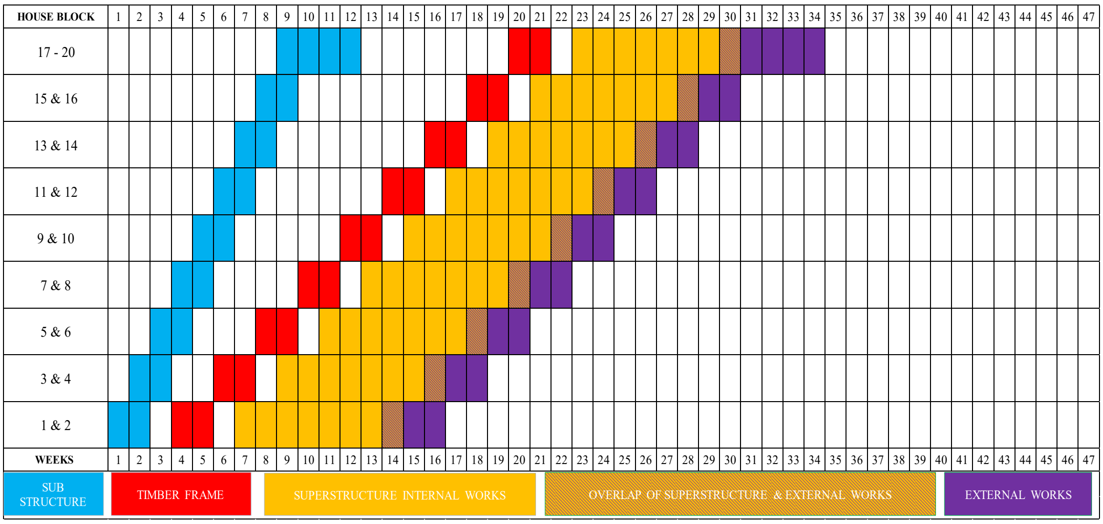

Figure 6: Proposed sequence of work in Line of Balance format

Table 2: Proposed timings in tabular format

	Substructure		Timber Frame		Superstructure		Services & Ext Works	
House	Start	Finish	Start	Finish	Start	Finish	Start	Finish
1 & 2	1	2	4	5	7	14	14	16
3 & 4	2	3	6	7	9	16	16	18
5 & 6	3	4	8	9	11	18	18	20
7 & 8	4	5	10	11	13	20	20	22
9 & 10	5	6	12	13	15	22	22	24
11 & 12	6	7	14	15	17	24	24	26
13 & 14	7	8	16	17	19	26	26	28
15 & 16	8	9	18	19	21	28	28	30
17 - 20	9	12	20	21	23	30	30	34

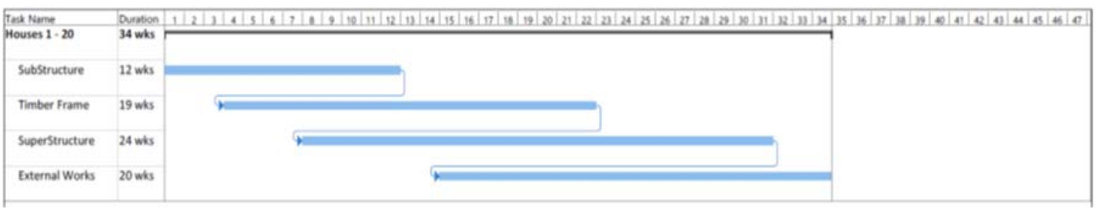

Figure 7: Proposed schedule presented in simplified bar chart format

Table 3: Time savings in tabular format

Ref	Substructure		Timber Frame		Superstructure		Services & Ext Works	
House	Actual	Proposed	Actual	Proposed	Actual	Proposed	Actual	Proposed
1 - 20	15	10	10	18	36	30	47	34

There is a potential saving in time of 13 weeks compared to the observed duration time of 47 weeks. There is a 16-week period allocated to the construction of each block of the sample (consisting of two semi-detached units or 4 terraced houses). Within these 16 weeks, there is some buffer time provided. Buffer time allows for adjustments if unforeseen circumstances are encountered.

This illustrates that the use of the Line of Balance can enhance the programming of repetitive work, such as timber frame housing. The proposals made do not deviate from the original sequence, as shown in Figure 2. The proposals simply order the project into a more efficient programme. The aim of the proposal is to demonstrate the potential of Line of Balance to assist in creating better work flow in repetitive projects.

CONCLUSIONS

The case study has established that significant time savings can be achieved by the application of LOB techniques to this repetitive housing project. Problems with the existing work flow sequencing in the main contractor's bar chart programme were more easily-visualised using LOB in the case study, suggesting that if a more efficient plan (focussing on maintaining flow) was adopted, that the sample of 20 houses could have been completed 13 weeks earlier. The importance of collecting accurate and detailed base data from the site, to improve planning efforts over time, was also established. The potential for wider generalisation was also considered. Whilst this paper reports from a single case study, the authors note, from their field experience, the typicality of the approach used by the SME main contractors to production planning in Ireland. This suggests significant potential for contractor practitioners to improve their production planning, utilising the LOB approach. The work also highlights the potential for LOB to provide accurate project data for use in lean programming approaches, such as the Last Planner System. The implementation of production planning improvements can encounter resistance for a variety of reasons. Such resistance should be expected and diffused by engaging the stakeholders in the planning process. This research presented the results of a hypothetical analysis into the potential for improvement. The authors are currently working with the main contractor, towards application of LOB to improve their programming on forthcoming projects. This will give greater insights into the potential for LOB in production planning.

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COMPARISON OF COLLABORATION AND TRADE PARTNER COMMITMENT IN TAKT IMPLEMENTATION CASES

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ABSTRACT

This study addresses the possible ways to improve takt implementation in projects. The purpose of this study is to gain knowledge of the stakeholder commitment and collaboration in takt projects where takt production is implemented. The study aims to explore which enablers and barriers affect collaboration in takt implementation projects, and how they differ between cases in Finland and California.

The study was conducted as a qualitative multiple case study. The case projects were purposefully chosen for this study. The data collection was conducted as a triangulation of interview, observation and documentation observation. The enablers and barriers from different cases were clustered into plusses, deltas, and drivers between Finnish and Californian cases as well as jointly. The results were then analysed in a workshop and recommendations for further takt implementations as well as further research were made.

Recommended actions for further takt implementation cases of more complete Lean understanding, and more transparent partnership between trade partners. However, the results and recommendations are based on a single study with a limited amount of cases, and therefore further research inside the topic is needed.

KEYWORDS

takt production; collaboration; stakeholders; implementation

INTRODUCTION

Tools for production planning in construction have developed significantly during the past two decades. The possibility of turning the construction from resource to flow-efficient production has been demonstrated with tools such as Last Planner System (LPS) (Ballard

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2000) and takt production methods such as Takt Time Planning (Frandson et al. 2013) and Takt Planning and Takt Control (Dlouhy & Binninger 2016). Takt, a concept originated from lean manufacturing, represents a "beat" of the production and refers to a predefined interval of time where one set of work is done (Hagsheno et al. 2016). Takt production has lately received significant attention inside the lean construction community. The improvement of flow efficiency inside the production has been documented in several occasions, for example, Frandson et al. (2013;2014), Vatne & Drevland (2016) and Binninger et al. (2018). In addition to the existing literature, takt implementation in the construction industry is going forward in several ongoing implementation cases.

Previous results indicate that understanding social aspects better in takt production could lead to remarkable benefits (Tommelein 2017). Frandson et al. (2013) stated that "*in order to improve production slightly, crews just have to work a little bit harder; however, to improve production dramatically, the entire team must work together and really think about every task*." Frandson & Tommelein (2016) mentioned how the general contractor and the trade partners evolved to become a production team, which was able to plan the production more collaboratively. However, little research yet exists on the broader collaboration aspect of takt production, and the research has been mostly focusing on developing technical methods in use. The comparison of the collaboration of different stakeholders between different takt implementation cases has also been limited.

More research is needed on how the collaboration is utilized in takt cases, and how different social barriers and enablers affect on implementation of takt methods. Lately, several takt production pilots have been performed in Finland, which have partially utilized the methods described by Frandson et al. (2013). However, the working culture in takt production and collaboration between different stakeholders in Finnish takt cases has not been studied yet. It would be beneficial to understand how the barriers and enablers vary between different implementation cases, and how the collaboration aspect is managed in California and what kind of improvements could be brought to different entities, such as Finland.

The scope of this study is to find possible similarities and ways to improve the collaboration between different stakeholders in takt cases, by comparing the social barriers and enablers from different case projects. The study aims to answer the following questions: *1) What kind of social barriers, enablers, and drivers effect collaboration in takt projects between different cases? 2) How the working culture in takt projects in Finland could be improved by implementing Californian takt practices?*

RESEARCH METHOD

CASE STUDY

The study was conducted as a multiple case study with purposeful sampling. Purposeful sampling is commonly used in qualitative research when resources are limited in information-rich cases (Patton 2002). The case projects were chosen to represent two different working cultures and different views as well as different maturity level in takt related construction projects. The study contains two cases for each of the two views for validity purposes.

The more matured way, which is referred in this study as the Californian way, has been used and documented on multiple occasions by Frandson & Tommelein (e.g., 2013, 2015, 2017). The Californian way can be seen as a six-step method presented by Frandson et al. (2013), *1) Gather information, 2) Define zones, 3) Understand the Trade sequence, 4) Balance the workflow, 5) Understand the Individual Trade Duration, 6) Production planning*.

The Finnish way of implementing takt has not been yet documented in the literature. However, the process of the Finnish way used in the Finnish cases echoes partially from the Location-Based Management System (LBMS, Seppänen & Kenley 2010). LBMS is a method of construction planning and production control based on the movement of resources through the construction site, aiming to maximize continuous use of labor and productivity, reduce waste and risk, increase transparency and improve predictability and flow (Kenley and Seppänen 2010). Frandson et al. (2015) compared the similarities and differences between LBMS and takt time planning which showed a lot of similarities and few differences. Both methods aim for continuous flow of work through production areas at a set beat for each phase of work. (Frandson et al. 2015) Even though the case projects from different regions varied from their grounding of implementing takt production, they were seen as an adequate match concerning the subject under study.

METHODS OF DATA COLLECTION AND ANALYSIS

The data was collected as a triangulation of interview, observation and document familiarization in all of the four cases. The interviews focused on production planning and control as well as social and technical sides of those aspects. The interviews also included in-depth 5-why analysis concerning social enablers and barriers of production planning and control. Observations were carried out as site visits along with participation on multiple trade partner meetings. The focus during the observations were pointed on production and especially on the interaction between different trade partners. The documents which were familiarized were production plans, blueprints, and other production related documents. A cross-analysis from the collected data were carried out by the authors where the founded social aspects were divided into three different clusters as plusses, deltas and to drivers influencing these effects.

CASE DESCRIPTIONS

The study compares four cases, (Table 1.), which are from Finland and California. Two of the studied cases were residential construction projects located in Finland. Two other cases were located in California and were multi-storey medical and research facilities.

The cases from Finland were a seven-storey residential building and a six storey residential building for students located in Helsinki area. Both cases used an intensive 1-day takt. Takt production plan was used in the interior and finishing phases of the project. Both of the cases used takt planning methods to radically decrease the durations of the interior phases.

The case projects from California were both multi-storey medical and research facilities located in Northern California. The production plan in both of the cases based on the six-step method by Frandson et al. (2013). During the study, the first case was in its interior and finishing phase and used a 5-day takt. The second case was in its core phase and used a 5 and 4-day takt. During this study, the interior phase was still under planning. Both cases used takt planning as a method to gain savings in the total duration and to make the production more stable.

Table 21: Case project basic information

Information	Finland case 1	Finland case 2	California case 1	California case 2
Type of project	Residential building	Residential building	Multi-storey medical & research facility	Multi-storey medical & research facility
Takt time	1 day	1 day	5 days	4 & 5 days
Takt implementation phase	Interior and finishes	Interior and finishes	Core, interior, and finishes	Core
Objective of takt	Shorter duration compared to projects executed without takt	Shorter duration compared to projects executed without takt	Shorter duration compared to projects executed without takt and better stability	Shorter duration compared to projects executed without takt and better stability

RESULTS AND ANALYSIS

The data collected from the different cases were evaluated and analysed by the authors, and the social aspects were divided into three different clusters as plusses, deltas and to drivers influencing these effects (Table 2). Plusses represent objects that succeeded, deltas represent the objects that need to be improved and drivers represent objects and entities that especially helped the project to succeed.

PLUSSES, DELTAS, AND DRIVERS

Table 22: Unique and common plusses, deltas, and drivers

Finland	California	Both
Plusses: Technical capability in production planning Potential of technological development	**Plusses:** Trust between GC, trade partners, and client Lean leadership	**Plusses:** Quick results Increased stability
Deltas: Ineffective contract models Lack of leadership and knowledge in lean principles	**Deltas:** Trade partner resourcing Trade partner commitment at the beginning	**Deltas:** Understanding of resource vs flow efficiency Resistance towards new methods
Drivers: Proactivity and commitment of project crew and key subs	**Drivers:** Knowledge in takt production Lean culture	**Drivers:** Takt experts Project crew Daily huddles Visualization of plans

Observations that were unique for the Finnish cases

In both Finnish implementation cases, strong knowledge in production planning and continuous support from office to the site was recognized as efficient enablers for successful implementation of takt production. Especially the main contractor's firm understanding of location-based planning provided a solid ground for piloting intensive 1-day takt. As the supporting operations continuously helped in the planning phase, the starting point for technically effective takt was developed. Also, in case 1 the implementation of new digital production planning tools were recognized as a potential enabler for continuous learning in the long term.

Conflicting contract models with lack of lean leadership and trust between parties were the most visible deltas. It was quickly recognized that the old contract models did not support flow-efficiency and intensive requirements of short takt, while the subcontractors were not aware of the requirements or benefits of the new method of working. The lack of disciplined lean leadership and thorough understanding of lean principles from the general contractor was seen as a delta towards collaboration, which also affected negatively towards the trust between the general contractor and the subcontractors. Even though the leadership would have been adequate for "traditional" project management, it did not meet the requirements for a situation where intensive change management was needed. Problems were also partly caused by the nature of the pilot projects, where the persons in charge were not yet aware of the tight requirements for the lean leadership from the beginning.

However, the proactivity, commitment, and positive attitude towards learning by the site managers and the key subcontractors (for example, HVAC in Finland case 1) were seen as drivers for success. Their ability to adapt and contribution to innovating solutions together during the production was seen as a clear enabler, which developed the process from the starting point. A collaborative planning session between the GC and subcontractors is illustrated in Figure 1.

Figure 1: A planning session in Finland case 1

Observations that were unique for the California cases

In the California cases, (Figure 2), mutual trust between the general contractor and subcontractors was found to be a plus, regarding the collaboration between different stakeholders. The first indication of that was the fact that the subcontractors were defined and treated as trade partners, which refers to equal partnership instead of a hierarchic allocation. The atmosphere inside trade partner meetings indicated that a mutual trust and team spirit between general contractor and trade partners was on high level. For example, the General Superintendent treated everyone participating in the trade partner meeting as an equal and made everyone feel that they were part of a team. Drivers affecting the mutual trust was found in the general contractor's level of knowledge in takt time planning as well as in their strong culture in lean construction and lean leadership.

The strong lean culture and leadership appeared in the Big Room usage as well as in the lean spirit inside site offices. For example, inside the site offices, there were posters with lean statements, such as the eight deadly wastes, plusses/deltas charts, and vision and values regarding the current project. The usage of the Big Room facility was seen helpful in building collaboration as well as sharing information with project stakeholders. Disciplined but soft leadership skills seemed to create trust between the stakeholders. The trust between the general contractor and the client was also seen as a driver towards stronger collaboration.

Deltas were found in the trade partners resourcing with the takt production. The resource changes within different takt areas created difficulties for some of the key trade partners. Another delta was found in the trade partner commitment to takt production. There had been a situation where a certain trade partner had to be changed do to disagreements in the view of production planning.

Figure 2: California case site views

Similarities between cases

Several similarities were found between the cases. The quick visible results in production and the more reliable production plan was found as a common plus in all of the cases. The highly visual and logical production plan affected positively on developing trust between stakeholders as well as helped them to gain mutual understanding during the projects. The common view of production plan created stability throughout the projects.

The positive feeling evolving from successful takt cases was found as a driver towards better collaboration within stakeholders. The help and commitment of takt experts, such as researchers, was found as a key driver in the creation of a common path for collaboration. The output from the open-minded project crews was equally important, as they were the ones who made the collaboration between stakeholders possible. Daily huddles were seen as a potential way to start a working day with the sharing of information and reviewing the progress of the previous day.

Common deltas between the cases were found in the mindset of certain stakeholders. Trade partners had problems in the ability to see the difference between resource efficiency and flow efficiency. This was seen as a common barrier in all of the cases and it complicated the production planning and control. Other common deltas were the lack of understanding takt as a method and the fear of new ways of working, which were seen as a common barrier for effective implementation.

DISCUSSION AND RECOMMENDATIONS

The Californian cases focused and relied more on the social aspects and trust between stakeholders, while the Finnish cases focused on the technical side of production planning by the general contractor. The strong lean culture imposed by the general contractor from the California cases were a big factor in the building of collaboration between stakeholders, and the proving ground for the creation of transparent processes.

The strong knowledge in the technical side of production planning can be seen as a good base for takt production development in Finland. In contrast, the biggest development areas seem to be on the social side and in the collaboration between trade partners and especially between subcontractors. The trust between stakeholders can make a great impact on production planning when transparency and teamwork between different sides is mutual.

The problem with takt production and the contract models in the Finnish cases brings up the question: *Should the contracts between the general contractors and subcontractors be strict and well takted, or could the right way be more dependent on trust and openness between the parties?*

The model of Social Subcontract presented by Priven & Sacks (2016) with LPS improved the coordination of the projects compared to projects that used LPS alone. Priven & Sacks (2016) describe that the Social Subcontract aims to strengthen the collaboration between the general contractor and the subcontractors as well as to guide them towards the common goal. Social Subcontract process consists of multiple meetings with the GC and all of the subcontractors involved in the project. Within these meetings, all the subcontractors are given an opportunity to express their needs and specific steps for productive work and to discuss about them with each other to gain a more complete overview of the production of the project. Within these meetings, a more collaborative relationship is formalized between the subcontractors and the GC and the common goal is expressed as a written agreement signed by all the participants. The agreement is then monitored in beforehand agreed meetings. These meetings include a peer-evaluation between the GC and all of the subcontractors where everyone has to evaluate each other. The sanction of social shaming was seen as the matter that maintains a commitment to the agreement (Priven & Sacks 2016.) There was also a strong positive effect on the general contractor's motivation to improve the make-ready process for the overall flow of the project when the subcontractors were better included in the production planning phase (Priven & Sacks 2016). There seems to be a pattern in reliability and trust between stakeholders with the efficiency of production. Therefore, it could be assumed that takt production could benefit from SSub, too.

Finnish cases provided excellent results for pilots by radically reducing the duration while the quality and costs remained the same. However, it is clear that in order to develop the process further a better collaboration between the stakeholders is vital. Aspects that should be taken in consideration in the future development are deeper and more specific collaboration in the production planning with the subcontractors, consideration of SSub model with known partners and the augmentation of lean as a way of working.

The limitations of this study include the limited amount of inspected projects, the limited amount of time observed in the California cases, and that the observation was done between residential and medical facility cases. Taking these limitations into consideration the findings are still noteworthy.

CONCLUSIONS

The object of this study was to address and compare possible similarities in collaboration between different stakeholders in takt implementation cases. There was also a goal to find possible ways to improve collaboration in future takt implementation cases in Finland.

The study addressed multiple enablers, barriers, and drivers, which were seen influencing the collaboration between stakeholders in takt implementation cases. Even though the maturity level in takt production between Finnish and Californian cases varied, a common view regarding the importance of stakeholder collaboration was seen.

The study also aroused similarities between cases from Finland and California as well as possible ways for improvement in the collaboration between different stakeholders in future takt implementation cases in Finland. The maturity level of takt production in the construction industry in Finland is currently low and the use of old fashioned and strict contract models were seen as a problem. An opportunity for better trade partner commitment in near future takt implementation cases was seen possible with more open contract models.

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EVALUATING MULTISKILLING IN RESIDENTIAL CONSTRUCTION PROJECTS USING REGIONAL INDUSTRY SIMULATION

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ABSTRACT

The Makerhoods project in Newark NJ, USA, is a planned affordable live/work development for low-income residents. With a background in Lean Manufacturing, and confronted with industry norms of low productivity, extensive subcontracting, unreliable plans, and incomplete information, the developer sought to ways to optimize construction cost, schedule and quality by and minimizing uncertainty and variation and by improving workflow. The developer sought to establish how Lean interventions might improve the performance of the production system that was being designed for the product. Specifically, the challenge was to determine how the concept of producing with laborers reorganized from trade-specific teams into multi-skilled work cells might impact the Makerhoods project, given the reality of the local construction market.

To test these questions, Agent-Based Modelling was used. First, analogs of the local market and project of interest were recreated within the modeling environment. Next, the project delivery techniques were tested to find the highest probability of project success with the lowest band of outcome uncertainty. We hope the results will lead to new ways of approaching project management and potentially to establishment of new types of construction firms (i.e. the "finishing cells" composed of multi-skilled teams capable of completely building an apartment's interior).

KEYWORDS

Batch size, GC, Lean construction, multiskilling, simulation, strategies

INTRODUCTION

The use of subcontracted labor is a central prevailing paradigm in the modern construction industry (Korb and Ballard 2018), and thus the relationships between the General Contractor (GC) and the subcontractors are of paramount importance to the outcome of the project. The strategies that each of these parties use in advancing the needs of the project

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as well as their own individual goals (knowingly or unknowingly) strongly influence the flow and duration of the project (Sacks 2016). At one level the two interact in procurement relationships where work volume is bought and sold (usually to the lowest-cost bidder), but due to the inherently interdependent relationship of works in a construction project, there is also a relationship between stability and resource allocation. Harel and Sacks (2006) examined this dynamic through the lens of game theory at the level of a single subcontractor interacting with a single GC. What is necessary as a next step is the ability to apply these models at a multi-project level to properly capture the emergent industry-wide dynamics. This in turn requires simulation within a regional industry context (Korb and Sacks 2018).

Makerhoods is a New York City-based real estate development company with a mission to increase self-employment among low-income entrepreneurs ("Makers") by creating affordable live/work communities (Telyas 2016). A typical project consists of light-industrial space, usually under 1,000 sf. per tenant, alongside multi-family housing, clustered about a central courtyard which becomes the physical gathering point and marketplace to showcase the Makers' products; an artist's conception appears in Figure 1. The Makerhoods project in Newark, NJ, consists of 66 residential apartments (ranging from studio apartments to three-bedroom in size) in a five-story L-shaped building. The ground floor will house a number of workshops for some of the residents to host their "maker-focused" businesses. Also included on the site is a small shopping area/food court, and a preexisting historic structure on the site will be refurbished as a Center of Entrepreneurship co-working space. The founder of the Makerhoods project (second author of this paper) is a long-time advocate and practitioner of Lean Management (Manrique et al. 2007; Yu et al. 2013), and thus he naturally sought to pursue the implementation of Lean concepts and paradigms in this new venture. Given the constraints that prevailing rental rates in the target area placed on the construction budget, the potential cost reduction from a less wasteful and more productive construction process (i.e. Lean) is seen as key to the project's ambition to deliver extra value without added expense.

The Newark, NJ, Housing Market Area (HMA) consists of Essex County (where Newark is located) and the neighboring Union County (Office of Policy Development and Research 2015). As in any construction market, the limited resource pool of the construction industry put the various constructions projects at odds with one another as they compete for the subcontractors' resources. Competition influences resource allocation behavior, and the outcome of any Lean intervention in procurement or production system design is mutually dependent on the resulting behaviors. This local market dynamic was one that the current research sought to explore, using the Newark area as a case study region.

Figure 1: An artist's rendering of the Makerhoods project in Newark, NJ. Workshops are located on the ground floor, residential units on the floors above. To the left is the Food Factory and Greenhouse. Credit: Makerhoods

The goal for the analysis to explore the impact on the project, and on the local industry, of using multi-skilled labor instead of traditional subcontractors each specializing in a particular trade. These multi-skilled crews can work on a comprehensive scope of activities following the cell production paradigm (Black and Hunter 2003).

By including local/regional information, it should also be possible to analyse system-wide perturbations and point in the direction of more resilient projects. Simulation creates a "sandbox" environment in which it is possible to review the impact of several delivery methods on a project and serves as a tool for designing a project plan in that light such that the probability of success is maximized.

The main purpose of a simulation that includes the owner's project as well as other projects in the area is that it allows the inclusion of regional variables and regional market dynamics in planning, which in turn fosters understanding the meta-project dynamics at work. Every construction project has had to deal with a subcontractor who doesn't show up when planned; very often it is not just an abject dereliction of duty, but rather the subcontractor weighing the pros and cons of their current status and deciding to send the work crews to a different project where they believe their return on investment (of the resources, borne out in profit) will be higher (Sacks and Harel 2006). The meta-project scope afforded by the simulation may help address the root causes of project unreliability.

BACKGROUND

Construction has persistently experienced low productivity relative to other sectors of the economy, with high levels of waste and untapped value (Egan 1998). Traditional Construction Management Systems (CMS) based on the principles defined in the Project Management Book of Knowledge (PMBOK) (Project Management Institute 2017) have not significantly improved productivity, and despite the interest in Lean Construction, this methodology has not yet provoked wide-reaching industry improvement. The reasons are many, but a primary root cause is that information (which forms the basis of all CMS systems) is unreliable and limited in scope. The US military has recognized the difficulty of top down planning in an environment it calls VUCA: Volatility, Uncertainty, Complexity, and Ambiguity (U.S. Army Heritage & Education Center 2018). All of these terms are applicable to the reality facing construction professionals, and in a VUCA context information quality is not likely to improve in the foreseeable future. This means that new approaches are needed.

Manufacturing techniques hold the promise of order-of-magnitude increases in productivity, but attempts to introduce a production mindset to construction sites have not yet delivered on this promise. Construction is planned as a system, but in reality, given local and regional variables, it is a system of systems and a resilient project delivery method must take these dynamic variables into account if it is to succeed. One way to improve the Construction Management System (CMS) is to divide projects into smaller, more visible and manageable work packages (i.e. locations, scopes, Work Breakdown Structure [WBS], chunks) that localize and decouple the risk wherever possible (Kenley and Seppänen 2010). For this approach to work, the work packages must be independent of one another and have some form of redundancy. Then, these smaller packages of work can be "fed" to multi-skilled teams of workers (Sacks and Goldin 2007), which function as small independent work cells. While construction cannot be as precisely tuned to the level of optimization as is the norm in a Toyota plant manufacturing cars, by dividing the work into smaller, human-centered "chunks" and decoupling dependent tasks (adding redundancy wherever possible), the "flow" of the construction line can be improved (Sacks 2016). If shocks to the system are inevitable, then a system designed to localize and minimize the negative impact of the shocks can prevent them from propagating through the system in a chain reaction.

The prevailing strategy in construction subcontracting is to choose the lowest price bid, and the typical contract is based on "piece work" – payment for set work volume, with no stipulation for the quantity of resources consumed or the exact timing of the work unit. In this scenario, subcontractors have an incentive to achieve high productivity when they are on site, even if this means delaying the project progression as they wait for a backlog of work to build up (Sacks and Harel 2006).

Simulation has been used in the past as a research tool in construction management, since it provides insights that the complex realities of a real-life experiment on a construction site might muddle. In addition to the inability to control all of the input variables or isolate their impact, other benefits of simulation include the scope of work in a real situation, the inability to maintain control in real-life experiments, and experimental studies that are sufficiently similar. Examples of simulation being used to explore construction management dynamics include the Parade of Trades game (Tommelein et al. 1999) which examined the impact of varying work rates of individual subs on the outcome of the entire project, or the extensive use of Discrete-Event Simulation (DES) such as CYCLONE (Sawhney et al. 1998) and Stroboscope (Martinez 1996), two DES platforms which were developed specifically for construction. Closer afield, work has been done in modelling the GC-sub interaction using both DES (Esquenazi and Sacks 2006; Sacks et al.

2007) and Agent-Based Modeling (ABM) (Ben-Alon and Sacks 2015, 2017), finding that Lean improvements in the context of a single project tend to improve project cash flow, duration, WIP, and delivery or products according to customer specifications.

Multiskilling (Carley et al. 2003; Nasirian et al. 2019a; b) is an approach in which work resources (in this case, construction tradesmen) are trained to complete larger sections of the work process. This approach creates redundancy in the laborforce (Angelidis et al. 2013; Eitzen et al. 2004), making production systems more flexible. For the purposes of construction, by training workers to carry out more work packages than they currently do in their hyper-specialized trades, it may be possible to unify trades that were previously separate into teams that can be deployed together as a team to serve as "work cell", rapidly completing the work on a given work location by removing the waiting times between the arrivals of the formerly separate crews. Agent-Based Modeling is a simulation approach where individual "agents" are created, each replete with attributes and behaviors, and set loose to interact with each other. One key feature of ABM is the ability to see emergent behavior at the level of the system, behavior that grows out of the collective interactions of the typically much-simpler instructions of the individual agents (Macal 2016; Macal and North 2010).

ALTERNATIVE PRODUCTION SYSTEMS

In this work, a CMS is proposed that focuses on Cellular Project Delivery (CPD) (Black and Hunter 2003), designed to be resilient, more reliable and easier to manage. The CPD CMS uses the building elements to define the work packages, allowing the Construction Manager (CM) or Owner to concentrate their focus on a limited number of aggregate work efforts (or cells) that are semi-independent of, and sometimes redundant to one other. Each work package is performed with exclusive access to that location, enhancing a transparent understanding of quality and schedule. Handoffs to the next work cell (and transition of the cell members to the next location) are conditioned on the successful outcome of an extensive QC review of the completed work. The CPD system is designed to reduce system variation, which is expected to yield reduced project duration and total cost, through improved productivity.

The Last Planner System (Ballard 2000) constitutes another Lean Construction-related acknowledgement of the ravages of VUCA unchecked, as well as proposed countermeasures to address them. Last Planner does so by pulling only work that is "sound" (i.e. with all prerequisites met, ready to be transformed from planned to done). This approach is not sufficient in and of itself because while the work may start with some degree of certainty when all the prerequisites have been addressed thanks to the efforts of the Last Planner System (LPS), it may or may not end on time (uncertain duration) or at the quality level required. This is due to the lack of standardized work in construction (standardized work, a key concept in Lean) and the fact that the subcontractors may have interruptions to their work (both internal – in the case of unexpected developments – and external – in the case of the subcontractors being pulled out of the work location to go to another location or even another project).

Despite the marked interest in applying Lean to the field of construction, and except in a few unique situations with highly-motivated teams, Lean Construction has not proven to be a “magic bullet” in reducing VUCA across the industry (Dave et al. 2015; Koskenvesa and Koskela 2012). At root is the fact that it is nearly impossible to smooth out and then automate an unreliable process:

- A lack of standardized work means task durations are difficult to forecast.
- Task dependencies lead to domino-effects of missed targets beyond the local area of emergent problems - the 'ripple' effect, (Thomas and Oloufa 1995).
- Contractual structures can stifle cooperation by creating zero-sum game lose-lose relationships.
- Local factors can further complicate planning, such as an unexpected spike in the cost of a key input to the project.

These strategies include transitioning from single-skilled traditional workers working in sequence one after the other to a market where work is carried out by multi-skilled teams that are able to completely finish the work in the apartments on their own. The hypothesis here is that by removing the interfaces between multiple teams (each of which is a potential point of delay if the next crew doesn’t arrive on time), the outcomes will also be improved. This is the creation of work cells comprised of a number of processing steps collocated (in the case of the mobile production line of construction, collocated in time as much as in physical location).

Reducing batch size is a key concept in Lean, and will be tested as a variable in the simulation. The hypothesis is that reducing the size of the batches (work chunks) contracted to the subcontracting teams (in this case, reducing the batch from all the work locations on a floor of the building as is common practices to just a single apartments) will have a commensurate increase in the flow of the process and reduce the overall project duration.

GOALS OF THE SIMULATION

For the Makerhoods project, the simulation environment was intended to model, to the extent possible, the local construction market. The main parameters are the volume of construction, the range of project types and sizes, the number and type of subcontracting trade crews available to be hired, typical work rates for the trades, and the usual work flow for the prevailing product compositions in the area, etc. In particular, the specific work volumes for the Makerhoods project itself were assessed using the design data for the project (unit size, area of floors or walls, etc.). Once the general scenario was set up, different project delivery strategies that the management can take could be tested.

STRUCTURE OF THE SIMULATION

To carry out the simulation, we used a multi-site construction management simulation engine called LeapconX (Korb and Sacks 2019) that was compiled in Netlogo, an Agent-Based Modeling platform (Wilensky and Rand 2015). A screenshot appears in Figure 2.

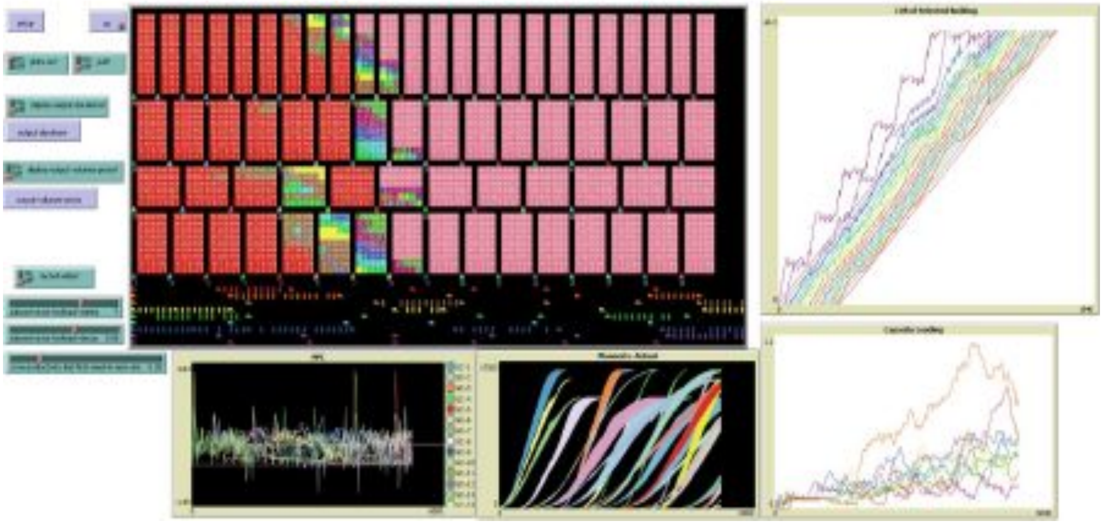

Figure 2: Screenshot of the Multi-site ABM Simulation Platform in Netlogo.

This simulation allows the input of multiple projects in the local market. There are four agents: GCs, Subs, Work Crews, Apartments. Each of the agents in this model has a set of attributes that govern its behavior and the relationships it has with other agents. For example, work crews have a rate of work and number of workers, which govern the amount of work they can do in a given day. They then update the work volume of the apartment they are working in that day, reducing the work remaining of the apartment accordingly.

For each project, the GC negotiates contracts with the subcontractors, each of which has a number of work crews that can be deployed to relevant projects. The color of each subcontractor is the trade, with the work sequence also defined by the sequence of colors of each work package

Of particular interest for this research is the ability to set the strategies the GC will undertake, allowing the evaluation of the outcome for each project relative to the strategies that it employs. Thus the GC has a trait of how many subcontractors it will employ, whether it works in batches or in one-piece flow. The use of multi-skilled teams is a state parameter affecting the entire economy, and thus is not implemented on a GC-by-GC basis.

The “ticks” of the simulation represent a discrete increment of time, and the “week length” relating the number of ticks to a typical work week is a parameter that can be set by the user, allowing the simulation to be run at varying levels of granularity. The start date of each project is another parameter, allowing projects to come online at varying intervals, mimicking the real-life behavior of a local market (new projects begin from time to time). Likewise, the time before beginning the work at which point the GCs will put out a request for bids to the subcontractors and then actually contract with the relevant subs can be tweaked for each project.

Each week, the GC reviews the master schedule for its project, and determines work volumes for each trade that will be required to meet the schedule (as well as closing out any delays that have accumulated). This information is distributed to the subcontractors as the request for weekly work. In turn, the subcontractors collect the requests they have accumulated from the various GCs, and decide where to allocate their work crews. The decision is based on the work requested, but that information is processed based on the status of each project, the reliability of the particular GC in the past (i.e. was the GC able to provide the amount of work requested in the previous weeks?), a transfer/travel penalty if a new site is to be opened up, etc. Finally, the crews are distributed to projects based on the sub's best estimate of where the most profit is to be had in the upcoming week.

Once on site, the GCs direct the crews to which work locations to work on, and the crews do their work.

The project specifics for the Makerhoods project (work packages and work volumes) were loaded into the Netlogo model, based on information from the project design (bill of quantities). The rates of work for the trades represented in the project were taken from RSMeans, a database of construction-related data, which offers the ability to drill down from a national (US) level down to a particular city (Gordian 2019). The Residential New Construction data for Newark, NJ were used. The US Census Bureau reports how many apartment units were granted permits on an annual basis in the Newark area for tall buildings (i.e. not single-family homes), and the US Bureau of Labor Statistics provided data for the total labor force for each trade in the same metropolitan area. The 2007 data was used, since that was the most recent full-year data available. The US Department of Housing and Urban Development defines the central submarket of the Newark Housing Market Area as the New Jersey counties of Essex and Union, which includes the city of Newark itself (Office of Policy Development and Research 2015).

A time span of the number of buildings that began construction over the course of two years was chosen as a reasonable balance between computing time and validity of the results, due to the need to overcome the "ramp-up" of the simulation in approximating the relative steady state condition of any real-life construction market. Korb (2019) provides a full description of the simulation and its parameters. A picture of the simulation output mid-run (approximately 1.8 years into the run) appears in Figure 3. The buildings are arranged such that their start date correlates to their location on the x-axis. The location of the buildings on the y-axis is of no consequence and merely allows multiple projects to be portrayed in parallel. As can be seen, at this point the first projects have already been completed (all units are red), and the last ones have not yet begun.

Figure 3: Netlogo simulation of the Makerhoods project in the Newark, NJ residential construction market, using traditional project management methods

Once this scenario was run through the simulation and data were gathered, and then it was re-run as a multi-skilled scenario. In the multi-skilled scenario, all of the work volumes of the work packages are pooled together as a single work package, and each of the subcontractor crews is reassigned from being a specific trade to being multi-skilled. A picture of the multi-skilled, reduced batch-size scenario (with all other data being kept identical) appears in Figure 4.

Figure 4: Netlogo simulation of the Makerhoods project in the Newark, NJ residential construction market, using reduced batch size and multi-skilled teams

RESULTS

Overall, the introduction of multiskilling and reduced batch size served to reduce the overall duration of the simulation run by 8.2%. The average length of the simulated Makerhoods project within this environment was likewise reduced, by 38.7%. This is in line with production theory, such as Little's Law (Hopp and Spearman 2011), which states that a reduction in batch size should lead to a concomitant reduction in the lead time of a project. In addition, the application of multiskilling allowed for greater subcontractor utilization, as there were fewer waiting times created by uneven work durations among the trades.

Another experiment was run to look at the impact of implementing reduced batch size for only the Makerhoods project, assuming all other projects in the simulation use the traditional batching method of releasing a number of apartments together for the exclusive use of one subcontractor. By so doing, it is possible to see the impact of being an "innovator" in the midst of traditionally-managed projects. In the baseline runs, with the Makerhoods project also using batch production control, the average project duration was 3.03 years. Implementing one-piece flow (reduced batch size) lead to a reduction of the project duration to an average of 2.21 years. This represents a time savings of 27.2%, which means improved cash flow for the company and reduced time-dependent project overheads.

CONCLUSION

This work set out to use a new simulation platform to assess the impact of various Lean-inspired strategies that can be applied in a construction project, in an attempt to bring elements of Lean that matured in manufacturing environments to the construction site. A local construction market was re-created within the simulation environment in order to increase the fidelity of the simulation relative to the target project under study, the Makerhoods Newark, NJ project.

Based on the simulation, it is clear that the Makerhoods project would see an improvement in the two key outcome metrics of project duration and project cost if it were to implement the changes discussed above, namely building "work cells" comprised of tradesmen that have the ability to fully complete the work in the work location without the need for multiple entries, exits, coordination among them, etc. The work locations could then be shrunk from batch sizes of a block of apartments on the same floor to a single apartment. This reduction in batch size would further reduce the amount of time required for the project duration by removing a lot of the waiting times in a typical project.

This simulation and the results indicate that other companies in the field of construction could also benefit from these strategies, and the simulation platform can serve as a good environment in which to test them.

That said, like any result based on simulation, it is necessary to validate the prescriptions in the field, and it is the hope of the authors that the Makerhoods project will do just that. As the Makerhoods project comes to fruition, we will continue to document the impacts of the implementation of these Lean principles.

Future research will explore this simulation tool in greater depth, testing other Lean Construction interventions that GCs can take, to see their effect individually and in combination on project outcomes. The results presented in this paper are thus only the preliminary results of what we hope to be a very insightful line of research. The multi-project nature of the simulation will give us the ability to test not only the effects of the Lean strategies, but also do so at different levels of market adoption, from innovators and early adapters through to a new paradigm in which all players in the new market have adopted the Lean approaches.

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RESULTS OF INDICATORS FROM THE LINGUISTIC ACTION PERSPECTIVE IN THE LAST PLANNER® SYSTEM

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ABSTRACT

The correct implementation of the Last Planner® System has been proven to increase the reliability of the planning and performance levels of projects by managing commitments. However, the current management of commitments in weekly planning meetings has not been sufficiently analyzed to teach people how to make reliable promises. Therefore, it is essential to deepen the measurement indicators of the Linguistic Action Perspective to generate reliable commitments that reduce uncertainty and variability in the projects. This study, based on "design science research", shows the first results of the indicators of the fundamental elements of language and action in construction projects in Chile. The results are an improvement over the previous indicators. Previous indicators have only been validated in a classroom setting, whereas this paper presents a validation based on case studies on actual construction projects which carry out weekly meetings using LPS. The authors invite the researchers around the world to measure and compare these indicators.

KEYWORDS

Linguistic Action Perspective, Last Planner® System, Commitments Management, Case Study, Planning meetings.

INTRODUCTION

According to Barbosa et al. (2017), annual productivity of construction has increased 1% per year in the last 20 years, while its spending accounts for 13% of the annual GDP. In order to increase productivity, construction must improve projects' planning and control.

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Ballard (2000) addresses this problem by the introduction of Lean principles in project management by applying the Last Planner® System (LPS). This paper seeks to further improve the planning process by developing and analyzing indicators to measure and ultimately improve the management of commitment in weekly planning on the LPS. This paper is based on Linguistic Action Perspective (LAP) and builds on previous indicators developed by Salazar et al. (2018). This paper proposes the replacement of some of the indicators and adds new ones based on the analysis of several case studies in construction projects. Previous indicators develop by Salazar et al. (2018), were validated in the classroom through the Villego® Simulation, while this paper presents a validation based on case studies on concrete construction projects which carry out weekly meetings using LPS.

LAST PLANNER® SYSTEM AND LINGUISTIC ACTION PERSPECTIVE

The Last Planner® System (LPS) is a methodology to plan and control commitments. Based on the principles of Lean production, LPS seeks to increase the reliability of planning and performance levels (Ballard & Tommelein 2016) and reduce the uncertainty and variability of projects. Through several investigations, the effectiveness of this system has been demonstrated; for example, González et al. (2008) established a direct relationship between the reliability of planning and productivity. Specifically, in Chile, the implementation and study of LPS has generated the incorporation of more actors in the planning process, less variability, more reliable promises and increased productivity (Alarcón et al. 2002). This section explains commitment management in the LPS and Linguistic Action Perspective (LAP).

COMMITMENT MANAGEMENT IN THE LAST PLANNER® SYSTEM (LPS)

According to Koskela & Howell 2002, the implicit theory in traditional project management assumes that the necessary predecessor activities and the resources to execute such activities are always available. However, in practice, this is extremely unlikely. It is assumed that the task is fully understood, initiated and completed according to plan without considering the importance that the worker as the executor must have (Koskela & Howell 2002). Therefore, Howell et al. (2004) propose that LAP improves the effectiveness of LPS.

LINGUISTIC ACTION PERSPECTIVE (LAP)

The Linguistic Action, which was developed by Flores (2015), applies the theory of speech acts of Austin (1971) and Searle (1969) to organizational management. Flores (2015) argues that certain “speech acts” such as promises are themselves actions in the world.

Understanding "conversations for action" as conversations whose purpose is the coordination of diverse actions (Salazar et al. 2018), Flores (2015) proposes a basic and universal structure based on four speech acts. The four speech acts that contain all conversations for action are: 1) request or offer, 2) promise or acceptance, 3) declaration of compliance and 4) declaration of satisfaction.

Flores (2015) defines four stages of a conversation for action, which is called the network or chain of commitments: 1) preparation of a request; 2) negotiation and agreements; 3) execution and declaration of compliance; 4) acceptance and declaration of satisfaction. It is expected that in construction projects, there are variations in the basic movements, such as renegotiation, revoking a previous commitment, or canceling an order. According to Flores (2015), these variations increase the confidence of the commitments.

PRACTICAL PROBLEM BEING ADDRESSED

Although the LPS has made an effort to improve the management of commitments, and Salazar et al. (2018) created indicators to measure the specific elements of the LAP in the LPS, the qualitative analysis has not measured the degree of incorporation of LAP elements in construction projects that use LPS worldwide.

Hence, our proposal is to show the results of the measurement of the indicators of Salazar et al. (2018) and to propose new indicators that complement the work to improve the management of commitments in construction projects.

RESEARCH METHODOLOGY

The research methodology was based on Hevner's "*A Three Cycle View of Design Science Research*" (2007) and builds on Salazar et al. (2018) previews research. The steps performance are as follows:

1. Study the Linguistic Action Perspective and Last Planner® System to generate a *Knowledge Base* mainly based on Flores (2015) and Ballard (2000).
2. Identify the main elements of the Linguistic Action Perspective that could be quantifiable; create a list of concepts and data to be measured.
3. Develop indicators that could measure and control the main elements of this perspective through the *Design Science Research*.
4. Measure the proposed indicators in four construction projects in Chile to validate them through the *Environment* in a normal construction situation. The researcher recorder, analyzed videotapes of weekly meetings and interviewed participants when necessary to evaluate each commitment for each proposed indicators.
5. Compare the proposed indicators by Salazar et al. (2018), which were validated using Villego® Simulation, and the once proposed in this paper.

INDICATORS: IMPROVEMENT AND NEW PROPOSAL

In this paper, the authors propose a new set of *key performance indicators* (KPIs) measured in the field, which complements the proposed indicators by Salazar et al. (2018). According to the Linguistic Action Perspective, to measure and control the fundamental aspects of the commitments, requests, promises and foundations of trust, these indicators are a useful tool to measure, control and improve the management of commitments in weekly planning meetings, since they provide a quick and specific feedback, which enriches the implementation of the Last Planner® System (Salazar et al. 2018).

To test the KPIs proposed by Salazar et al. (2018) in real projects, measurements were implemented in four construction projects in Santiago, Chile.

The field test led to a series of changes and additions to the original proposal as follows:

1. **Proposal to eliminate indicators**
   - The authors propose not to measure the % verification of the availability of performers in execution because most of the foremen verify the availability of their workers after the weekly meeting and in the field huddle, and these indicators are designed to be measured exclusively in weekly planning meetings.
   - We propose to eliminate the % of incomplete requests and promises because it is confusing to measure it in the field.
   - Finally, we propose to eliminate the % compliance of the performer's competence because it is associated with the worker's curriculum vitae and it is not possible to measure in the weekly meeting. It can only be associated with the correct fulfillment of each commitment or PPC (Percent Plan Complete).
2. **Proposal to change the indicators**
   - The authors propose modifying the % declaration of the importance of each commitment because they consider it more appropriate to use the word “priority”, so the indicator should be renamed as % declaration of the priority of commitment. This change is proposed because it is necessary to deepen the conditions of satisfaction of the most relevant commitments. See Table 1.
   - In addition, the modification of the % reliability compliance is proposed because we found a point of confusion in the formula of the indicator regarding the concept of counteroffers, since counteroffers occur in the same meeting, whereas the concept after the meeting is “renegotiation”. Additionally, "cancel" a commitment is added. See Table 1.
3. **Measurement of original indicators**
   - Table 1 shows the average results of the indicators measured during a month, which incorporate the changes that we mentioned to the proposal by Salazar et al. (2018).
4. **New proposed indicators**
   - The authors propose seven new indicators, which complement the work done by Salazar et al. (2018). See Table 2.

These indicators seek to analyze the management of commitments in weekly planning meetings, so the frequency of measurement is always every 7 days. However, it is necessary to perform at least 2 weekly meetings to analyze the results, according to Salazar et al. (2018).

CASE STUDIES

Regarding the strategy to select the case studies, the "information-oriented selection" was used to establish "extreme cases/deviations" (Flyvbjerg 2006). The units of the analysis were 4 multistory building projects with the LPS implemented with different degrees of maturity, in Santiago, Chile. This number was determined according to the recommendation of Hernández et al. (2014), who recommend a maximum of 8 cases, when a multiple in-depth study is carried out (Yin 2003), since the study does not represent a "sample", as if an experiment does.

As mentioned, the team used the "information-oriented selection" due to the feasibility of research with companies belonging to the Collaborative Group of the Center of Excellence in Production Management (GEPUC).

RESULTS OF THE INDICATORS

The authors consider it appropriate to analyze the results of each indicator proposed by Salazar et al. (2018), which were measured in 4 construction projects, in the Last Planner meetings.

1. Compliance network or chain of commitments

In general, compliance was observed with the first movement "Preparation of a request" and the third movement "Declaration of compliance", according to the 4 basic movements of conversations for action (Flores 2015). However, there is no negotiation process but only the imposition by the client. For example, the boss says, "it must be ready on Tuesday", and there was no declaration of satisfaction verified, i.e., there was no "Ok" or "Well done". The foregoing shows a lack of knowledge and/or application of LAP in the analyzed projects.

2. Definition of roles and responsibilities

The roles were intrinsically defined, in which there is a clearly established figure for their client and another for the performer. However, the main problem is the scope of the commitments, not being clear the responsibilities of the performers, and what the performer ought to do. For example, the boss asks the enclosure to install the reinforcement in a specific place of the work, but the boss does not specify whether the reinforcement should be purchased, cut, folded and placed, or only placed.

3. Fulfillment of the roles and responsibilities of the performers

What differentiates the construction projects from other projects in regard to the LAP is that, in general, the performer does not make commitments, but instead, the chief performer (foreman) does, except in administrative aspects that the management team commits and executes. Therefore, in construction projects, it does not make much sense to strictly apply rules saying "the performer, and not another, should fulfill the promise and declare compliance to the client", since the foremen are committed on behalf of their workers who perform the work.

4. Declaration of the priority of the commitment

No declaration of priority on the part of the clients was observed, which affected the subsequent planning of the foremen in the field huddle because they did not execute the commitments in the correct order. One of the events that confirmed the importance of this indicator occurred in a meeting of review of commitments; the planner (client) reprimanded the foreman (performer) because he had performed 9/10 activities (90%), but the only activity he did not do "was the most important thing", and therefore, the foreman was "incompetent" and "not reliable".

TABLE 1. Measurement of the KPI Linguistic Action Perspective in the Last Planner® System (proposed by Salazar et al. 2018)

Objective	Measure Name	Description	Formula	Results	General Comments
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	0%	* The preparation of the petition is observed * There is no negotiation process, but rather an imposition by the client * The declaration of compliance is verified * The declaration of satisfaction is not observed
	% 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	83%	* In general, roles are defined intrinsically: client requests and performers agrees. Regarding responsibilities, the scope of the commitment is not always clearly established
	% 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 completed commitments) x 100	15%	* In general, in the construction works the performer does not commit, the one who commits is the head of the performer (foreman) * Performer is engaged in administrative aspects (management team)
	% declaration of the priority 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	10%	* In general, the priority of the commitments is not declared. This does not allow the foremen to carry out an adequate planning regarding the execution order of the assumed commitments
	% compliance with priority commitments	KPI measures the percentage of commitments that were declared priority and that are effectively met	(Number of priority commitments fulfilled) / (Total number of priority commitments) x 100	100%	* The few commitments that were declared a priority were completed. The foregoing demonstrates the importance of making the priority statement
	% 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	18%	* There is a low percentage of verification of the availability of performers in the stage of negotiation and agreements
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	10%	* In general, only the date is specified, but it is not detailed schedule, or if it will be completed in the morning or in the afternoon
	% 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	3%	* Low percentage in weekly meetings * According to the workers, the foremen often make unnecessary requests on the field
Measurement and Control of Fundamentals of Trust	% 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 renegotiations + number of commitments canceled) / (Total number of commitments) x 100	81%	* It must always be a percentage equal to or greater than the PPC * Complements the PPC with additional movements, which happen after the initial agreement
	% 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	48%	* High degree of participation (only 10% left the meeting) * No meeting started at the agreed time * A lot of interaction with the cell phone during the meeting (calls, chat and e-mail) * Interruptions by radio * Some moments spoke two or more people at the same time * 60% of the team takes note (everyone should take note) * Non-verbal language indicates fatigue and lack of attention

Source: Own elaboration, based on (Salazar et. Al, 2018)

TABLE 2. Measurement of the newly proposed KPI from the Linguistic Action Perspective in the Last Planner® System

Objective	Measure Name	Description	Formula	Results	General Comments
Measurement and Control of Commitments	% fulfillment of a request	KPI measures the compliance percentage of the first movement; preparation of a request by the client	(Number of commitments in which the petition is prepared) / (Total number of commitments) x 100	100%	* Client is clear about the request (what) and to whom it will be entrusted (performer)
	% compliance negotiation and agreements	KPI measures the compliance percentage of the second movement; negotiation and agreements	(Number of commitments in which a negotiation and agreement is made) / (Total number of commitments) x 100	20%	* In general, there is no negotiation before the agreement. The performer assumes the order established by the client. Sometimes he does not answer if he can or does not comply with the agreement
	% declaration of compliance with the commitment	KPI measures the percentage compliance of the third movement; execution and declaration of compliance with the commitment by the performer	(Number of commitments in which compliance is declared) / (Total number of commitments completed) x 100	78%	* It is verified by questions to clients and performers before the weekly meeting that there is a high percentage of declarations of compliance with the commitments. However, there are performers who do not inform clients that they finished with the assigned task
	% fulfillment declaration of satisfaction	KPI measures the percentage of compliance of the fourth movement; acceptance and declaration of satisfaction by the client	(Number of commitments in which satisfaction is accepted and declared) / (Total number of commitments completed) x 100	5%	* There is a low percentage of commitments in which satisfaction is declared by the client. In general, it is only indicated if the commitment is fulfilled or not, without giving feedback to the performer
Measurement and Control of Fundamentals of Trust	% revoked commitments	KPI measures the percentage of commitments revoked	(Number of commitments revoked) / (Total number of commitments) x 100	4%	* Minor percentage of commitments are revoked after the weekly meeting
	% renegotiated commitments	KPI measures the percentage of renegotiated commitments	(Number of renegotiated commitments) / (Total number of commitments) x 100	2%	* Practically no renegotiation of commitments after the weekly meeting
	% canceled commitments	KPI measures the percentage of canceled commitments	(Number of canceled commitments) / (Total number of commitments) x 100	1%	* Practically no cancellation of commitments after the weekly meeting

Source: Own elaboration

5. Compliance with priority commitments

The commitments that were declared as priorities by the clients were completed in time by the foremen. The foregoing demonstrates the importance of prioritizing commitments and not leaving this responsibility to foremen.

6. Verification of availability of performers in agreements

In general, there was no verification of the availability of workers by the foremen. Therefore, the foremen don´t arrive at the meeting with their agenda and the agenda of their work teams.

7. Specify the deadline

It was mandatory that a specific day but not an hour was established as a deadline. Thus, we recommend establishing at least one AM or PM schedule to obtain more specific planning.

8. Unnecessary requests

There was a smaller number of unnecessary requests in the weekly meetings but a high percentage in the field huddle, as mentioned by the workers.

9. Reliability compliance

This indicator seeks to complement the PPC according to the 3 additional movements that occurred after the weekly planning meeting. The authors work on establishing the appropriate deadline (last responsible moment) to renegotiate, revoke and cancel a commitment, without affecting the planning of the project. The difference between canceling and revoking, is the person performing the action; in a cancellation, the client breaks the commitment, whereas in a revocation, the performer cannot comply.

10. Engaged participants

This indicator seeks to measure the engagement of the participants in the meeting, according to the following checklist: if the person arrives within the hour or in the afternoon, interacts with a cell phone, leaves the room, interacts with a walkie talkie, intervenes in the meeting, takes notes or looks at the person he is talking to.

RESULTS OF THE NEW INDICATORS

The result of each new indicator is explained below:

1. Fulfillment of a request

The client was clear about the request and who would be responsible for it; it is an intrinsic part of the Last Planner® System. For the above, the indicator was 100% satisfactory.

2. Compliance negotiation and agreements

The performer assumed the order established by the client and has no negotiation process, as such. Many times, the performer did not even answer affirmatively, and the establishment of the commitment was assumed.

3. Declaration of compliance with the commitment

The performer should have fulfilled the task entrusted and have made the declaration of compliance immediately, before the weekly meeting so that clients could verify the commitment and give the corresponding declaration of satisfaction. However, there was a significant percentage of performers who waited until the weekly meeting to report that they fulfilled the previously agreed commitment.

4. Fulfillment declaration of satisfaction

In general, this declaration only indicates whether the commitment is fulfilled without providing feedback to the performer regarding the conditions of satisfaction, how to improve in a next installment or any appreciation for the work done.

5. Revoked commitments

The revoked commitments are those in which the performer informs the client after the meeting that he will not be able to fulfill the required commitment. The main problem detected is that the foremen, despite knowing that their team could not fulfill the commitment, did not inform the client in time. The applicable rule is that the moment a performer becomes uncertain that he can keep a promise, he must inform the 'client' (requestor) and the entire team.

6. Renegotiated commitments

The renegotiated commitments are those in which the performer (or client) wishes to change the conditions of satisfaction after the meeting to generate a new negotiation. One of the detected problems is that most of the foremen attempted to comply with the % of work requested, but did not renegotiate a lower % or an alternative task.

7. Canceled commitments

The canceled commitments are those in which the client informs the performer after the meeting that the acquired commitment is no longer necessary. Although this situation is unlikely to occur, the planners must know that they can cancel a commitment and request another one after the meeting (renegotiation).

CONCLUSIONS

The study in this paper shows the application of the Linguistic Action Perspective (Flores 2015) in four construction projects and updates the study conducted by Salazar et al. (2018) by proposing improvements and creating new indicators for the measurement and control of the management of commitments in construction projects. To validate these measurements, contractors who participated in in Last Planner® System meeting were consulted about their perceptions, they stated that these measurements improved the ability to provide reliable promises, since they understood the importance of speech acts, satisfaction conditions and trust in the management of commitments.

Therefore, the entire community linked to the construction industry is invited to use the proposed indicators to compare with the "location dimension" (Flyvbjerg 2006). The differences and similarities among different projects around the world, with the objective of determining the effect of the culture of the people and organization in the management of commitments and the general performance of construction projects.

Also, in future studies, the authors propose to apply case studies in weekly planning meetings in other industries worldwide and to determine the recommended values to improve communication and achieve the proper implementation of LAP in LPS.

Finally, the authors consider that this second generation of key performance indicators measured in the field (eliminating, changing and proposing the KPI from the first generation) generate a powerful tool to measure, control and improve the management of commitments in weekly planning meetings, since they enable quick feedback that undoubtedly enriches the Last Planner® System.

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TEAM-LEADER WALK AS INTERDICIPLINARY COMUNICATION TOOL AT THE BUILDING SITE

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ABSTRACT

This paper introduces the concept of ‘team-leader walk’ as part of the construction process organized through TAKT production. The purpose of the team-leader walk, is to help team-leaders see, communicate and plan further ahead in the construction process. By systematically walking through the different zones of the building under construction, while discussing plans and coordination issues one to three weeks ahead, the building site is used as communication tool in the interdisciplinary communication between the team-leaders. Appealing to the often-well-developed practical intelligence of the team-leaders, we argue that the building site itself, enhances the ability to look ahead better than visualisation tools alone. The team-leaders, as last planners become better equipped to take part in the continuous planning. A condition for the team-leader walk, as presented here, is that the construction is organised according to a systematic movement in time and space – such as TAKT production.

The study is based on observations and interviews at two building projects where the team-leader walk was tested in 2018. While the validity is limited by the number of cases, the building company in study find the results so promising they have decided to implement the team-leader walk in further building projects.

KEYWORDS

Lean construction, team-leader walk, last planner, takt.

INTRODUCTION

A core idea in the last planner system is to engage those who actually do the job in the planning of it (Ballard 2000). This implies involving builders and team-leaders in the planning process. In particular the team leaders play an essential role in planning and coordinating the activities at the production front of the building site. In the present case study of two building projects lead by the same entrepreneur, the team-leaders engage in planning activities organised in a system similar to the last planner system, called Involved Planning (IP).

Table 1: The time horizons of different meetings in IP (from Andersen 2016)

Type of meeting:	Time horizon:
Team meeting	1 week
Team-leader meeting	1-3 weeks
Operations meeting	4-8 weeks
Construction meeting	More than 8 weeks

In this system, the team-leaders meet every week. The team-leader meeting’s contribution to planning implies looking ahead, from only one to three weeks. However, experiences from

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previous projects indicate that looking three weeks ahead is difficult as there is a tendency that the planning ahead is overshadowed by here and now concerns (Andersen 2016). The three-week perspective is made a topic at the meeting, but the experience is that it has been difficult to engage the team-leaders to come up with issues in great enough detail that concern the three-week time-frame. The poorer the process control, the shorter the time horizon (Andersen 2016). The result has been that issues which should have been sorted out three weeks before production, are discovered too late, creating problems for the construction proses.

In response to this situation, the team-leader walk, or just 'walk' (in Norwegian 'Basrunde') is introduced in order to help the team-leader meeting to see and plan three weeks ahead. One aspect separating this approach to the team-leader walk from similar planning practises is its explicit relation to the TAKT organisation of the building process. With TAKT the production front and horizon three weeks ahead is structured in a specific way in terms of systematic movement in time and space through the building, divided in zones.

From team-leader walk case 1.

METHOD

This paper is based on action research where the authors in collaboration with the entrepreneur have suggested and implemented the team-leader walk as an innovation to the established building processes. The walk is implemented and studied in two case studies in Norway: The first is a mid-sized hospital building, the second a sport stadium. The idea of the team-leader walk is based on previous studies at the same building company by the authors (Andersen 2016; Fyhn and Søraa 2018) which indicate the need for an implementation enhancing the ability to see three weeks ahead. The walk is adapted to the specific production system and production philosophy at the entrepreneur in study; a combination of TAKT production and "Involved Panning" (quite similar to Last Planner).

The implementation of the walk is made in close collaboration with the company management, the construction, and operations managers, and the team-leaders. The implementation is studied by *participatory observations* where the authors joined the team-leader walks as well as team-leader meetings, taking notes to what was said and done, which topics came up and how they were solved/not solved. In addition, *semi-structured interviews* were conducted with team-leaders, builders, engineers and management. The interviews focused on experiences with the walk as well as with the building process in general, and with suggestions for improvements.

The first case study was conducted from January to April 2018, involving observation of three team-leader walks and team-leader meetings. Interviews with team-leaders for carpenters, electricians and locksmiths was conducted in association with the observations. Follow up interviews was conducted with operation manger and construction manager. All interviews were semi-structured and qualitative.

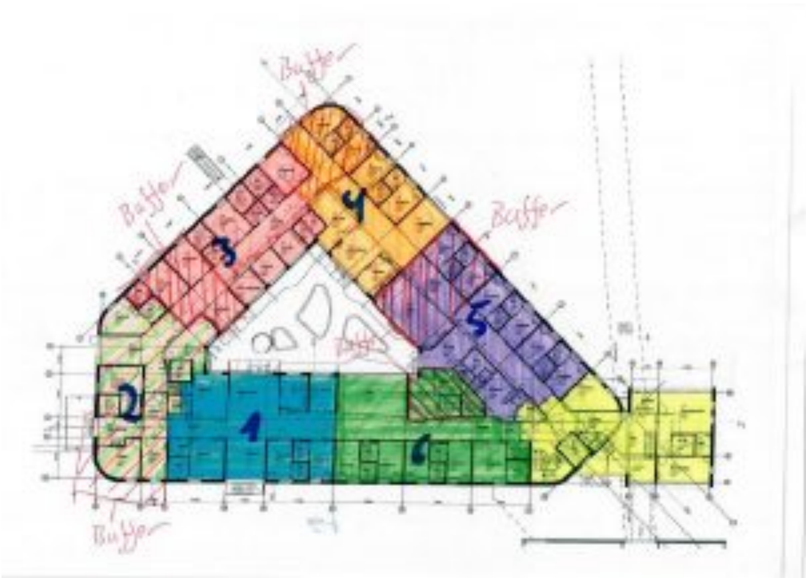
For the second case, the implementation was studied from April to November 2018, including observations of six team-leader walks and the corresponding team-leader meetings. In addition, six semi structured qualitative interviews were conducted at the end of the period: with the team-leader for carpenters; team leaders for electricians, ventilation and plumbing; two carpenters; the foreman; operation manager; construction manager. For both cases, workshops with the responsible partners where held at the start of the observation period, mid-way and after the observations. This to ensure proper dialogue between researchers and industry partner in the development of the team-leader walk, research and implementation method, as well as to ensure relevance of the results. The workshop in the start was used to introduce the concept of team leader walk, as well as to find solutions for practical application in collaboration with the team leaders and management. The mid-way workshop was held to adjust the course of the experiment, and gather responses so far. The last workshop was held after the observation period when we hade systematised the finding. The purpose was to present results from the observations and to discuss them with the involved team-leaders and management.

THE TEAM-LEADER WALK EXPLAINED

Within a Lean mind-set, the team-leader walk draws on the Japanese concept ‘Gemba walk’, a tool in Lean leadership (Womack 2011) with parallels to the less structured western concept ‘management by walking around’. In contrast to the Gemba walk, the team-leader walk is not about management leaving their office to walk the shop-floors, but rather about the team-leaders which already work at the ‘floor’ of the construction-site, walking around this site in a systematic manner when planning ahead. The idea is not primarily to allow team-leaders to experience the ‘construction floor’ but rather allow the actual construction site to enhance the interdisciplinary communication between the team-leaders, helping them to see further ahead in their interdisciplinary construction process. As such, it is the respect for the actual place - the ‘Gensi genbutsu’- which resonates the most with established Lean leadership principles.

Using the actual place, the building site, to enhance the interdisciplinary communication between team-leaders makes the building site into a *boundary object*; an object shared by participants of interdisciplinary communication allowing for common meeting ground despite differences (Boland and Tenkasi 1995). As a mediating object, the building under construction should be understood as a similar tool along with technical drawings, BIM models and time schedules on the wall; objects expressing the intended building or state of the art in various levels of detail. These are objects used by builders and team-leaders when communicating, planning and coordinating the work process. They are not only used to communicate ideas, plans and concerns, but also serve as mediums for developing ideas, plans and solutions, for example when the team-leader draw new lines on the technical drawing in order to show adjustments or new details. A more precise term than boundary object, may be ‘communication tool’. Understood as communication tool the building under construction has certain properties which differs from drawings and BIM models. It is at any time the most updated version of the building progress. It also seems to appeal to practical thinking over the more theoretical associated with representational models, thus it may fit better into the cognitive expertise of many builders.

The team-leader walk is developed in a context of TAKT, where the flow of production is managed through the systematic movement of teams of builders through zones of the building. TAKT was the organising principle for the construction process in both cases studied in this paper. The buildings where divided into a number of zones estimated to imply close to similar amounts of work for the teams of builders.



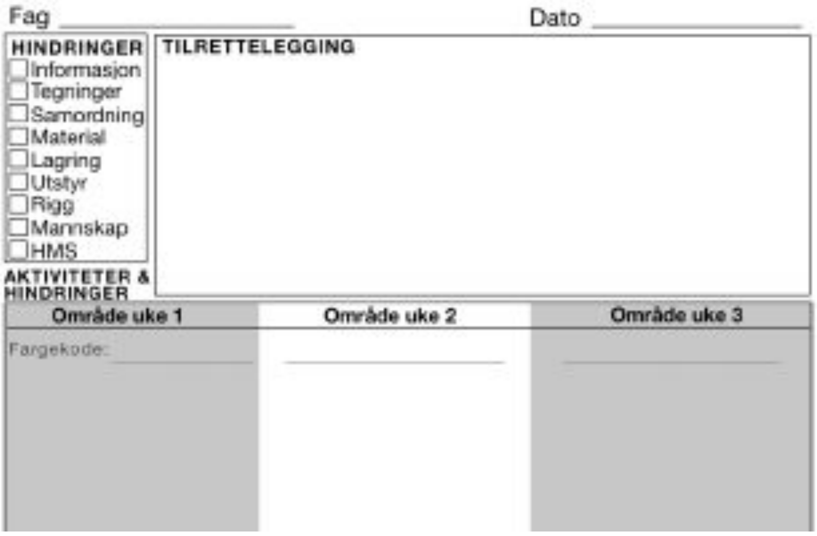
The TAKT plan for case 1, where the building is divided into zones 1-6. Yellow area is built outside TAKT and the hatched areas are buffer zones.

In both cases, the zones were defined as one week of work. Thus, the teams of builders, called wagons, moved though the building, one after the other like a train using one week in each zone: Typically starting which carpenters, followed by plumbers, electricians, more carpenters, etc. The important point which allows for the team-leader walk, is that the building is divided into specific zones which each team/wagon will move through according to a defined route. The idea it that when working within the TAKT production, the systematic movement through the different zones, movement in space becomes like movement in time, allowing the situation coming up three weeks ahead to manifest ‘here and now’, as they walk into that particular zone. Thus, the walk uses a possibility produced by the particular structure of the production front is given in TAKT organisation.

As the team-leaders walk through the building, they follow the same route as when constructing. Thus, if a team leader starts the walk in the zone he or she is presently working in, the team-leader will first walk into the next zone where he or she shall work next week, after that, the team-leader will walk into the zone he or she will be working in two weeks ahead, the final zone to walk through is the one laying three weeks ahead. As the group of team-leaders walk together, they are given opportunity to discuss plans and problems that will arise in one, two and three weeks ahead.

As the team leaders normally work in different wagons, following each other, the zone where one team, e.g. carpenters, works one week, will be the zone the next team, e.g. electricians, will work the week after. By walking together though this particular zone, they are given opportunity to discuss how the next team would prefer various details to be preserved when taking over the zone from the previous team; for example, the electrician requests from the carpenter in the wagon ahead that he would like to have a certain amount of space in a certain wall to ease his work with cabling. At the team-leader walk, it is possible to discuss this before the carpenters start putting up that particular wall.

In order to structure the discussions at the walk, the professions representing the wagons of week 1, 2 and 3 would take turns presenting status, particular needs and concerns in the interdisciplinary junctions with the other wagons. Also, they would discuss particular concerns and uncertainties regarding deliveries, solutions. A dedicated form vas developed in order to accommodate the note-taking during the walk, the form was printed as a note-book:



Fag ______________ Dato ______________

HINDRINGER
- Informasjon
- Tegninger
- Samordning
- Material
- Lagring
- Utstyr
- Rigg
- Mannskap
- HMS

TILRETTELEGGING

AKTIVITETER & HINDRINGER

Område uke 1	Område uke 2	Område uke 3
Fargekode:		

The form (designed by Marie Nilsen). The first field on top right is for 'obstacles' (information, drawings, coordination, materials, storing, equipment, rig, staffing, safety). The second field on top is for 'measures taken'. Below is three fields for notes, pointing 1, 2 and 3 weeks ahead. Each field has a place on top to note the colour of the specific control area in question (the control areas are distinguished by different colours).

Ideally, the team leader walk should not take up more time than 30-45 minutes. Issues brought up during the walk should be brought to the following team-leader meeting (using the above form), where also the foreman and operation manager is present, making this meeting more able to actually solve issues laying two-three weeks ahead.

EXPERIENCES WITH THE TEAM-LEADER WALK

The first experiment with the team-leader walk was with case one, a hospital building specialised for psychiatric patients. The building is approximately 27 000 m^2, with a budget of €19 million. The construction process was organised according to principles of Lean construction and Last planner, using VDC. The building was organised in control zones where production was organised according to TAKT. The wagons of the construction train consisted of 1) carpenters, 2) technical, 3) carpenters, 4) painters, 5) ventilation, 6) carpenters, 7) technical, 8) carpenters. The building started in 2017 and was already running as the researchers came in. The implementation of the team-leader walk happened at time when walls and roof was up, but the interior work remained. Thus, the professions being most active in these team-leader walks was carpenters and technical installers (electro and locksmiths). The main focus was on the collaboration between these three team-leaders.

In this project, the TAKT organisation run into trouble due to delays in plans from the design team, and in the deliveries of certain producers, causing the drawings of certain walls and technical systems to be incomplete at the time the first wagons of the TAKT train arrived at the control zone. For example, the solutions to the roofs of certain hallways and the exact location of certain plumbs were not decided, also the builders had to wait several months for the right kinds of doors to arrive. Having to leave these elements for later when moving ahead according to the TAKT plan, the train soon lost its logistic rail and an increasing number of builders started to move back and forth in the building in order to fix things they had have to leave for later. Eventually the whole TAKT system was given up, causing also the team-leader walk to be given up. As such, the experiment had to be determined prematurely. Observations and interviews with the involved team-leaders, however, still indicated that this approach had helped them see ahead in the building process, even though their vision had been blurred by the lack of stringent movement in time and space. In particular we observed how the team-leaders managed to detect certain details such as the positioning of wholes for wires for electric door locks, by discussing the issue while standing by the doors in question. This way the locksmith was able to plan two weeks ahead, saving time and work, by making sure the carpenters enhanced optimal positioning for the wires the very first time. But in this particular project the future proved to be quite unpredictable. We should note that the builders managed to finish the project relatively on time, despite the loss of TAKT.

The second case is an indoor sports arena, which also is intended used as concert hall, housing 12 000 people. Part of the arena is an office building, which is a redesigned and extended part of an already existing building. The office building is constructed using TAKT production. The budget is approximately €4,5 million, implying a TAKT team of 15 builders from various professions.

In this case, the team-leader walk was introduced earlier in the project compared to case one. The walk was conducted Fridays, while the team-leader meeting was held the following Monday, with the operations- and construction meeting the following days. Following the team-leaders at six walks though out the constriction process. The walk gathered team-leaders from carpenters, painters, plumbing and ventilation. Again, the walk proved fruitful as a medium for team-leaders to recognise and discuss coordination of details the different professions were interdependent of.

As in case one, the TAKT production encountered problems also in case two. Particularly the carpenters had increasing problems keeping up the planned pace of production, keeping the train on track. There were many reasons for these problems: One being an initial understaffing of carpenters when laying the TAKT plan. Another was delayed decisions from the project owner, causing essential aspects of the building (such as the façade solutions) to be unsettled long after the TAKT train had started. Also, the ground work outside the building had been given priority, causing problems for the right-on-time deliveries as the most useful accesses to the building site was closed in periods. Finally, there where exhibition arrangements in parts of the building during production, interrupting the logistic of production. In sum, these interruptions caused severe problems for the TAKT production. After a couple of months, the TAKT production was given up. At this point, in June 2918, the team-leader walk was well established. Despite giving up TAKT the team-leaders decided to go on with the team-leader walk (the decision was made without input from the researchers). In contrast to case one, it was here possible to keep up the walk as the production was still space-based (Kenely and Seppänen 2009) and moved systematically though defined zones, though not according to the strict procedures and timing of TAKT.

During the walks the team leader for carpenters tended to take lead and initiated most activities. This is natural as the carpenters represented the constructing company and played a role in providing for the other disciplines. The carpenter team leader used his own note book in addition to the dedicated forms. Team leaders from the other disciplines did not take notes regularly. The team leaders tended not to use drawings or BIM during the walk (with a few exceptions). This was used more regularly during the team leader meetings.

Discussion during the walk tended to be very place specific, ant the team leaders pointed to the walls, joints and installations in question. They even painted marks straight on the walls to indicate where certain installations should be. All disciplines at the site were involved in discussions.

Issues form the team leader walk was brought back to the team-leader meeting the following Mondays, but not all that had been discussed during the walk was taken up. One of the team-leaders commented: ‘The team-leader walk was useful; a lot of things were solved right there.” Based on our observations of both walks and meetings, it seems that the majority of issues were solved at the walk directly, freeing up time in the meeting. In general, the kind of issues which tended to be solved was connected to coordination between the teams. The most common topics was:

- Details about storing materials and equipment: For example, the team leader for ventilation installers said that they would have a rather large pile of pipes coming in next Friday, and discussed with the carpenter and the electrician where to store it in order for it to be out of the way for their work, while still being accessible for his team.
- Details about location of pipes, electrical installations, timber frames and rails.
- Details regarding dimensions of walls, fittings and holes.
- Misunderstandings that had occurred during team leader meetings and other planning activities which were discovered during the walk.

The kinds of issues *not* being solved at the walks, tended to be related to decisions outside the jurisdiction of the team-leaders and the team-leader meeting. For example, mayor deviations from the model they saw the need for, but which involved decisions calling for management or architects. Also, issues regarding staffing is included in this category. During the walks, certain issues also came up which could not be solved in a satisfying way, even if it was brought to the team leader meeting and ‘up in the system’. Such issues were for example delayed deliverances from component producers, groundwork blocking the way for just in time deliveries, or missing decisions from client. Many of these hindrances was detected during the team leader walk earlier than they would have been without the walk. As such, actions were taken earlier, but as they could not be solved in time, they also created frustration (and eventually contributed to the break-down of TAKT production).

DISCUSSION

Observations of the team-leader walks indicate that it helped the team-leaders to see further ahead when planning and coordinating their work. The follow-up interviews confirmed this observation. However, the team leader from the carpenters found the walk to be more useful than the team-leaders from the technical professions. A reason for this difference may be that the technical team-leaders work for sub-contractors, while the carpenter team-leader represent the contracting entrepreneur, thus having the mayor responsibility for coordinating the work on the site. Also by the very nature of their work (building the walls and roofs holding the technical installations), the carpenters played a greater role in accommodating for the other disciplines. The carpenter team-leader also was the one who took reasonability for organising the walks.

While all team-leaders was positive regarding the effect of the walk, they also voiced concerns for the time-use caused by the walk. The technical team-leaders, were significantly more concerned than the team-leader from the carpenters. This difference can be explained by the different roles they had: The carpenter was dedicated to team-leading, spending all his time managing the team of carpenters. The technical team-leaders on the other hand also took active part in the production, as their teams only consisted of 3-5 professionals. Thus, less time could be dedicated to leader tasks.

Further, the experiments with the team-leader walk raised issues pointing to other aspects of the way the construction process was organised, in particular regarding the link between the team-leader level and the higher levels in the project. Enhancing the team-leaders ability to see and plan in more detail three weeks ahead, reviled the importance for the team-leaders to be able to discuss issues laying three weeks ahead with the higher levels. Here we saw a weakness in the production system which it wold be beneficial to address.

The need to discuss issues with management should be seen in connection with the Last Planner-like practice of Involved Planning. Involvement of builders did not only concern making the TAKT-plan. The involvement in planning also continued during the production. TAKT as a production system did not run like an autonomous machine. The 'machine' of TAKT needs continuous planning, adjustment and modification in order to be shielded from the irregularities of the outer world and run smoothly (Fyhn and Søraa 2017). This continuous planning calls for good routines allowing the levels of planners to work together. Here we see that the team leader walk can contribute, and the contribution may be enhanced by improving the communication between team-leader level and the higher levels (e.g. from team-leader meeting to operation meeting).

Considered as a *communication tool*, the team-leader walk, using the building itself as such tool, holds certain qualities other communication tools does not hold, qualities giving it potential to improve the construction process. The building is at any time the most updated version of the construction-process, thus ensuring the discussion and planning to be accurate and up to date. The building site also seems to appeal to an embodied understanding of time, space and tasks, as the team leaders actually walk through the actual space which represent their own status in 1-3 weeks. The physical nature of the building also seems to appeal to practical and embodied thinking over the more abstract thinking associated with representational engineering models. As such, it fits better into the cognitive expertise of many team-leaders, which are craftspeople, not engineers.

A possible down side of this communication tool is that one has to leave the meeting room (a room specially set up to enhance talking and planning) in order to use it. The actual building site tends to be a place filled with noise, dust and danger. Also, it is less ideal for combining with drawings and BIM, even though these tools are possible to use at the site. One reason why these tools was not used so much may be because the carpenters tended to rely on drawing, while the technical team leaders tended to rely on BIM directly.

Understood as communication tool, the team-leader walk should be considered in relation to BIM, drawings and other communication tools in use. A hypothesis for further studies is that a more systematic use of these tools, in particular BIM on a pad, could make the walk even more productive.

CONCLUSION

Experiences with the team-leader walk from two case studies indicate that it is a useful supplement to the team-leader meeting in TAKT and space-based construction processes. By appealing to the practical expertise of team-leaders, and giving the planned progression in time a spatial expression, it helps the team-leaders to better look ahead in their interdisciplinary planning and coordination of activities. The fact that the team-leaders decided to continue the walks, even without TAKT production indicates that the team-leader walk can be more robust than the TAKT production itself.

The walk is useful to give inputs to the team-leader meeting, and for sorting out coordination issues during the walk. A question for further research is how to integrate the team-leader walk in the established meeting structure enhancing the contribution of team-leaders in the planning. Another question worth pursuing is the combination of team leader walk and other communication tools.

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STREAM 21: THINKING ABOUT BATCHES AND FLOW

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SUPPLY CHAIN RHYTHM: MULTIDISCIPLINARY TEAMS THROUGH COLLABORATIVE WORK STRUCTURING

Rafaella D. Broft[150] and Stephen Pryke[151]

ABSTRACT

Collaborative work structuring methods are increasingly used in the construction industry to support project teams on delivering their projects on time, within budget and with high quality. By breaking down the work to be done in so-called manageable chunks, work structuring plays an important role in the creation of flow.

The optimisation of flow is important due to the fragmented nature of the industry. Despite successful examples of the application of these methods, it is believed that the advantages remain limited to achieving better project results. Where current examples organise working packages around the work of different trades, this paper explores the consequences of a more supply chain-driven approach to collaborative work structuring. It challenges trades to design a "Supply Chain Rhythm". The results presented in this paper show additional advantages, where multidisciplinary teams have been created within a project. This way, the configuration of the crew performing the work chunk exceeds the boundaries of organisations or trades, and leads to further optimisation of the work flow.

KEYWORDS

Production system design, work structuring, collaboration, multidisciplinary teams, supply chain rhythm.

INTRODUCTION

Planning tools are increasingly used in the construction industry to support project teams on delivering their projects on time, within budget and with high quality. These tools relate to production system design and specifically to work structuring, and can be interlinked with other lean concepts, such as standardisation, continuous flow and predictability. They are considered transparent and more collaborative than most traditional methods used in the management of projects.

Work structuring is considered important in optimising work flow. It breaks down the work to be done in so-called chunks – where work structuring methods used to focus on

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the activity, more and more work structuring methods, such as Line of Balance, Flowline and planning with the use of a ‘Takt’ (Takt is a design parameter used for production in manufacturing), consider the location or location units as leading.

Alignment of the different activities (within the different units) of a construction process and the creation of flow seem important because of the fragmented nature of the industry. Despite successful examples of the application of these methods, it is believed that the advantages remain limited to achieving better project results. Currently, in order to minimise the costs of each sub process, focus exists on the efficiency of every supplier’s process and competitive pricing (Broft & Koskela, 2018). Or in other words, every organisation or trade tends to focus on the efficiency of their own sub-process, leading to more specialised tasks and subsequently, prefabrication or off-site production as part of these tasks. In current examples of collaborative work structuring work packages are created around the (efficient) work of different trades.

This paper explores the consequences of a more supply chain-driven approach to collaborative work structuring. It describes an intervention, referred to as the design of a “Supply Chain Rhythm”, that is collaboratively created with the members of a construction supply chain and applied to a first project.

The paper starts by describing the research context and by providing the reader with a short theoretical background. Hereafter, the intervention, the case study and the results are presented.

RESEARCH CONTEXT

As part of a long-term expert programme on SCM in construction, suppliers have been carefully selected for executing work for a particular type of projects. In other words, and in this particular case, all housing projects within the main contractor’s portfolio are pursued with the same team of organisations.

The overall aim of the programme is to improve collaboration and subsequently, the competitive position of the construction supply chain gradually with every project. At this point of time, all members involved are aware of basic lean principles, project-oriented tools and driven to explore more opportunities for improving processes. This paper focuses on one of the interventions within the programme, aiming for the design of a collaborative production system with the help of a “Supply Chain Rhythm”. This research is also part of a PhD research.

THEORETICAL BACKGROUND

PRODUCTION SYSTEM DESIGN

Production system design (PSD) is one of three core activities – design, operation and improvement – of production management (Koskela & Ballard, 2003). Alternatives of production organisation are studied in order to select the most appropriate strategy for achieving the desired results (Meredith & Shafer, 2009), for both designing and making products. This intended production strategy needs to be translated into a set of decisions, which define the structure for managing the different activities and create appropriate conditions for control and improvement (Schramm et al., 2006). Askin and Goldberg (2002) state that PSD involves managing production resources in order to meet customer demands.

PRODUCTION SYSTEM DESIGN IN CONSTRUCTION

In construction, main contractors are contractually responsible for the construction of projects, but following from the high percentage of subcontracting, they rely on suppliers to execute the works (Clarke & Herrmann, 2004). Main contractors are involved to organise and coordinate operations (Akintan & Morledge, 2013) and subsequently, have a central position in managing construction (Broft & Pryke, 2016). Besides site production, this includes a focus on managing the organisations or trades that deliver or produce services/materials on-site, or in other words, managing production.

In operational terms, the aim is to create favourable conditions for a highly performing production system by devising the construction layout, and material and information flows (Schramm et al., 2006). For a long time, theories regarding production management and production management practices as known in the 'highly productive and fast operating' repetitive manufacturing – high technological standards, rapidly changing demands and intense (global) competition have pressed these industries to manage processes throughout the supply chain in an effective and efficient way (Cagliano et al., 2006) – have been, both successfully or unsuccessfully, transferred to construction.

PSD is believed to be important for achieving the most important project goals, while it also represents the most basic form and opportunity for minimising the effect of variability on production (Ballard et al. 2001). According to Koskela (2000), the design of production systems has three main goals in construction: 1) deliver the project, 2) maximise value, and 3) minimise waste. PSD should take place before the execution phase in order to provide the project team with an overview of alternatives for production organisation including consequences for budget, time, and workflow (Biotto et al., 2017). It reaches from global organisation to the specific design of operations, i.e., from decisions regarding who is to be involved in what roles to decisions regarding how the physical work will be accomplished. One of the PSD outputs is a master plan that will be used once operation of the system starts (Schramm et al. 2004), also referred to as phase scheduling. Phase scheduling is a design activity used to structure each project phase and to produce a collaborative plan for completing it (Ballard et al., 2001). With this, the project team will be able to adapt the production system in case of any variabilities or uncertainties, minimising effects on production (Biotto et al., 2017). Work structuring is then used to break down phase activities into specific processes and operations, and to define the hand-offs between trades, crews of sequential activities and the different project phases.

WORK STRUCTURING

While production system design focuses on the set of strategic decisions on a project's viability, budget and lead time, phase scheduling focuses on a clear definition of phase activities and its lead times, and work structuring on breaking down the work to be done in work chunks, hand-offs and production units, and the creation of flow (Biotto et al., 2017).

The three important concepts in work structuring (Tsao, 2005) include:

- Production unit – “a group of production workers that do or share responsibility for similar work, drawing on the same skills and techniques”;
- Work chunk – “a unit of work that can be handed off from one production unit to the next”;
- Hand-off – “the combined (1) completion of a work chunk by a production unit that allows a subsequent production unit to further transform the work chunk or execute a different work chunk as planned, (2) declaration of completion of the work chunk by the production unit and release to the subsequent production unit, and (3) acceptance of the released work by the subsequent production unit”.

In other words, work structuring breaks down both the product and the process into parts, sequences and assignments to realise (improvement of the) work flow, by reducing variability and waste, while increasing the value (Ballard, 1999). These so-called work chunks become more manageable. Each chunk includes work of a certain scope that will be performed by a crew of a certain configuration (number of crew members with their individual and combined skills), using certain means and methods (Tommelein, 2017).

WORK STRUCTURING METHODS

Different types of work structuring methods exist. Some of these are activity based planning tools, such as the Critical Path Method and PERT, whereas others are location based planning tools, such as Line of Balance, Flowline and planning with the use of a ‘Takt’. The latter have originally been developed in manufacturing and adapted for construction by changing the vertical axis unit: location or zones instead of units produced (Kenley & Seppänen 2010). This is a result of the differences that exist between the industries as in construction the work stations, or resources, move through the product to be delivered (Broft & Koskela, 2018).

INTERVENTION

Work structuring is considered important in optimising work flow and therefore, considered a relevant step for growth in supply chain maturity (Broft et al., 2016), which is the overall aim of the expert programme. This paper describes an intervention, referred to as the design of a “Supply Chain Rhythm”, that is case-specific and practice-based, created by the researcher in collaboration with different stakeholders involved in the project team. An additional drive for the supply chain to engage in this intervention was the limited availability of worker capacity, which is a result of the growing market. It was believed that optimisation could solve this extra problem.

SUPPLY CHAIN RHYTHM

In production management, ‘Takt’ refers to the regularity with which something gets done. It 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)” (Hopp & Spearman, 2011, pp. 467-468), or in other words: Takt time = available net working time / customer demand in that time. Rhythm is defined as “a strong, regular repeated pattern of movement or sound” or “a regularly recurring sequence of events or processes” (Oxford dictionary, 2019). In music, rhythm refers to the variety of tones of different duration. It is a repetition of something equivalent within comparable units (Müller & Enskat, 1973), so-called rhythmic units. A rhythmic unit is a durational pattern (where its duration is related to its tempo) that synchronises with a pulse or Takt (Winold, 1975).

A rhythm thus encompasses Takt, a regularity of its content and a distrubition of its time. In construction, the objective of takt planning has been to provide a balanced work flow for trades (Frandson & Tommelein, 2016) to increase productivity and shorten the overall lead time (Heinonen & Seppänen, 2016). Supply chain rhythm goes beyond existing patterns of individual organisations or trades and refers to collaboratively composed patterns: "…*all use the ability of rhythm to unite human individuals into a shared collective identity where group members put the interests of the group above their individual interests and safety*…" (Jordania, 2011). The difference made in this paper exists to indicate a certain freedom, within a regularity, providing a supply chain with freedom to adapt its work content, to move work within work packages and to allow changes in tasks, within a set time frame. A rhythm is believed to invite movement. "Once one becomes consequent in its rhythm, one can start working on the speed."

CASE STUDY DESCRIPTION

The project team comprises suppliers with a long-term collaboration (which means all of them had previously worked together on other projects for the same main contractor) around the construction of houses in the Netherlands.

The case study that was selected for this specific research comprises a total of 21 houses – two blocks that are part of a bigger project (Figure 1). Together with representatives of all the organisations involved (five organisations representing six trades), one of the authors had focused on the design of an alternative production system to deliver this part of the project. The execution, including on- and off-site production, and logistics to site were then based on this PSD.

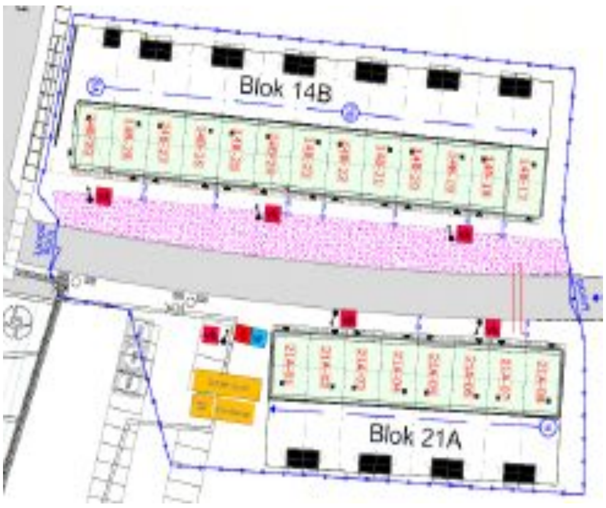

Figure 1: Case study – site plan including the 21 houses.

APPROACH

The intervention aims to explore the consequences of collaborative production system design, and specifically collaborative work structuring that is supply-chain driven. As part of this work structuring process different sessions were organised. The first question involved: At what speed should the 'production line' progress? Or in other words, what is the duration of a rhythmic unit? Previous measurements provided the supply chain with information on how to choose an appropriate speed. Based on this information and some further research, the five organisations involved decided on this speed/duration and the 'Takt' (which includes information on the boundary of zones). The content – work sequence, packaging of the tasks and the different hand-offs – was established during next sessions, first more generally using a template, then applied specifically to this first project.

This 'rhythm', including a detailed plan for the project, was the starting point for all the preparations necessary for successful execution, i.e. logistics based on the agreed zones, adapted coordination of all material suppliers and the careful involvement of site members. All work had to be done with restricted site access. Because of this an hourly plan for the logistics had to be added to avoid stagnation of deliveries. At the start of the project a kick-off was organised on-site to be sure to include all site members and provide them with the basic information. Daily and weekly stands were organised to monitor the process.

As part of the research, structured interviews were held with all the members on-site, before and after implemention of the changes. Moreover, direct observations were registered of all the activities being executed on-site. To increase the involvement of all workers on-site, recommendations for improvement were collected.

RESULTS & ANALYSIS

Every organisation has established a standard process for executing work on housing projects. This work involves a similar content and sequence from project to project. The results presented here show the changes in the overall sequence of the work – following from the new work structure, this has changed from horizontal to diagonal production (Figure 2a), which is a direct result of the location-based focus where the aim had been set to deliver one zone per a set amount of hours. Besides advantages in lead time – a reduction of 12 days (38 instead of 50 working days) – site members have mentioned other advantages, such as less inventory waiting for the next activity, the efficient use of the same crane, an increased reliability of planned work and people taking better account of others. These advantages have been classified: some can be related to collaborative work structuring in general, others seem specific to the intervention (as will be pointed out later).

All the activities per member have been registered providing the team with detailed information on work packages and work sequence, including a total of activities and hours per zone (Figure 2b). After analysis, differences between what had been originally planned versus realised through the collaborative work structuring method – a percentage of 51% had been achieved – became visible, giving input for re-design of the production system for future projects.

Moreover, the exact configuration of the project crew in a situation following the intervention, presented as the case, could be analysed through time.

Figure 2a: Impression of site activities. 2b: Impression of the registration of activities.

The results presented in Table 1 show that in a 'situation-as-is' usually 15 members from five different organisations, representing six different disciplines or trades, show up on-site. During the sessions, the team established to involve 13 members organised in three consecutive teams, whereas, during execution, this amount reduced further to 11 members (this change is shown with the two numbers presented in the third column).

Table 1: Structure of teams

Organisation	# Members on-site (Usually)	# Members on-site (Case study)	Team
Organisation A	5	4 4	I
Organisation B	2	2 1	I
Organisation C	2	2 2	II
	2	1 1	II
Organisation D	2	2 2	III
Organisation X	2	2 1	III

Team I include 5 members from organisation A and B, team II includes 3 members from two different departments of organisation C, and team III includes 3 members of organisation D and X. This way, three multidisciplinary teams have been created, all encompassing at least two trades. The activity registration shows the amount of times that members supported each other on tasks and/or took over tasks from each other – members from organisation A and B have both supported each other, one department of organisation C has supported the other department, and organisation D has supported organisation X with their tasks. This seems to be a result of the increasing 'interdependency' which some have mentioned to have increased.

With the interviews, all site members involved had a chance to express their thoughts and ideas. More than 100 recommendations for improvement have been collected, of which some have been incorporated directly for the zones or houses still to be built. The collaboration on site had been valued by most members by a '+' with the reason that the atmosphere on site is pleasant and good. A few of them have been critical stating that there is still room for improvement, i.e. "Not everyone seems to be used to this way of building. Some remain stuck on their little island, while a bit more collaboration is needed".

CONCLUSIONS

Different (successful) applications of work structuring methods have been described before. Despite successful examples of the application of these methods, it was believed that the advantages remain limited to achieving better project results. Where current examples organise working packages around the work of different trades, this paper has explored the consequences of a more supply chain-driven approach to collaborative work structuring. It challenges trades to design a "Supply Chain Rhythm". The results presented in this paper show additional advantages, where multidisciplinary teams have been created within a project. This way, the configuration of the crew performing the work chunk exceeds the boundaries of organisations or trades, moving away from further specialisation and fragmentation, and shows a possible step in further optimisation of the work flow. Not just by combining steps into working packages, but by transferring tasks to other organisations. Instead of a "Parade of Trades" (Tommelein et al., 1999) a "Parade of Teams" is created – moving through space with one team following the other in sequence, all marching to a drum beat, and – ideally – with no variability.

The results presented here are limited to one project and therefore, case-specific. Further research is being done on practical validity and generalisability – in other words, further evaluation based on different type of projects, and design loops need to be done. As mentioned before, the results of this paper are part of a PhD research.

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FLOW IN TAKTED PROJECTS – A PRACTICAL ANALYSIS OF FLOW AND RESOURCE EFFICIENCY

Marco Binninger[1], Janosch Dlouhy[2], and Shervin Haghsheno[3]

ABSTRACT

In recent years, the methods of Takt Planning and Takt Control (TPTC) have gained significance in construction practice. The foundations for takted construction practices as well as the methods of Takt Planning and Takt Control have been described in numerous papers within the framework of the IGLC (Binninger u. a. 2017a; Frandson u. a. 2013; Frandson und Tommelein 2016; Haghsheno u. a. 2016; Heinonen und Seppänen 2016; Tommelein 2017). One of the primary goals of the methods is to create flow, allowing construction processes to be executed efficiently.

In order to investigate the relationship between the methods TPTC and flow in takted construction projects, the issues of how flow is implemented in takted projects during Takt Planning and Takt Control as well as how this affects project participants were discussed.

The foundations of the flow production principle were then outlined and an assessment method for determining the quality of flow was devised. The applied approach was based on the book "This is Lean" by Modig und Åhlström (2015). Hereby, workflows were measured from two perspectives and compared using an efficiency matrix.

Data from practice in the form of takt plans from 40 takted projects were analyzed and empirically assessed.

To date, an assessment of takted projects in relation to workflow has not been completed in any academic study. This paper provides a foundation for further research and sets a standard for assessment of flow in takted projects in real-life practice. This research serves as a pilot study in this field and invites further detailed studies of the characteristics of flow to be conducted in the future.

KEYWORDS

Flow, flow efficiency, takt, TPTS

INTRODUCTION

In recent years, the methods of Takt Planning and Takt Control (TPTC) have gained significance in construction practice. One of the primary goals of these methods is to

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create flow, allowing construction processes to be executed efficiently. Flow is one of the basic principles of Lean Management.

Research into takted projects in relation to workflow has not been conducted in any academic study to date. This research attempts to explore the effects of flow in takted construction projects. The results can be seen as a status quo of flow in takted projects and the findings can be used to improve the effectiveness of Takt Planning in further projects.

The paper is divided into three main chapters. The section Theory of Flow outlines the theoretical foundations of flow as a production principle and shows various flow perspectives from participants of the system.

Building on this, an assessment method was created as a basis for empirical analysis of data from industry practice and described in the chapter Methodology. This chapter will answer the question of how flow can be measured and evaluated in takted projects.

Using an efficiency matrix, the assessment of 40 projects shows the quality of flow before and after execution of construction projects. In the final section, Analysis of Practical Cases, results are interpreted and their effect on the various roles in the construction process are discussed.

RESEARCH QUESTION

The aim of this paper is to identify characteristics of flow quality and its effect on takted projects. To this end, the paper aims to answer the following research question:

- How well can flow in takted production be planned and controlled?

APPROACH

The content of the paper is based on a literature review of flow and takt in construction. An evaluation system to measure the effectiveness of flow in takted projects was created. The system is based on the theory of the book “This is Lean” from Modig and Åhlström. The new developed measurement system is the base for the analysis of 40 takted projects. The results are shown in an efficiency matrix and discussed by the authors and their practical experience.

THEORY OF FLOW – A LITERATURE REVIEW

Historically, the production line and flow have played critical roles in industrial mass production. Ford recognized the potential of flow (see Womack und Jones 2003, p.22) and implemented the principle in his production line. As the Toyota Production System (TPS) is fundamentally based on mass production, flow is one of the main elements in its design. Womack und Jones (2003) also classified flow as one of the five principles of Lean Management.

The goal of the principle of flow is to arrange all the necessary activities for the creation of a product into a consistent and continuous sequence without queues, interruptions and wasted effort (see Womack und Jones 2003, p.52). The result is the development of routine and increased efficiency. For this reason flow also plays a critical role in the construction industry. Koskela (1992) also describes the significance of flow in his Transformation-Flow-Value (TFV) Model.

FLOW PERSPECTIVES

According to Shingo und Dillon (1989, p.4), the processes of stationary production can be considered from two perspectives. Figure 1 shows the structure of a production site. The horizontal axis shows the product perspective from raw material to a completed product ready for the customer. The second perspective describes a product from an operational perspective, in this case of a worker or of a work station (see Shingo und Dillon 1989, p.4 f).

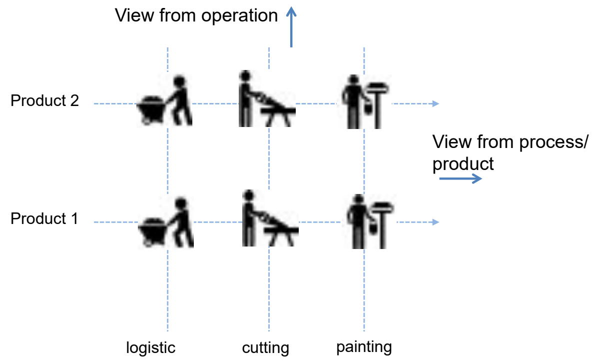

Figure 48: Structure of stationary production (in reference to Shingo und Dillon 1989, p.4)

If this structure is to be applied to construction sites, its underlying conditions and distinct features must be examined. In the construction industry, it is not the product but rather the worker who must move in flow through a construction site (see Nezval 1960, p.31). Friedrich et al. (see 2013, p.46) describe this phenomenon with the terms 'subject' and 'object'. As opposed to stationary production, the value creators (subject) in the construction industry flow through the stationary product (object). Koskela (see 2000 pp. 52-54) reinforces the theory of flow. Sacks et al. (see 2016, p.651) further develop this approach. In this paper, flow from a production perspective is defined as 'location flow', while flow from an operational perspective is defined as 'trade flow'. A perspective of a wider portfolio as per Sacks is defined with the cross-project term 'flow'. Due to the focus on individual projects in the construction sector, the portfolio flow approach was not considered in this paper.

PROPERTIES OF FLOW

Nezval describes flow quality based on the three characteristics: rhythm, consistency and continuity (see 1960, p.35). **Coninuity** is characterized by constant fulfillment in relation to the horizontal time axis. Where flow has perfect Continuity, there are no time gaps.

Rhythm is also a time-related characteristic (see Nezval 1960, p.35). More specifically, Neval describes rhythmic work as a work that "…repeats itself after a precise time interval and takes the same amount of time each time it is repeated" (Nezval 1960, p.35).

The definition of **consistency,** according to Nezval, is primarily from the specific perspective of labor. In this context, it states, "… that individual workers or workforces with the same makeup will provide the same amount of work when repeating the same tasks with the same amount of time available. Hereby they require the same amount of raw materials and operate machinery, transport equipment etc. in a uniform way"

(Nezval 1960, p.35). This suggests that the workload (production volume) of a work package is consistent across various takt times. Specifically, consistency describes the volume of production (Nezval 1960, p.35) of a work package in relation to time. Nezval does not provide a definition or precise description of this parameter.

The three characteristics can be shown as per the following diagrams (figure 2).

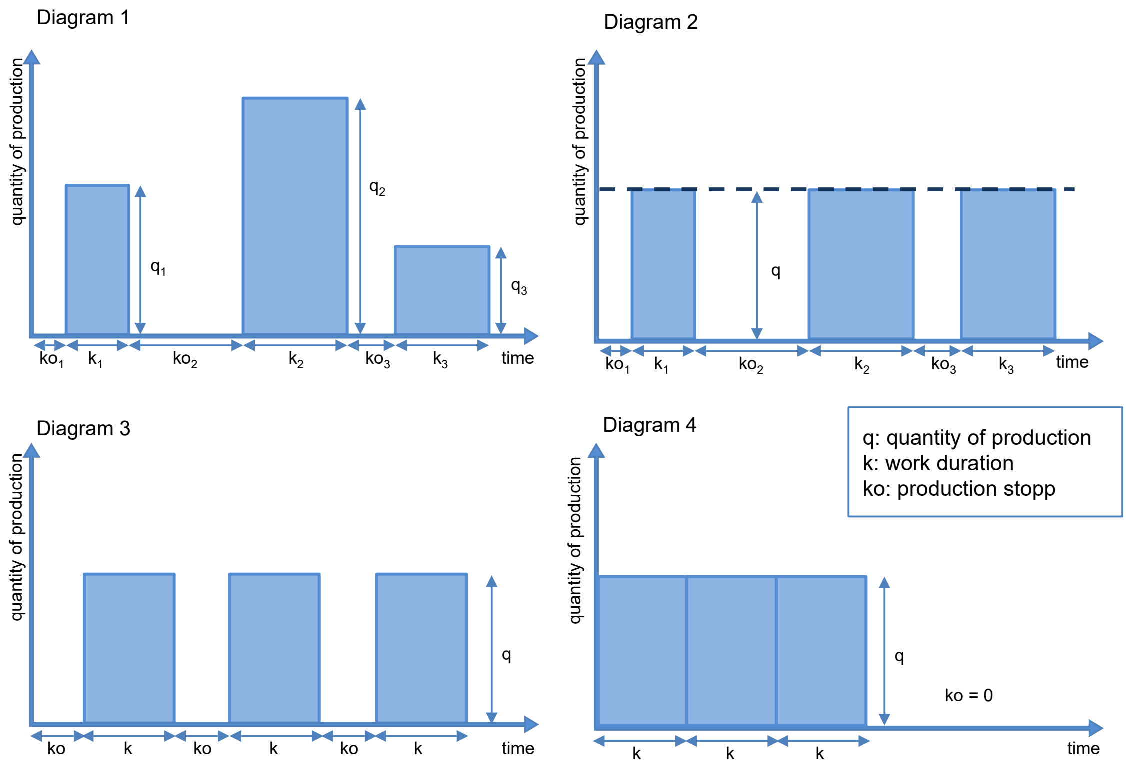

Figure 49: The characteristics of rhythm, consistency and continuity (in reference to Nezval 1960, p.36 f)

Figure 2 shows four diagrams. The X-axes show the volume of production of the work described. The Y-axes show time with working time expressed as ‘k’ and interruptions expressed as ‘ko’. Diagram 1 shows the baseline situation without accounting for the effects of the characteristics. The volume of production q_x is variable. The durations k_x and ko_x are also subject to variation. Diagram 2 shows a leveled volume of production q. The division of labor can be described as consistent. Diagram 3 adds constant time intervals k and ko. The work, thereby, has both rhythm and consistency. In the case of continuous production, interruptions to working time are eliminated (ko=0). Therefore, diagram 4 shows consistency, rhythm and continuity (see Nezval 1960, p.35 ff).

Continuity as a Key Property

In takted systems following the method of TPTC (Binninger et al. 2017a), the SSU approach allows consistency through dividing work into takt areas. In each takt time a uniform unit of work is carried out. Takt creates the rhythm of the system. Every unit of work starts at the beginning of a takt time and the units are defined, in the takt plan, to have a duration of one takt. Thereby, the characteristics of rhythm and consistency, as defined in this paper, are both covered in takted construction production and their criteria can be seen as having been met. Therefore, the characteristic of continuity was selected for assessing flow in takted projects.

MODIG AND ÅHLSTRÖM´S EFFICIENCY MATRIX

In their book "This is Lean" Modig and Åhlström focus on the characteristic continuity and describe the relationship between two perspectives. They use the term 'flow' for the product perspective and the term 'resource' for the operational perspective (see Modig und Åhlström 2015, p.24). Modig und Åhlström devised an efficiency coefficient for each perspective. These can be used to compare the value-creating time in comparison to the total time period. This matrix is shown in figure 3.

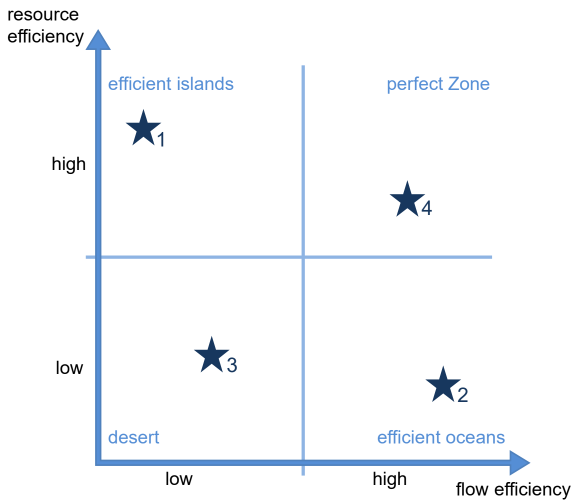

Figure 50: Flow efficiency matrix (Modig und Åhlström 2015)

In practice, the two perspectives often contradict one another. Resource efficiency is a more traditional perspective and more widely used (see Modig und Åhlström 2015, p.7). Here, the focus lies on maximizing the utilization of machines and individual workers. This results in 'islands of efficiency' and the organization can be classified on the left side of the matrix. As a consequence, intermediate storage between different work stations and the throughput time in terms of materials increases substantially. Changes to the production sequence such as disruptions or variations in the number of orders received have a negative effect on both coefficients (see Modig und Åhlström 2015, p.119).

Modig und Åhlström's terms of 'flow efficiency' and 'resource efficiency' are not appropriate to the construction industry as it is not the product that moves, but rather the resource. In this paper flow efficiency is only discussed in general terms and is only considered from the perspectives of 'location flow' and 'trade flow'.

METHODOLOGY

The following chapter answers the questions of how flow can be integrated into takted projects and how can it be measured.

TPTC AND THE TAKTPLAN

Flow in takted projects was investigated. The takted projects are based on the method Takt Planning and Takt Control (TPTC) as per Binninger et al. (2017a). This method is not discussed further in this paper, as only the result – the takt plan – is significant for the work under consideration.

The paper "Adjustment Mechanisms for Demand-Oriented Optimization in Takt Planning and Takt Control" (Binninger et al. 2017b) suggests that the execution of takt plans often does not go as planned due to outside influences during construction. The figure below demonstrates the impact of such influences on the takt plan.

Figure 51: Comparison of planned vs. actual takt plans

FLOW PERSPECTIVES IN THE TAKT PLAN

Both perspectives for considering flow can be seen in the takt plan.

The location perspective considers workflow with regards to a spatial unit (takt area) which will later be handed over to the customer. It is shown as a horizontal workflow on the takt plan. This perspective is of high interest to the customer.

The trade perspective considers the workflow in relation to a specific workforce allocated to a specific subcontractor. This is displayed in the vertical direction on the takt plan. Thereby, the work packages (boxes) are summed and shown as a cumulative curve. This perspective is of interest to the subcontractors and workers.

The general contractor considers both perspectives and seeks to harmonize them.

MEASUREMENT OF CONTINUITY IN THE TAKTPLAN

According to Modig und Åhlström (2015) flow efficiency (FE) reflects the relationship between time spent creating value and the total time taken. Applied to a takt plan the filled boxes can be considered value-creating time and the empty boxes can be considered waste in the form of unutilized time. This results in the following formula:

$$FE\,[-] = \frac{filled\ boxes[-]}{filled\ boxes\,[-] + \text{empty boxes}\,[-]}$$

Formel 1: Workflow efficiency of the Takt Plan

For calculating workflow efficiency from the location perspective, the boxes of the takt plan were evaluated across the horizontal axis. For the trade perspective, the takt plan was considered along the vertical axis. In each case this results in a calculated flow efficiency from the trade perspective (FE_{Trade}) and from the location persepctive ($FE_{Location}$). An example for calculating the efficiencies is shown in the figure below.

	TT 1	TT 2	TT 3	TT 4	TT 5	TT 6	TT 7	TT 8	TT 9	TT 10	TT 11	TT 12	TT 13	TT 14	TT 15	TT 16	TT 17	TT 18
TA 1	W1	W2	W3	1	2	W4	3	W5	4	5	6	W6						
TA 2		W1	W2	W3			W4		W5			W6						
TA 3			W1	W2	W3				W4		W5			W6				
TA 4				W1	W2	W3			W4			W5		W6				
TA 5					W1	W2	W3			W4			W5		W6			
TA 6								W1	W2	W3	W4			W5	W6			
TA 7									W1	W2	W3	W4			W5		W6	
TA 8										W1	W2	W3		W4		W5	W6	

1	2	3	4	5	1	2	6	7	8

Figure 52: Example of different flow efficencies for a takt plan

In the example given, takt area 1 has a calculated $FE_{Location}$ of 0.5. This means that value is generated during 50% of the total time.

$$FE_{Location}\,[-] = \frac{filled\ boxes[-]}{filled\ boxes\,[-]+\text{empty boxes}\,[-]} = \frac{6}{6+6} = 0{,}5 = 50\%$$

Formula 2: Location based workflow efficiency of the Takt Plan

The trade marked in dark blue has a FE_{Trade} of 0.8. This means that value is generated during 80% of the time that the subcontractor was on site.

$$FE_{Trade}\,[-] = \frac{filled\ boxes[-]}{filled\ boxes\,[-]+\text{empty boxes}\,[-]} = \frac{8}{8+2} = 0{,}8 = 80\%$$

Formula 3: Trade based workflow efficiency of the Takt Plan

This results in multiple flow efficiency values for trade and takt areas for each project. By calculating a median value per perspective a representative index figure can be determined for each project. This allows comparison of values for the trade and location perspectives in a matrix.

The results were assessed on the normalized level of the Three Level Model (Dlouhy u. a. 2016). Detailed consideration of the content of each box and details of works completed on site is at the micro level and therefore, is not considered in this paper.

ANALYSIS OF PRACTICAL CASES

PROJECT DESCRIPTION

In order to make an assessment of the quality of the practical application of flow in takted projects, the takt plans of 40 projects were evaluated to compare their planned and actual states. All projects were based on a takt time of one week. The projects can be categorized as turnkey construction, encompassing a range from interior fit-outs to apartment buildings and from aged care facilities to offices.

RESULTS

The average flow efficiency of the 40 selected projects are shown in an efficiency matrix based on Modig and Åhlström (2015). The flow efficiency from the location perspective is shown on the X-Axis while flow efficiency from the trade perspective is shown on the Y-Axis. Each project is shown as a data point on the matrix. The result is plotted in figure 6. Red data points show the results as projected by the takt plans while the blue data points show the actual status at the end of each project. The darker colored point in each color reflects the average values.

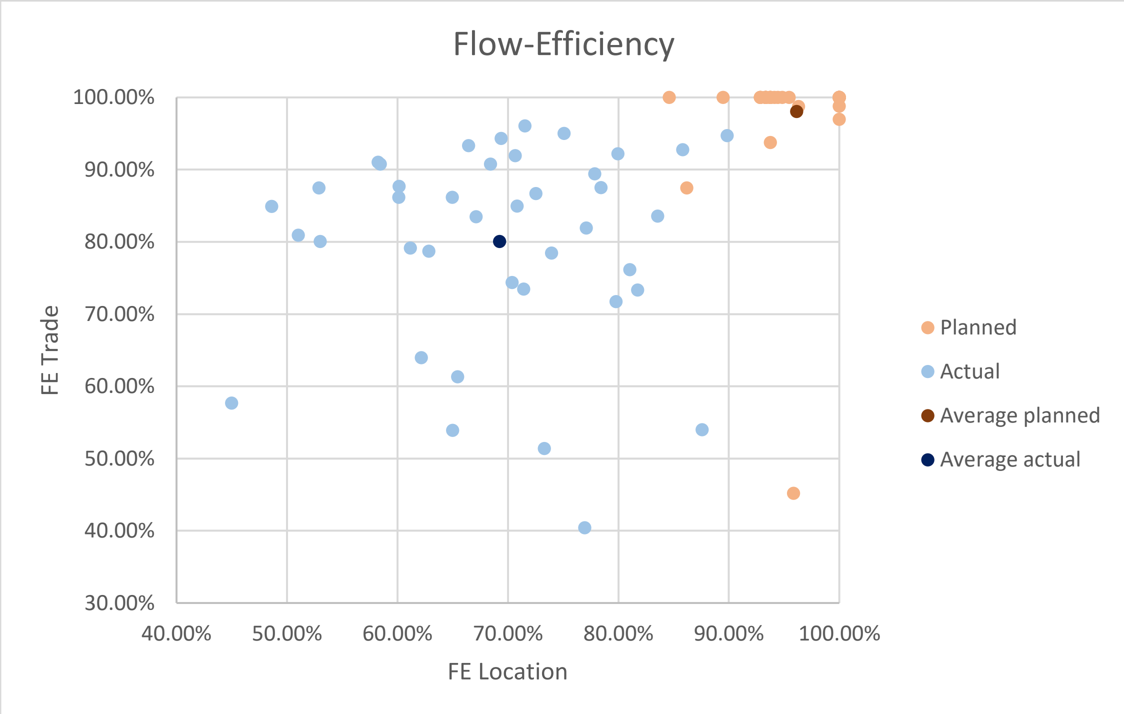

Figure 53: Flow Efficiency matrix

The takt plans in their planned state show only isolated instances of empty boxes. This is reflected in their high flow efficiency ratings. The takt plans intend for average flow efficiencies of 98.02% from the trade perspective and 96.13% from the location perspective. The location perspective lies slightly below the trade perspective because these are also influenced by drying times. It is likely that the takt plans, derived from the process of Takt Planning, represent the ideal outcome for which projects should aim.

During the construction phase, various situations affecting the takt plan arise. As a consequence, the quantity of gaps within the takt plan increases significantly, resulting in a more scattered appearance. This becomes clear in the efficiency matrix where the blue data points lie significantly below the red data points. The average flow efficiency in the actual situation is 69.25% as considered from the location perspective and 80.03% from the trades perspective. The average values are shown in the following table. The results don't depend on the project type.

Table 23: Overview of average flow efficiency

	Planned [%]	Actual [%]	Difference [% points]
FE Trade	98,02	80,03	-17,99
FE Location	96,13	69,25	-26,88

CONCLUSION AND OUTLOOK

The paper is a first step in the field of flow in takted projects. In this research paper the basis on measurement of flow is given. 40 projetcs were analyzed and the results were discussed. The results can be used for further projects.

The paper shows that the relationship between flow and takt are decisive in determining the success of on-site execution of construction projects. Various perspectives of flow must be considered and harmonized.

The first finding of the paper is the decrease of flow efficiency during Takt Control. There is a significant difference between planned flow efficiency and the actual situation as assessed after project completion. The difference between the two is not due to coincidence, but rather it is the result of takt control, which reacts with various actions as a result of real-life factors on construction sites. The actions are referred to as mechanisms and are described in the paper 'Adjustment Mechanisms for Demand-Oriented Optimization in Takt Planning and Takt Control' (Binninger et al. 2017b). The individual mechanisms have various consequences with regard to the workflows of the takt plan, although they are not the focus of this paper. In practice, it is particularly important to recognize relationships between various factors and to select the appropriate mechanism in response. As general contractors must consider and address both perspectives appropriately, because it's a mix of short delivery times of the product from the client perspective and stability and consistency of resources from the subcontractors perspective. This represents an area of great research potential. Further research is neccessary in order to understand the question why the flow efficiency decreases during construction control.

Moreover, the differences in flow efficiency between the location and trade perspectives are notable. From the trade perspective a higher level of flow efficiency is measured. This suggests that management of construction sites is primarily focused on the trades perspective, giving preference to the perspectives of subcontractors and workers. A reason for this could be the current market situation, where there is an existing lack of resources in the construction sector. If for example the trade perspective would not be focused, the cost can overrun the budget, because of an unstable use of resources. These findings underline those of Modig und Ählström and seem plausible when considering the current market situation in the construction industry. The construction manager decides on the mechanisms to be implemented and discusses these with subcontractors. Provided the mechanisms do not have any effect on the duration of construction as per the contract, the change has no effect on the product or customer. The trade however, is affected by the change.

Overall the two perspectives belong together and a focus on just one perspective is not useful. Further research is necessary to understand the relationship between the perspectives and the interaction and influence between them. Depending on the type of construction site, differing perspectives may have priority. E.g. construction projects with high focus on construction time would likely concentrate on the location flow. It is another field for further research.

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WHY WOULD LOCATION-BASED SCHEDULING BE APPLICABLE FOR OFFSHORE WIND TURBINE CONSTRUCTION?

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ABSTRACT

The focus in this research was the conversion of a traditional activity-based construction schedule to a location-based schedule. The case investigated was an offshore wind turbine project in the British sector of the North Sea. This exploratory case study used a deductive approach studying the literature. The initial step was a review of the location-based scheduling literature. The applicability of the theory could be tested through understanding the patterns from existing location-based scheduling literature. These patterns were the adapted from the construction context to the offshore wind construction context. With the knowledge of how and why from a theoretical perspective, the authors analyzed the existing construction schedule which was based on the critical path methodology. The results from this analysis provided knowledge about how location-based scheduling is applicable from an industrial perspective. This research contributes knowledge by testing the theory of location-based scheduling in the context of offshore wind turbine construction industry.

KEYWORDS

Construction, flowline, LBMS, offshore wind, work-sequencing

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INTRODUCTION

Offshore wind turbine construction divides their projects into distinct phases, namely production, pre-assembly, installation, commissioning (Barlow et al. 2015; Vis and Ursavas 2016). After the construction project the wind farm is handed over to operations (Petersen et al. 2016). This research focuses on the construction activities which start with the pre-assembly at the harbor as described by Barlow et al. (2014) , and continues with the installation phase initiated when the jack up vessels arrives at the quay side ready to bring the main components offshore (Barlow et al. 2014; Irawan et al. 2017). Final construction phase is commissioning, where final assembly and testing is conducted prior to operations. The commissioning activities are perceived similar to operations activities, here Petersen et al. (2016) recognized lean as a method for improvements of the maintenance activities.The focus of this research is on scheduling of the construction phases, by means of analyzing an existing activity-based construction schedule.

In previous literature, a few alternative planning and scheduling methodologies have been introduced for offshore wind construction. Alla et al. (2013) illustrated how linear programming with fixed scenarios could be applied for planning the construction of an offshore wind farm. Barlow et al. (2014) focused their perspective at installation of the turbines and how simulation of the installation vessel operations could impact the choice of vessels for strategy purposes. However, these presented examples do not defy the fact that critical path methodology is dominant for planning purposes in multiple industries (Galloway 2006). This is also the case in offshore wind turbine construction projects. For example, Hofmann (2011) presented an overview of multiple CPM based planning methods.

In the field of lean construction, the understanding of construction as a production system was developed through the theory transformation-flow-value by Koskela (2000). The Last Planner® System of Production Control (Ballard 2000) was introduced to plan and control the complexity in construction projects through collaboration and commitments among trades. Kenley (2005) described how construction has been perceived as chaotic by some and how location based management system (LBMS) could reduce its complexity. However, these methods have not been used in offshore wind construction context.

Therefore, this research was motivated by the potential of optimizing the construction planning by adapting the lean construction planning method Last Planner® System of Production Control (Ballard 2000) and location-based management system (LBMS) as introduced by Kenley & Seppänen (2010). It was chosen to proceed with the LBMS methodology, as a conversion of the existing activity-based schedule would be possible without direct interaction with the project team as described by Olivieri et al. (2018). As LPS is a social process between actors in the system (Ballard 2000), a research attempt to convert the existing schedule to the Last Planner® methodology cannot easily be done without participation of the teams (Ballard 2000). Olivieri et al. (2018) illustrated how LBMS could improve flow and resource usage by converting CPM schedules to LBMS schedules. The scope of the research is thus developing the understanding of the location-based scheduling methodology and evaluating if it could be applicable in the offshore wind construction industry.

The first part of the paper describes the contribution to the knowledge of location-based scheduling by a literature review. Then the context of offshore wind turbine construction and lean construction is introduced. The following section will develop the understanding of the exploratory case study with explanation of the theoretical patterns. The theoretical patterns are then adapted and applied to the existing Critical Path Method construction schedule. This leads to the discussion of implications of adapting location-based schedule in offshore wind industry, followed by the conclusions of the research.

BACKGROUND

The offshore wind energy industry has through years focused on becoming competitive on the levelized cost of energy (LCoE) in comparison to coal and other energy sources. The project costs are directly linked to the LCoE and equally affected by the tendering bids for new offshore wind farms. Lacal-Arántegui et al. (2018) explains how the tender bids have declined from 140 EUR/ MWh in 2012 to 49EUR in 2020. This has led engineering innovation through upscaling the power output per unit from 3,6MW in 2008 to 8MW in 2015(Rodrigues et al. 2015). Another perspective is the vessel innovations to accommodate these increases in dimensions(Paterson et al. 2018). Other sources has been contributing to the cost reduction through optimized planning and scheduling.

METHOD

The framework for this exploratory case study is inspired by Yin (2014) and used to test existing theory as described by Chris et al. (2002). A deductive approach was chosen to understand why and how the theory of location-based scheduling would adapt to the phenomenon of offshore wind turbine construction. First the theoretical patterns were identified and then the empirical data was analyzed to find similar patterns. The identified theoretical approach and the results follow an identical sequence, both follows the theoretical sequence for replication purposes and a consistent flow in the case study (Yin 1994). This was also used to increase the internal validity. The external validity was increased through setting up planning workshops with the project organization, including the project planner and technical experts. It was required to have multiple participants with each their perspectives on the planning and schedule as the projects are divided in three distinct phases; pre-assembly, installation, and commissioning (Barlow et al. 2014; Vis and Ursavas 2016). The literature review was conducted by searching the databases; Scopus, Google Scholar, and IGLC conference proceedings. The first search string contained; "LBMS", "location-based scheduling", "line-of-balance", "repetitive scheduling", "offshore" and "construction". LBMS was the consistent keyword with the other keywords in various combinations gave zero results. This indicated a gap in the knowledge of why LBMS would be applicable in offshore context. The literature reviewed illustrated different perspectives as illustrated in table 1, differentiating between construction, manufacturing and offshore wind industries. The first column is source, the second is industry, and then methodologies selected which are CPM, LBMS and LPS. Domain and methodology combined illustrates a clear gap in the body of knowledge for the offshore wind domain. The method comparison shows that LBMS has been primarily discussed within construction context.

Table 1: Literature comparison, domain and methods

Source	Domain			Method		
	Construction	Manufacturing	Offshore wind	CPM	LBMS (flowline)	LPS
Alla et al. (2013)			x	x		
Backe and Haugland (2017)			x	x		
Ballard, H. G. (2000)	x					x
Barlow et al. (2014)			x	x		
Barlow et al. (2015)			x	x		
Devoy McAuliffe et al. (2018)			x	x		
Galloway, P. D. (2006)		x		x		
Hofmann, M. (2011)			x	x		
Irawan, C. A., Jones, D., and Ouelhadj, D. (2017)			x	x		
Kenley, R. (2005)	x				x	
Kenley, R., and Seppänen, O. (2010)	x				x	
Kerzner and Kerzner (2017)		x		x		
Lacal-Arántegui et al. (2018)			x	x		
Lucko and Gattei (2016)	x				x	
Lucko et al. (2014)	x				x	
Olivieri et al. (2018)	x			x	x	
Seppänen, O., Ballard, G., and Pesonen, S. (2010).	x				x	x
Seppänen, O., Evinger, J., and Mouflard, C. (2014)	x				x	

Ursavas (2017)			x	x	
Valente, Montenegro, Brito, Biotto, and Mota (2014)	x				x
Vis, I. F. A., and Ursavas, E. (2016).			x	x	
Vollmann et al. (2004)		x		x	

EMPIRICAL DATA

The empirical data provided is from an existing construction schedule which has been planned for the construction of a wind farm in the British sector of the North Sea. This was initially delivered in an activity-based schedule from the Primavera software. The schedule was then converted to Excel and structured to meet the patterns described. In addition, the following information was also used in the transformation to a location-based schedule: site plan of pre-assembly on harbour, the wind farms turbine location overview and the design specifications of the model with power output above 7.0 Mega Watt. The activity-based schedule provided, consists of tasks and durations with their dependencies. The planned resources are kept separately in the original schedule. The case owner provided resources for different workshops, two small workshops with the planner of the existing schedule, first for clarification purposes and to ensure correct interpretation. Second workshop for confirmation of the conversion and potential generalisability. Besides these workshops two independent workshops with construction experts, one foremen and one with an offshore foreman and two commissioning technicians. These with three pre-assembly workshops were to establish external validly, by confirmation of the converted schedule, locations, tasks and dependencies from a practical and a planning perspective. The scheduling conversion was implemented by using the Schedule Planner module of Vico Office suite by Trimble.

RESULTS

The following section contains the conversion results from the activity-based schedule to the location-based schedule. Olivieri et al. (2018) thoroughly describe the conversion of CPM registered activities into flowline (LBMS) from 3 cases, with a focus on resource loaded tasks. In this case resources were not considered during investigation of applicability because they add an additional layer on top of LBMS and thus applicability is not directly affected by this. In our case, first the locations were specified. Next, each task was entered with the duration in each location identical to the original schedule.

LOCATION BREAKDOWN STRUCTURE (LBS)

The LBS was defined as follows; first we reviewed how the structure is set up in construction projects, then we investigated how it would apply in in the offshore wind turbine environment. In construction, the location breakdown structure is hierarchically broken down from the highest structurally independent hierarchy level which contains the lower levels, this can in some situations include logical locations which are non-physical (Kenley and Seppänen 2010). Olivieri et al. (2018) compose tasks by locations which crews complete before moving to next location. Valente et al. (2014) describe how the locations could be divided in equally sizes measured by duration for the trades.

Pre-assembly

In pre-assembly LBS, the logical areas are divided in hierarchy levels, determining the location flow by completeness and movement of the main components. The levels are described in comparison to Kenley and Seppänen (2010) presentation of construction LBS.

1. Highest level which is structurally independent is the pre-assembly harbor area, in construction this could be the building, stadium etc.
2. Middle levels here are the main components or geographical areas on the harbor, which in construction could be risers, floors or bays.
3. Lowest level are onshore segregated in; 'laydown area' or 'assembly area', in construction this would be apartments or levels.

Offshore locations

Offshore the activities move through the product location, similarly to what is seen in construction of high rise buildings. The hierarchy of locations are then being "offshore" which becomes segregated by each individual turbine location and further down into levels or space inside the turbine structures.

1. Highest level here is offshore as it is independent from the pre-assembly level and could be perceived as a second building. If it is a large wind farm it can be further segregated in fields or horizonal position.
2. Middle level are the identified turbine locations in the offshore farm named by numbers or their specific identity tags.
3. Lowest level logically consists of main components as one team at the time can work here, this case did not require this level of detail.

Figure 1 illustrates the location breakdown structure differentiating between onshore pre-assembly (Vis and Ursavas 2016) and the offshore locations with final assembly (Barlow et al. 2015).

ACTIVITIES AND DURATIONS

The case activities in the original CPM schedule were structured by turbine numbering each activity for identification and sequencing purposes, which also made filtering possible in the plan exported to Excel. Here the sequence of a single turbine was investigated. The activities listed under each turbine were repetitive and confirmed the location breakdown structure of Figure 1. The repetitive activities were quantified by hours and could have been changed into flowline tasks, but it was chosen to keep the original activities and durations. The workshops took a starting point in figure 2, this flow view illustrates the high-level shifts between project phases. The figure illustrates how there is a change from pushing to a supermarket onshore, then pulling a batch during installation and finalizing by pulling singular turbines in the commissioning phase. From the high-level flow diagram, the workshops focused on the converted schedule ensuring that the sequencing and technical dependencies matched. Having pre-assembly tasks organized until a given set of main components was ready, then in batches these components were transferred to the installation vessel (loadout) (Barlow et al. 2015).

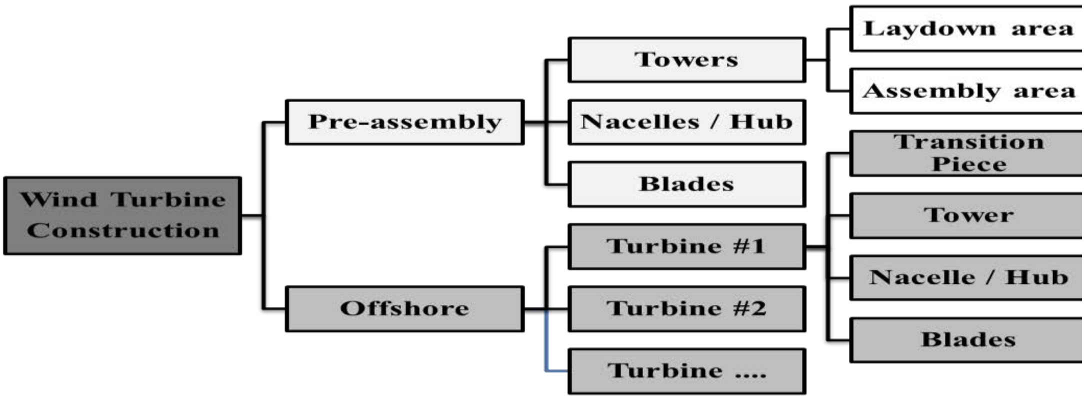

Figure 1: Location breakdown structure offshore wind construction

After loadout and transfer period, installation was performed in individual locations. When the installation vessel had finalized the installations of a given set it transferred back for a new loadout. This process was repeated until all the turbines had been installed. The commissioning tasks were then planned, including reliability tests and the first service period, leading to the take-over certificate which is final milestone for each turbine in the plan.

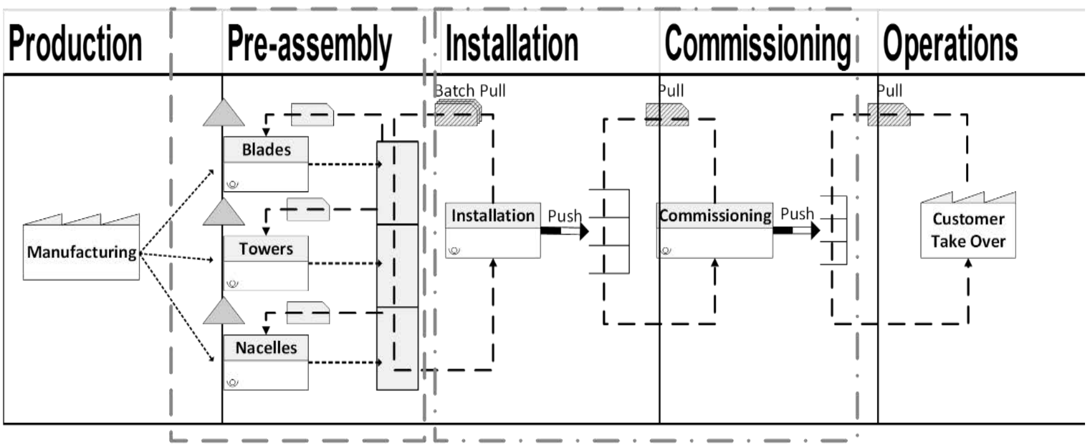

Figure 2: Wind turbine operations product flow chart

DEPENDENCIES

The CPM activities and their technical dependencies were visible through the consistent sequences, to further generate understanding of the resources per task; the amount of

resources and equipment and specific dependencies was clarified by the workshops and process maps. Kenley and Seppänen (2010) specifies the logical layers, which Olivieri et al. (2018) used during their CPM conversion. The known CPM dependencies were not all outlined in the original schedule, which was identified through the workshops with the technical experts from both the pre-assembly and offshore. Especially new dependencies arising from constraints of locations, resources, equipment and components, were found during these workshops.
Figure 3 illustrates inconsistency in dependencies of the original schedule, multiple starts and stops, some locations having more activities than others without consideration to physical or geographical constraints of the location. Furthermore, resource and crane capabilities or productivity rates were not considered aspects in the original schedule. Figure 3 illustrates the workflow of 24 turbines, at pre-assembly which have clear differences in leadtimes. Besides this the original segregation of the project phases is kept, geographically for the pre-assembly areas and offshore turbine by turbine.

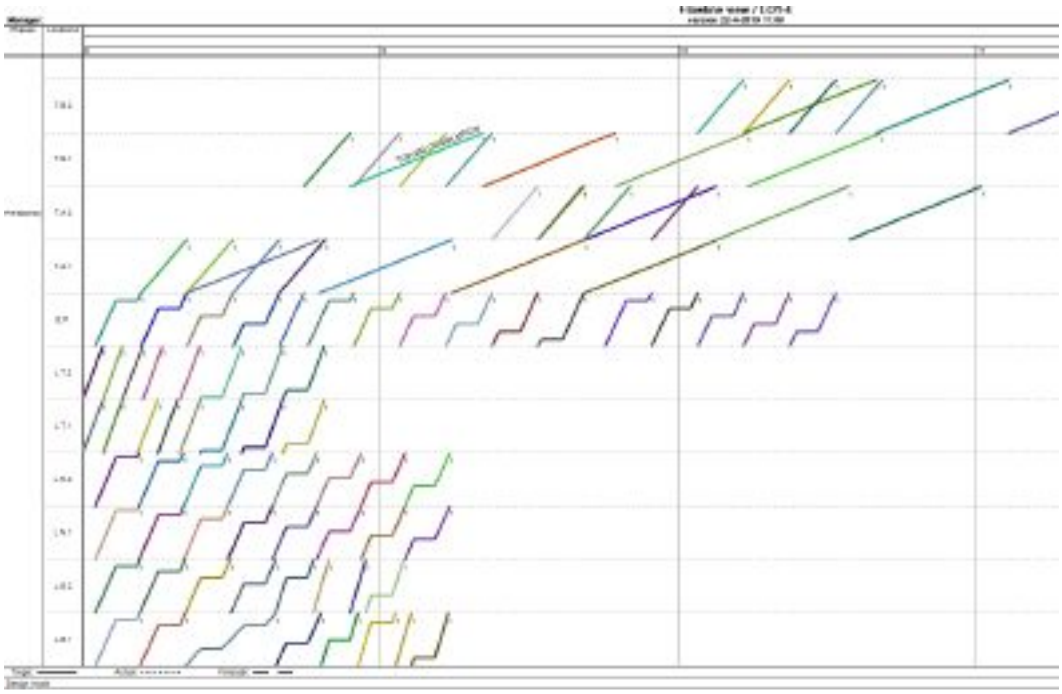

Figure 3: Direct conversion using location segregation from original schedule (Vico Schedule Planner)

DISCUSSION

The offshore wind literature reviewed indicated a clear preference for using CPM when planning (Alla et al. 2013; Barlow et al. 2015; Irawan et al. 2017) and simulating construction and operations (Backe and Haugland 2017; Barlow et al. 2014; Barlow et al. 2017; Devoy McAuliffe et al. 2018; Hofmann 2011). None of these methods consider resource levelling and workflow as Olivieri et al. (2018), or productivity like Lucko et al. (2014). Seppänen and Aalto (2005) argued for the importance of production rates and early detection of devations which could not be captured by CPM due to buffering. Goldratt (1997) critized CPM for its usage of activity buffers, only Vis and Ursavas (2016) touches upon actively protection of the activites through buffering. Our focus was not on the activity buffering, but it could be argued that it was handled as these buffers were removed through basing the conversion on resource hours per task not the scheduled durations. The offshore weather consists of waves and wind values which are aspects contionsly represented in the literature and not seen similarly in the construction literature. Offshore planning literature argues for inclusion of weather in their planning (Alla et al. 2013; Barlow et al. 2014; Barlow et al. 2015; Irawan et al. 2017; Vis and Ursavas 2016) but weather receives few mentions in LBMS literature because several case studies have mostly focused on improving the flow of interior work.

The schedule presented was created with a loop as the LBS was segregated in onshore and offshore, this enabled existing schedules CPM links. For instance fifth layer of CPM links (Kenley and Seppänen 2010) surfaces when relationships between loadout and installation is modeled, as there is a quantity limited buffer at pre-assembly. It could be argued that both offshore and onshore work could have been handled with the same location breakdown because even all offshore work is related to a specific turbine. Understanding the implication of changing the LBS would require further research. Visually, the alternative LBS would show all flowlines flowing through the same locations and the segregation between onshore and offshore could be handled by task naming and coloring.

IMPLICATIONS

The conversion was not conducted to evaluate the superiority of either planning method in the offshore wind construction context, but solely to test the applicability of LBMS in offshore wind construction. The learnings from the conversion could contribute to the debate of safety in offshore wind (Atkinson 2010) as the task collisions and location availability were made visible during the scheduling. By increasing the visibility of potential delays and thereby making these tangible (Lucko et al. 2014), productivity would then be expected to increase as argued by Seppänen et al. (2014) for construction. The dependencies described here are to the authors knowledge not earlier described, neither for construction industry or project management (Kenley and Seppänen 2010; Lucko et al. 2014), nor by Kenley (2005) within construction refurbishment. Further research might have similar implications as takt planning have had within manufacturing industries (Womack and Jones 2003). This could potentially inspire others to introduce LBMS in other similar industries and thereby strengthen the theory of LBMS.

CONCLUSION

The assembly of the wind turbine components with its similarities to modules from construction, supports why LBMS is applicable in the context of offshore wind turbine construction. The research also demonstrated that the logical layers for offshore wind turbine construction can be defined and presented in a flowline diagram. The location breakdown structure utilized here could have been changed as discussed. Further research is required to generate further knowledge of how to apply LBMS in practice, and what would be the practical implications of implementing LBMS.

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WHY WOULD LOCATION-BASED SCHEDULING BE APPLICABLE FOR OFFSHORE OIL AND GAS CONSTRUCTION?

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ABSTRACT

The focus of this research in testing the applicability of location-based scheduling within the offshore oil and gas construction domain. The case investigated is a larger oil and gas field undergoing refurbishment in the Danish sector of the North Sea. The exploratory case study took a deductive approach by analyzing the existing location-based scheduling literature. The theoretical patterns allow testing the applicability of the theory in the offshore construction domain. Adapting the patterns from the construction context to the offshore oil and gas construction context. With the knowledge of why and how from a theoretical perspective, we analyzed the original oil & gas construction schedule which is based on critical path method. This analysis provides knowledge about how location-based scheduling is applicable from an industrial perspective. This paper contributes knowledge by testing the theory of location-based scheduling in the offshore oil and gas construction context.

KEYWORDS

Job-sequencing, Location-Based Management System, Offshore, Oil and Gas, Work structuring

INTRODUCTION

The offshore oil and gas industry, with its producing platforms positioned in oil fields far offshore, continuously develops and seeks to mitigate the risks of cost overruns from construction, maintenance and refurbishment. These activities would require production (Findlay et al. 1989) to reduce its capacities for safety and practical reasons, which has significant financial impact due to lost revenue (Alonso et al. 2018; Halvorsen-Weare and Fagerholt 2017). Potential lost production emphasizes the high requirements for planning; ensuring that parts, equipment, resources and

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locations are available. Besides the operations planning, planning of the platform activities is also required to ensure construction productivity rates. Gupta and Grossmann (2012) presented a linear program to optimize oil field development, whereas Carvalho and Pinto (2006) focused on production through infrastructure. Halvorsen-Weare and Fagerholt (2017) presented a method for scheduling and optimizing supply logistics around the oil field. Sabri et al. (2015) presented a review of project management literature in the context of offshore oil and gas, including planning. These authors use critical path methodology (CPM) for the planning methods which they introduce to offshore oil and gas construction.

In the field of lean construction, the understanding of construction as a production system was developed with the theory of transformation-flow-value by Koskela (2000). The Last Planner® (LPS) System of Production Control (Ballard 2000) was introduced to plan and control the complexity in construction projects through collaboration and commitments among trades. Location-based management system (LBMS) was introduced by Kenley (2004) to reduce the same complexity in construction. In offshore oil and gas, lean construction has previously been developed by Kalsaas (2013). Inspired by the Last Planner System, Kalsaas (2013) investigated how to improve the buildability of offshore platforms. However, LBMS has to the knowledge of the authors not previously been used in offshore oil and gas construction context.

Therefore, this research project was motivated by the potential of optimizing construction planning by adapting the lean construction method location-based management system (LBMS), as introduced by Kenley and Seppänen (2010). It was decided to proceed with LBMS methodology. Olivieri et al. (2018) presented how location-based scheduling (LBS) could be applied in the construction industry without social interaction, which would have been required for testing LPS in a similar setting (Ballard 2000). Olivieri et al. (2018) illustrated how LBMS could improve flow and resource usage by converting CPM schedules to LBMS schedules. Seppänen et al. (2014) further developed the understanding of location-based scheduling and its impact on productivity from a construction management perspective. The scope of this research is to develop understanding of the location-based scheduling methodology and evaluate if it could be applicable in the offshore oil and gas construction industry.

The first part of this research is a literature review presenting the gap in the existing body of knowledge and this research contribution to fill it. The second part presents the offshore oil and gas construction domain. Third part give an understanding of the exploratory case study, displaying literature patterns and if LBS is applicable in the new domain of offshore oil and gas. The results are then presented and discussed along with implications in the offshore oil and gas industry.

METHOD

The framework for this exploratory single case study is inspired by Yin (2014) and used to test existing theory as described by Voss et al. (2002). A deductive approach was chosen to understand why and how the theory of location-based scheduling could be applied to offshore oil and gas refurbishment. This was accomplished by first identifying theoretical patterns and secondly analyzing the empirical data for similar patterns. To ensure replicability and internal validity the approach and results are listed in the sequence the case study unfolded as proposed by Yin (2014).

Two workshops and a final presentation of the findings were planned in cooperation with the case owner. The intention was to develop the external validity and to avoid potential misinterpretations of the original schedule (Yin 1994). It was found necessary to have multiple participants, with different perspectives on the planning and scheduling of the construction works. The literature review was conducted by searching the databases: Scopus, Google Scholar, and IGLC. The first search string contained: “LBMS”, “location-based scheduling” (LBS), “line-of-balance”, “repetitive scheduling”, “offshore”, “refurbishment” and “construction”. The key word combination was built with LBMS or LBS as the consistent words. LBMS and LBS didn’t give any results in the offshore oil and gas literature. This indicated a gap in the body knowledge for LBMS in offshore oil context. A further literature search was conducted with “offshore”, “planning”, “scheduling” and “construction”, the results of which has been presented in Table 1. The body of knowledge from the offshore oil and gas construction and production revealed that the majority of planning is based on CPM. Halvorsen-Weare and Fagerholt (2017); Halvorsen-Weare et al. (2012); Norstad et al. (2017) all looked into CPM based planning and simulating offshore oil and gas supply vessels. Alonso et al. (2018); Findlay et al. (1989); Gupta and Grossmann (2012); Lang and Zhao (2016) on the other hand developed and presented linear programming for daily or well production and shutdown planning.

Table 1 consists of a comparison of planning and scheduling literature from the domain of: construction, manufacturing and offshore oil and gas. 1st column in Table 1 contains the sources reviewed, 2nd column to the right is the applicable domain and 3rd column is the planning method presented. Table 1 shows LBMS is primarily used within the construction domain and CPM to be dominant in the offshore oil and gas domain.

Table 1: Literature comparison, domain and methods

	Domain			Method		
Source	**Construction**	**Manufacturing**	**Offshore oil and gas**	**CPM**	**LBMS (flowline)**	**LPS**
Alonso et al. (2018)			x	x		
Ballard, H. G. (2000)	x					x
Bull and Love (2019)			x	x		
Carvalho and Pinto (2006)			x	x		
Findlay et al. (1989)			x	x		
Galloway, P. D. (2006)		x		x		
Gomarn and Pongpeng (2018)			x			
Gupta and Grossmann (2012)			x	x		
(Halvorsen-Weare and Fagerholt 2011)			x	x		
Halvorsen-Weare and Fagerholt (2017)			x	x		
Kalsaas (2013b)			x			x
(Kenley 2004)	x				x	
Kenley, R. (2005)	x				x	
Kenley, R., and Seppänen, O. (2010)	x				x	
Kerzner and Kerzner (2017)		x		x		
Lang and Zhao (2016)			x	x		
Lucko, G., and Gattei, G. (2016)	x				x	
Lucko et al. (2014)	x				x	
Norstad et al. (2017)			x	x		
Olivieri et al. (2018)	x			x	x	
Seppänen, O., Ballard, G., and Pesonen, S. (2010).	x				x	x

Seppänen, O., Evinger, J., and Mouflard, C. (2014)	x				x
Smalley and Chebotar (2017)			x	x	
Tavallali and Karimi (2016)			x	x	
Valente et al. (2014)	x				x
Vollmann et al. (2004)		x		x	

EMPIRICAL DATA

The empirical data is gathered from an existing construction schedule which has been generated for the refurbishment of oil and gas production platforms in a large field in the Danish sector of the North Sea. The case owner provided an activity-based schedule from the software package Primavera, which is based on critical path methodology (CPM). The Primavera schedule data was converted to excel and structured according to platforms, then elevations and finally equipment. The activity-based schedule consisted of activities and durations, the dependencies and resources kept separate from the activities. Besides the schedule a complete set of 2D drawings was provided. Illustrating each platform elevation in the field, including side views and a list of equipment positions on the platforms. The case owner organized two workshops, first workshop was held with the project planner to clarify wordings, abbreviations and the schedule structure. The second workshop involved an engineer, a foreman and technician to clarify questions regarding activities, dependencies, resources and locations. Additionally, the two workshops led to an increased understanding of the weather impact on activities seen from a planning and practical perspective. The daily operations and safety concerns were elaborated, especially how these were affected by the construction works. After the workshops and completion of the conversion, the case owner facilitated a meeting for presentation of the findings. As directors and planning experts attended the meeting, it also confirmed the generalizability of the approach and method. The scheduling conversion was implemented by using the Schedule Planner module of Vico Office suite by Trimble.

RESULTS

The following section contains the conversion results of CPM schedule to the location-based schedule. The conversion of a CPM schedule into a location based schedule (LBS) has been handled similarly as described by Olivieri et al. (2018). Presenting 3 similar cases conducted within the construction focused on activities containing resources. This was not considered important for the confirmation of applicability in the offshore context. The initial phase of the conversion was used to understand the locations. Following the logical layers as described by Kenley and Seppänen (2010) page 133-144. After creating the location breakdown structure, all activities were entered with original durations and dependencies.

LOCATION BREAKDOWN STRUCTURE

The LBS was defined as follows; first through review we found the structure from construction projects, then we investigated the available 2D drawings, organized them in platforms, then by elevation heights. Kenley and Seppänen (2010) describes how locations are hierarchically broken down and structured for construction. The hierarchy is organized from the highest independent levels such as the overall building. Which contains the middle and lower levels, including logical locations of physical and non-physical character (Kenley and Seppänen 2010). Olivieri et al. (2018) define tasks by location using logical layers, describing how crews complete a location at the time, also described by Kenley and Seppänen (2010). Valente et al. (2014) divides the locations in equal sizes according to the trades expected durations.

OFFSHORE PLATFORMS

In the offshore oil and gas fields the platforms and their geographical position are to be perceived as independent locations / structures. This makes the platforms hierarchically highest from a location break down perspective. The location break down levels are described in comparison to the presentation of construction locations by Kenley and Seppänen (2010).

1. Highest levels which are the structurally independent platforms, in construction this could be the buildings, stadium etc.
2. Middle levels are elevations levels also defined as decks of the platform, in construction it could be risers, floors or bays.
3. Lower levels are equal within each geographical zone at each elevational level in construction apartments or zones.

Figure 1 illustrates the side view of platform “A” which is part of the case owner’s main objectives for their refurbishment project. The elevations are listed in the left side with feet above sea level and areas marked with alphabetic numbering. In figure 2 the ‘cellar deck’ at platform A at elevation of 22 feet above sea level is displayed and is in resemblance with floor drawings from a construction site.

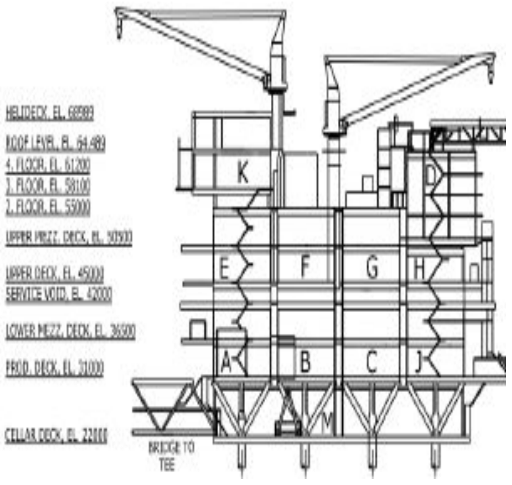

Figure 1: Side view of platform A elevations

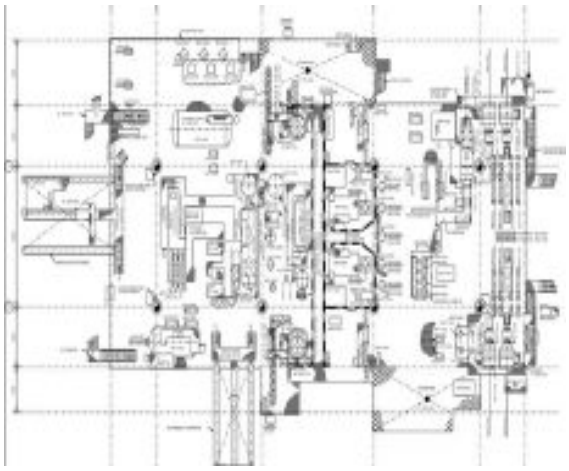

Figure 2: View of cellar deck el. 22 at platform A

ACTIVITIES AND DURATIONS

The activities in the original CPM schedule were structured according to the platforms by abbreviation. The activity lines were then further structured according to elevations and the equipment on each elevation. Activities were categorized as: scaffolding, electrical, mechanical, painting, rigging and service. These were structured with durations in budgeted hours, completed hours and start-finish defined as calendar dates. The planner confirmed the work breakdown structure, how the tasks were organized, and abbreviations used in the original schedule.

The activities could then be perceived as similar to location quantities and thereby repetitive as seen in Kenley and Seppänen (2010), and organized according to the external logical layers as described by Olivieri et al. (2018). With the external logic considering how the locations affect the flow of the tasks. The conversion of the CPM schedule into LBMS flowline was done by following the logical layers, but differing from Olivieri et al. (2018) in not considering whether the activities were resource loaded. Further analysis of the activities sought to identify repetitive activities, by identifying similar activities going through multiple locations. To broaden the understanding of the repetitive activities, it was investigated whether similar activities were assigned to equipment in differentiating locations. The equipment lists made it possible to pair similar equipment descriptions by having their locations revealed within the 2D drawings. This made it possible to update the lowest levels of the location structure, where this was required for accuracy. The workshop with the technical experts further developed the understanding of the activities and how they're logically linked together. Diagram 1 illustrates repetitive activities in the original CPM schedule. The flowlines in diagram 2, delivers a visual illustration of the same activities as diagram 1. The seemingly similar activities are with different activity speeds or productivity rates, which also is notable in the 3rd column in diagram 1 however less visual if studying the CPM schedule. The paint activities on the various well heads are identical tasks and further LBS accuracy could have been applied, which was confirmed during the workshop with the foreman, engineer and technicians. This could be explained as typos in the original schedule, easily recognizable in diagram 2. This visually illustrates the differences in durations between the tasks by their individual degree of angle. It could also be interpreted as a problem with the production rates and internal logic, leading to task collisions and interruptions as Diagram 2 illustrates.

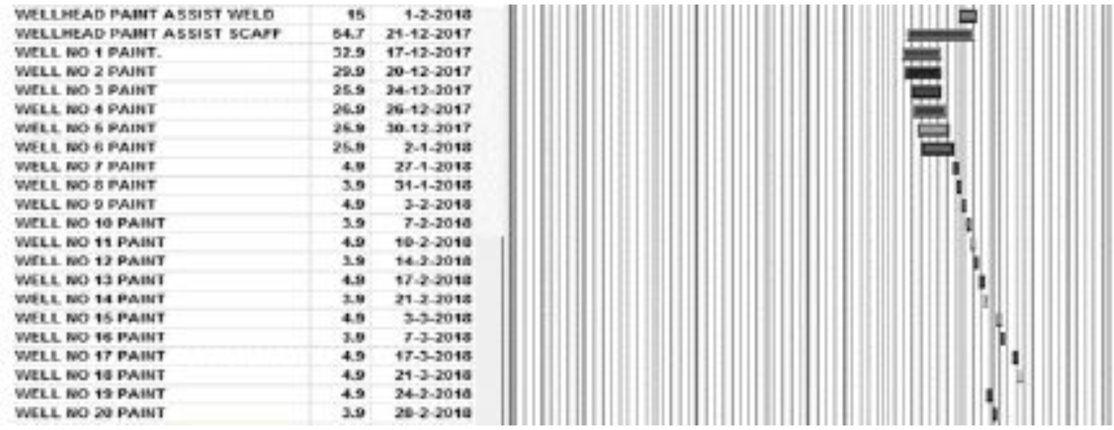

Diagram 1: Example taken from the original activity-based schedule

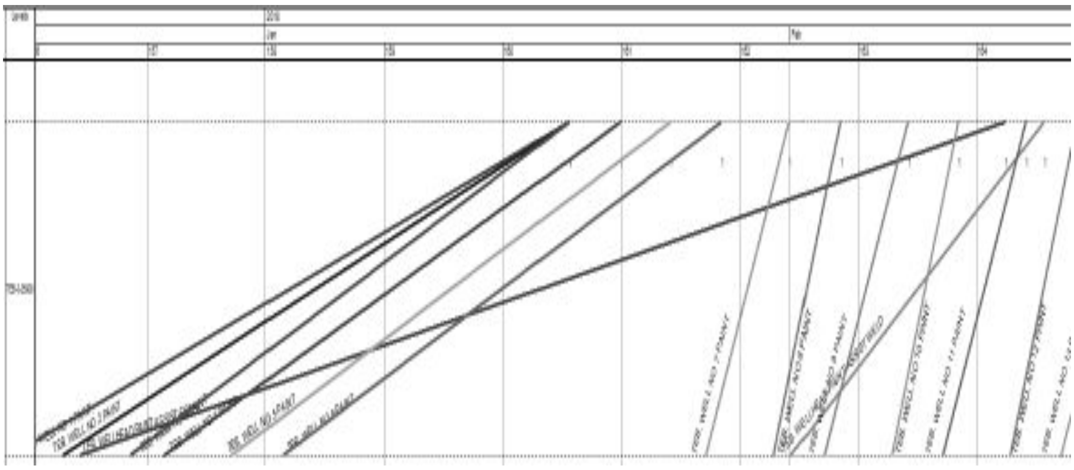

Diagram 2: Direct conversion of diagram 1 into Vico office scheduler

DEPENDENCIES

The CPM activities and their technical or logical dependencies were not clearly defined or outlined in the original CPM schedule other than start-finish and order of appearance. The workshop with the engineer, foreman and technicians produced the dependencies which helped define the amount of resources and equipment as well as specific dependencies between the activities. Olivieri et al. (2018) used logical layers for the conversion of the CPM schedule into flowlines as described by Kenley and Seppänen (2010). The location dependencies developed through the understanding of the logical sequencing between activities in various locations. The location dependencies are illustrated in diagram 2, where multiple activities are executed simultaneously, this could potentially delay the completion of the individual tasks and affect the overall performance. Furthermore, location accuracy was required for segregation among activities which were assigned to specific platform levels. Additional dependencies for teams working above and below each other were not established in the original schedule, these were visually identified and re-organized in schedule planner. As the activities were loaded with budgeted hours, it was possible to introduce quantities in terms of hours to the schedule. Then based on the expert evaluations, the activities resources could be added. Diagram 3 shows resource consumption in the schedule, variating from 20 to 80 technicians in peaks divided between five trades. The case owner commented on the resource varians, these had led to issues with accommodation on the platforms, to mitigate last minute solution had been required. The CPM schedule hadn't been able to identify the causes for the peaks as these are not related to the critical tasks but rather multiple, simultaneous activities.

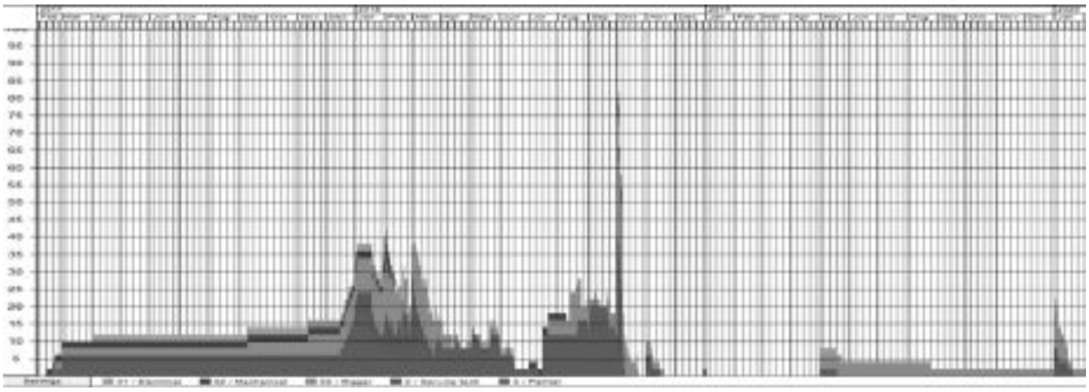

Diagram 3: The resource consumption divided between 5 trades

DISCUSSION

RESULTS

The offshore oil and gas literature indicated a preference for using CPM as other industries (Galloway 2006), when planning construction (Carvalho and Pinto 2006; Gomarn and Pongpeng 2018; Norstad et al. 2017; Sabri et al. 2015), production (Findlay et al. 1989; Lang and Zhao 2016) and maintenance (Alonso et al. 2018; Halvorsen-Weare and Fagerholt 2017). None of these consider resource leveling or workflow as Olivieri et al. (2018), neither did they consider productivity as Lucko et al. (2014) and Seppänen et al. (2014). In comparison to the provided CPM schedule the LBMS schedule illustrated inconsistency, which supports Olivieri et al. (2018) results, but they also found that CPM had similar feature for critical activities.

Resource levels, and production rates were visually demonstrated here, illustrating the inconsistencies from the CPM schedule. It could be argued that these key findings demonstrated imbalance in construction planning due to past methodologies. Kenley (2005) illustrates similar irregularities and argues for these to be production rate related which only supports the findings here.

Kenley (2005) similarly showed a direct conversion from a CPM schedule to a flowline schedule. Developing it from repetitive activities throughout the majority of its locations. The location quantities here were developed from hours, some might argue that this could be developed differently. As the material quantities could also have been loaded into each location using Vico suite.

Findlay et al. (1989); Norstad et al. (2017) illustrates a high focus on safety over time within the offshore literature, were Kines et al. (2010) in the context of construction presented how leaders with positive effect communicated about safety and risks. From an offshore oil and gas perspective it could be interesting to understand more about whether LBMS could affect safety during planning which Kalsaas (2013); Kalsaas (2013) also earlier addressed. From a safety perspective, the LBMS schedule allowed visual interpretation of task collisions. But also, if activities are executed simultaneously above or below each other, identifying risk of dropped objects. Where Smalley and Chebotar (2017) used CPM to develop a risk management framework and determine probability of occurrence. It could be argued that LBMS would allow risk management through risk identification in advance, also seen in Kenley (2005) as production rate predictions.

From a construction and planning perspective multiple features and aspects are similar in oil & gas construction. Further developing the understanding of how to apply LBMS in the offshore oil and gas industry, would require further research.

IMPLICATIONS

As this was the first step towards testing LBMS theory in in the domain of offshore oil and gas refurbishment. This conversion has further implications within the offshore oil and gas domain as the potential improvements here are still unexplored. It could be proposed to have similar implications in the offshore oil and gas maintenance, operations management and new build as their planning aspects are similar.

From an offshore oil and gas construction management perspective, it might be worthwhile to aid managers by optimizing the schedule and reducing operative safety risks. The case owner highlighted the safety factor of technicians not working above and below other teams could potentially reduce the risk of dropped objects between elevations. These safety factors could be positively affected by increased knowledge about the locations of workers in the scheduling phase of the offshore oil and gas refurbishment project and during execution, as operations on specific elevations of the platform are identified by expected start and finish similar to what is described by Kyoo-Jin and Langford (2006).

CONCLUSION

The refurbishment schedule of the oil and gas platforms with its quantity loaded locations led to a comparison with construction. The conversion revealed certain issues with safety, productivity and resource levels which can be related directly to previous research findings. Which supports why LBMS is applicable in the offshore oil and gas construction. The research also demonstrated that the logical layers for offshore oil and gas construction can be defined and presented in a flowline diagram.

Further research is required to generate further knowledge of how to apply LBMS in practice and what would be practical implications of implementing LBMS.

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HOW LONG DOES IT TAKE TO BUILD AN APARTMENT?

Sigmund Aslesen[1], Sigmund Reff[2], and Espen Stordal[3]

ABSTRACT

This paper explores how long it takes to build an apartment. In our effort to answer the question, we concentrate on the inventory phase. The phase involves the completion of every apartment. It includes several trades, a significant number of tasks and a great deal of coordination, and spans from erecting the walls to installing and coupling of technical systems and to the finishing of kitchen, bathroom(s), doors and all surfaces.

The paper is grounded in the research idea that to make construction more like manufacturing, we need to study it from a manufacturing viewpoint. Its starting point are the peculiarities of construction as emphasized by one-of-a-kind projects, site production, a temporary organization and intervention of regulatory authorities (Koskela 1992). While these particularities have played a fundamental role to understand the uniqueness of the construction building process, we argue in this paper to handle them with caution so that they do not hamper initiatives – and insights – based on the commonalities of the two types of production.

In the paper, a preliminary analysis is carried out based on a housing project including 127 apartments, divided by four, four-to-six storey high blocks. Using the single apartment as the production unit, we outline certain assessments which we plan to test full-scale in a sizeable housing project including 342 apartments. The paper discusses the potential benefits of defining an apartment as the production unit, and how it may assist production knowing how long it takes to build an apartment. We conclude that to build an apartment in a more effective and less wasteful manner than today, we should think of it as more of a manufacturing than a construction process.

KEYWORDS

Production planning and control, theory.

INTRODUCTION

How long does it take to build an apartment? In any housing project of a certain size, estimating the time to complete an apartment may help planning the total duration of the project. Using the apartment as the unit of production also makes sense from a customer point of view, since in housing projects the single flat is what is handed over to the end user. In our attempt to answer the question, we have decided to limit our attention to the

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inventory part of the construction process. Although leaving out other parts of the construction production implies a major simplification, we find the inventory phase more easily comparable to the assembly of products going on in manufacturing.

The authors work for a Norwegian general contractor involved in all kinds of construction and civil engineering. In the Oslo unit where we are employed, housing projects make up 40 per cent of the total turnover. On a yearly basis, we complete around 1000 apartments. In the housing production, we use a core of trade workers from our own company to do the concrete, carpentry and bricklaying parts of the job, while the technical work and other jobs are hired on a project basis. However, due to the volume of different jobs and for strategic reasons as well, we often end up with many of the same suppliers across projects. As for the clients, a few dominate the housing market in the Oslo area. This implies that over the years we have taken on numerous projects for much of the same clients. Consequently, we have earned considerable knowledge and experience about their preferences in the product. The combination of recurring clients, a voluminous housing production, the use of own workers and a network of suppliers and subcontractors, is what makes the question in the paper's title particularly relevant for us.

What kind of production is construction? This question was raised several years ago by Ballard and Howell (1998), in a paper holding the very same title. It was based in the belief that construction is a fundamentally different kind of production. We argue that there is no simple answer to that question, since it may vary substantially between different types of projects. Furthermore, that the character of the answer will depend on the level of observation. While every project is unique somehow, we think that to start by focusing on the uniqueness may easily lead to a tautological reasoning where every project – and thereby construction production – is said to have the same qualities. In the paper, we use a case study including one project only to do a preliminary analysis. The unit of investigation is not the housing project per se, but the completion of apartments going on as part of it. Our point of departure is this; that the production of housings, even though being conducted on site, has clear parallels to manufacturing production and that we have far more to gain by seeing them as akin rather than as counterparts.

THEORY

In 1992, Lauri Koskela published his study of what was called a new production philosophy and its application to construction (1992). The term "new production philosophy" here referred to the set of methodologies, techniques and tools evolved in Japanese car manufacturing, under the concepts of just-in-time, total quality management, world class manufacturing and Lean Production. The goal of his research was to assess whether this new production philosophy had implications for construction. Koskela concluded that construction should adopt the new production philosophy. His reasoning was based on seeing construction as flow processes and not only as a series of conversion activities. At the same time, an effort to overcome flow problems was needed to improve the construction production, which incorporated an understanding of its peculiarities (op.cit, p. 44). These peculiarities were: 1) the *one-of-a-kind nature* of construction projects caused by differing needs and priorities of the client, differing sites and surroundings, and differing views of designers on the best solutions, 2) *site production*, the way construction production is typically carried out at the final site of the constructed product, 3) *temporary multiorganization*, implying that a construction project organization is usually a temporary organization made up by different companies and practices, which have not necessarily worked together before and which are tied together by means of varying contractual arrangement, and 4) *intervention of regulatory authorities*, in design solutions and many work phases where the project is subject to checking and approval.

The peculiarities of construction production articulated by Koskela (1992) have later worked as guidelines or rules for the many who have approached Lean Construction with the aim to increase their understanding of the industry, or to improve it – in most cases both. Ballard and Howell (1998), two of the other founding fathers of Lean Construction, go as far as to state that we must learn how to manage uncertainty and complexity and quickness within these characteristic construction conditions. Their reasons for saying so are founded partly in the elaboration of various types of manufacturing, and partly from seeing construction as directives-driven where a key to efficient assembly is production planning and control. Ballard and Howell (op.cit) conclude by advocating a two-part implementation strategy, whereof one part consists of minimizing construction peculiarities to take advantage of lean techniques developed in manufacturing, and the other part includes to develop lean techniques adequate to dynamic construction.

Now, more than 20 years later, it is reasonable to say that the research and development initiated in the Lean Construction sphere has been fundamentally dominated by the developing of lean techniques adequate to dynamic construction. In doing so, one risks only coming halfway since taking advantage of lean techniques should also imply to look to manufacturing for improvements. There are, indeed, some important exceptions worth mentioning. A number of papers brings up the management of the construction supply chain and just-in-time deliveries (Vrijhof and Koskela 1999; Zimmer, Salem, Genaidi and Shell 2008), prefabrication (Ballard, Harper and Zabelle 2002; Ballard and Arbulu 2004; Höök and Stehn 2005) and off-site manufacturing (Pasquire and Connolly 2002, 2003), value stream mapping (Picchi and Granja 2004), modularization and industrialization (Bertelsen 2005; Lessing, Stehn and Ekholm 2005; Hermes 2015), construction manufacturing (Pasquire, Soar and Gibb 2006), mass customization (Tillmann and Formoso 2008), work standardization (Mariz, Picchi, Granja and de Melo 2012) and last, but not least, takt time planning (Frandson, Berghede and Tommelein 2013; Frandson, Seppänen and Tommelein 2015; Binninger, Dlouhy and Hagsheno 2017).

Our theoretic starting point is from a paper on the categorization of production. Here, Bølviken (2012) presents a matrix including four different forms of production, which are categorized according to types of organizations and products. In the matrix, construction is conceptualized as project production recognized by unique products and a temporary organization while mass production works as some sort of counterpart recognized by similar products and a permanent organization. What triggered us was how a classification like this is very useful to explain construction production the way it works today, but that it falls short in suggesting any direction for future development of the industry. This is why we draw an imaginary line from project production in the lower right corner of the matrix, to mass production in the upper left corner. Our intention is to challenge the traditional view, also existing within our company, that everyday problems which tend to reappear on site are due to the very characteristics of construction production and therefore more or less inevitable. In line with Koskela's (1992) reasoning, we believe one should follow the lead of manufacturing by reconceptualizing construction as flows (p. 37). Understanding the peculiarities of construction is thereby quite another matter than using them as an excuse. Improvement is to be able to avoid or alleviate their detrimental effects (op.cit, p. 44).

Following the lead of manufacturing, the Toyota Production System is a forerunner. Its basic idea is the elimination of inventories and other waste by applying a range of techniques to make sure continuous improvement of both operations, equipment and processes (Liker and Meier 2006). Its conceptual basis is production as a flow of materials and/or information. In this flow, the material is processed (converted), it is inspected, it is waiting, or it is moving (Koskela 1992, p. 15). While all these activities expend cost and consume time, only conversion activities add value to the material being transformed to a product. In turn, improvement of flow activities (inspection, waiting, moving) should focus on their reduction or elimination, whereas conversion activities must be made more efficient (op.cit, p. 16). Does it make sense to think of the production of apartments in much the same way? We think so. The completion of an apartment is a flow of materials being transformed to a product – a flat. While the production is ongoing, the different rooms making up the apartment is transformed from a structural basis to a complete product. Several times during the production, the apartment is being inspected. For quite some time, it is also empty – meaning that nothing is going on and it awaits being further processed. A major difference, though, concerns the product – the flat – which does not move while the workers and their work stations do, as opposed to automotive production where the car moves while being processed in the various work cells along the assembly line.

Does it still make sense to compare housing with automotive production? Absolutely. To apply a categorization of production forms is not the same as being categorical. Bølviken (2012) implicitly explains this point when discussing the development of the Toyota Production System which, although having mass production as a starting point, was designed as an order-based system driven by market pull. If we use the same rationale on housing production, we may come to see it as – although taking place within a project – being somewhat related to both mass and order production. This is important because seeing housing production as something else than just project-based production may trigger new thoughts about what should be the basic productivity strategy. According to Bølviken (2012), each production form in his matrix can be associated with a specific and basic productivity strategy. He goes on by referring to Ohno (1978), considered to be the father of the Toyota Production System, who described volume and standardization as the basic productivity strategy for mass production, and flow as the basis for order production. If we find the completion of apartments to be somewhere in between these two production forms, then the efforts to improve it should reflect its basic character. Although collaborative planning that includes all competencies – said to be basic productivity strategy for project production (Ballard 2000; Bølviken 2012) – will never be wrong and always be right, it may only bring you halfway when dealing with housing production to the point real challenges and characteristics are not sufficiently addressed.

METHODOLOGY

The paper is based on a combination of field research and a factory visit to a manufacturing plant. The first author has, for 12 months, taken part full time in a housing project to observe, describe and analyse the ongoing production and its planning and control processes. As part of the apartment completion, he has had responsibilities related to the following up of all the mounting of parquet and kitchens involved in this production. He has predominantly been concerned with the progress of these tasks, and likewise in different ways helped to secure an even flow in the housing production. The second author is the project manager of the biggest housing project in the history of the company, where potentially more than 2500 apartments are to be built and where the designing of the apartments for the first stage – including 342 apartments – is based on high levels of standardization. The third author is the site manager of the same project and has considerable experience from similar roles in earlier housing projects.

Data is collected using direct observation, in combination with participation in meetings. The factory visit was done as part of a four-day, intensive course in Lean production and takt planning arranged by Porsche Consulting. The course took place on the shop floor in their manufacturing plant in Leipzig, Germany.

RESEARCH

THROUGHPUT TIME

Throughput time denotes the amount of time required for a product to go through a manufacturing process. It includes the time spent for processing, inspection, moving and waiting. In the Porsche manufacturing plant in Leipzig, a new Porsche Macan or Panamera rolls off the final assembly line every 3.8 minutes. The average daily production is 650 cars, which adds up to 150.000 cars a year. Behind this impressive production rate is a throughput time of 8 hours per car. It covers the entire period from the car enters the final assembly line until it exits this process. If we also count in the time in the body and paint shop, throughput time sums up to roughly 48 hours per car. In the housing project in study, the inventory phase for the 127 apartments spans over a period of 43 weeks altogether if holidays are excluded, or totally 215 working days. If we reckon a working year to consist of 230 days, around 136 apartments are completed on a yearly basis. The throughput time for an apartment is, however, much longer than the production rate should indicate. The time from an apartment is started on to its completion is between 70-80 days.

WORK IN PROGRESS AND TAKT TIME

The combination of a high production rate with a long throughput time implies that it, during the inventory phase of a housing project, is a substantial amount of work in progress. Work in progress refers to all apartments where the processing is started on, but not yet completed. This matter, because work in progress is not worth as much as completed work. Simultaneously, a housing project is not completed before all apartments are completed and the project can be handed over to the client. If a project can produce 136 apartments on a yearly basis, the monthly production rate would be around 11,3 apartments (holidays excluded). However, housing production, at least the way it works today, is an uneven form of production. It has a bell-shaped curve. A production peak is reached when there are activities going on in almost every floor, in every block. Then, the manning is high, the crews are many and the work in progress substantial, following that progress planning becomes essential to coordinate actions and maintain control.

Whereas in a machine-paced manufacturing line, a takt or "rhythm" is developed to match the capabilities of all work cells in that line and/or to adjust capabilities to the takt, in a housing project crews controlling each other's progress is a key to maintaining speed throughout the inventory phase. Every floor works as a control zone to check status on progress (and the subsequent takt), to adjust the manning if needed and to avoid being interrupted by other trades. Just as Porsche's final assembly line has many cars being processed at the same time in different work cells, the production of housings goes on in parallel. To be more concrete, the crew doing the listing may be occupied on the third floor of a block, while kitchens are mounted on the floor below, following the parquet guys who have started laying the floors on the first level while the electricians install plugs on the ground floor. This moreover addresses two important principles in the housing production. First, that the different crews prefer to start on top of a stair shaft and move downwards, to ease the transportation of their work stations. Second, that the apartments are processed in small batches, the way crews complete their job floor-by-floor.

BUFFERS AND VARIATION

Buffers are used to compensate for variations in the production process. A simple calculation based on the housing project's plan for the inventory phase shows that on a floor including four apartments, the total expected processing time – all activities included – is 54 days, which divided by four is 13,5 effective days per apartment. This means that of the total 70-80 days of throughput time for an apartment, there is likely work going on in that apartment for less than 20 per cent of the time. The gap between throughput time and processing time indicates that housing production is buffered. The buffers, we shall see, come in various forms.

Time buffers allow for a "slack" or "pause" in the production. In the housing production, time buffers are found as "rest days" in the progress plan. They are especially apparent in the early part of the inventory phase. It includes all the preparatory work to make the apartment ready for the later interior part and is predominantly made up of carpentry work related to the mounting of walls. In between this work are small in-wall tasks related to the installing of boxes, pipes, fuse box and other stuff by the electrician, the coupling of water and drain in the bathroom and kitchen by the plumber, and in addition some duct work. The preparatory work is almost like a production of its own. It resembles the body shop in the Porsche production where aluminium and steel parts are joined step by step to form the vehicle's metal coat. Even more so, because of the quality control regime characterizing both these production lines. Despite the high degree of automation in the Porsche body shop, human efforts are here essential to do quality controls and system operation testing. Likewise, inspections are done of the preparatory work to make sure everything is in the right place and function before the interior part is started on. In both cases, time buffers are allowed to have time to uncover errors and make the necessary corrections.

The preparatory work goes on all the way to the sparkling of floors, which marks a split between the preparatory and interior part and which therefore functions as a milestone in the inventory phase. For the interior work, capacity buffers are inherent in the tasks and do not reveal themselves in the progress plan. A capacity buffer is when a crew is underloaded by setting aside more time to do a task than what is expected needed from that crew. This can happen for various reasons. The interior work involves many tasks, several trades and multiple interdependencies. Before kitchens are installed, painting and parquet must be done. Then, finishing goes on to make the apartment ready, by the installing of doors and listing, lighting and plugs, coupling of water and drain in kitchen, testing of various functions and so on. To calculate a certain surplus capacity may make it easier to handle the unforeseen, and still be on schedule. Maybe particularly so, because the task completions also follow a learning curve. A capacity buffer in the beginning can thus be a good strategy to keep the different crews from falling off the wagon. In addition, capacity buffers are counted in due to variation caused by differences in apartment size and additional choices made by the end users.

The sequential character of the interior work reminds of the final assembly line in Porsche's manufacturing plant. Here, you find work cells along the line performing standardized operations related to different completions. Time buffers are counted in, in between operations as every crew in each cell is provided with extra time to await and prepare for the next car on the line. As regards capacity buffers, the automotive production is much more fine-tuned to fit with the amount of operations in each cell so that the assembly line can hold an even pace all the way through this process. Besides, the variation in product mix has little impact on the assembly process since the processing times are balanced for different products.

INDUSTRIALIZED PROCESSES

A production rate of 136 apartments a year in a project would never be possible without the achievements to industrialize the housing production. Industrialization denotes the process whereby a manual based form of production becomes more alike a machine based, automated form of production. While car manufacturing is often used as an example of the latter, construction is often used as an example of the first. Nowhere is the effect of industrialization clearer than with the use of bathroom cabins. The cabins are produced offsite and delivered as fully equipped bathroom modules to the project, on site. They are installed already during the structural work, so that the inventory phase only includes their coupling to various technical systems (water, drain and electricity). If we were to build bathrooms on site instead, a rough estimate comprising all processes and trades sums up to about two weeks duration for each bathroom – for the inventory phase only. By the use of bathroom cabins, a major task is thereby ruled out of this phase.

There is a clear-cut resemblance between this modularized building process and the installation of dashboards in Porsche's manufacturing plant. The dashboard is installed as a complete module assisted by automated machinery, where operators do the job to connect it to the different systems in the car. In Porsche's production, there is also the car engine and propulsion system which are partly modularized, nevertheless being processed further in the factory before they are installed in the car. The final assembly otherwise includes prefabricated elements such as doors, lights, bumpers and so on, as well as the installing of tubes, cords and linings which are all pre-cut to fit perfectly with the car. When observing what the assembly workers do in Porsche's manufacturing plant, their operations appear as repetitive and procedural, they rely on support from automated machinery for many operations and the cells they operate are facilitated with supply of various hardware shipped onto where they stand from a storage located next to the assembly line. The housing production likewise includes the installing of pre-assembled elements such as for instance the kitchen hulls, which are put together in the kitchen manufacturing plant and delivered to the site as cabinets and drawers to be mounted on the wall. When it comes to what is going on within a process, a closer look at the crew doing the listing of doors, windows and floors may be of help. They are skilled, work in pairs and have been working together for numerous projects. The things they do are quite repetitive and procedural too, although adjusting to make things fit is also an important part of their job. For the materials they use, much of it is placed into every apartment ahead of production, in the right quantity and pre-cut.

DISCUSSION: HOUSING PRODUCTION – HOW TO MAKE IT MORE LIKE MANUFACTURING

What is the benefit of defining an apartment as the production unit? How does it assist production to know how long it takes to build an apartment? In the following, we discuss these two matters on the background of a housing project recently started up including 342 apartments. In the project, overall building costs are to be 20 per cent below the normal. Extraordinary measures are required to raise the production rate to a higher level. How come thinking of housing production in manufacturing terms should bring us any closer to achieving that goal?

By defining the apartment as the production unit, we want to turn the mindset in the work force from thinking about project completion to focusing on apartment completion. We want everyone to think in dual ways about the apartment; as a unit that is not only handed over to the next trade, but also to the residents who will live there in the end. In lean thinking, value for the customer is considered to be the ultimate goal. While the above-mentioned housing project has a real estate developer as client, it also includes 342 end users. Their customer satisfaction can easily come in opposition to what we want to achieve in this project, which is to eliminate waste. The end users are allowed to make additional choices as well as changes to their apartments. Multiple choices lead to many variances of flats, on top of the different types of flats already designed in the project. To handle this product variation is about avoiding all unnecessary errors, mistakes and left outs that potentially cause tremendous amount of waste in the production. We want the trade workers to act proactively upon quality so that things are done right the first time. Defining the apartment as the production unit we expect helps delineating their quality focus. However, information must flow in a timely and updated fashion to the trade worker stepping into the apartment, as otherwise errors will occur as unintended consequences of tasks done right but based on incomplete or incorrect information. There is also the risk of human errors or mistakes. While check, lists may, indeed, help ensuring the consistency and completeness in the carrying out of tasks, we think that by supplementing these with pictures and guidelines and sometimes even training on how to do things right the trade worker will know just what to do to. Still, errors will most likely occur. By using the apartment as the production unit, we want to trigger a proactive learning in the work force so that mistakes uncovered in one apartment are not repeated in the next one. This moreover requires systematic quality controls to be performed by each crew before the apartment is handed over to the next trade. Last but not least, we plan to hang up pictures of all the residents on the entrance door of each apartment. Every trade worker who enters can thereby say hello to those who own the apartment and suddenly faces are attached to the ones who will appreciate him or her doing a great job.

A famous quote by Henry Ford is the one saying that a customer can have a car painted in any colour as long as it's black. While the statement was made from practical concerns, it has later been used as an expression of a very standardized product. Ford had a vision to build a car for the great multitude[4]. The innovation competition our project won was initiated by the client from a similar desire, which was to provide "average Joe" with the opportunity to buy an apartment he would normally not afford. Defining the apartment as the production unit has helped substantially in the developing of its qualities, which are second to none at the same time as solutions sought are standardized. Ford explained his vision claiming that the car would be constructed of the best materials, by the best men to be hired, after the simplest designs that modern engineering can devise. The apartment we have designed, though being considerably more customized than the T-Ford, has been inspired by the very same ideas. One example being the supporting walls between the apartments, which are all straight to simplify the form work. When these walls are broken in corners, which they often are for architectural or other reasons, it makes them less buildable since the formwork has to be done in several stages instead of one. Another standardized solution relates to the placement of kitchen and bathroom, which in all apartments are connected directly to the shaft to simplify the technical installation. The unpractical and often costly process of pulling pipes from shafts to wet rooms and kitchens located elsewhere in the apartment, is thereby avoided. Furthermore, although we operate with altogether 28 apartment types in the project, five of these types make up 80 per cent of the apartments. We also use bathroom cabins, 3 types in all and not 30 or even 50 different types as we have in some of the other housing projects our company deliver. All in all, we have strived for an expedient design of the apartment to make it flexible in terms of letting the end user make it their own by adding qualities and making changes, at the same time as being rigid in some respects to make way for a standardized and repeated production process.

How does it assist production to know how long it takes to build an apartment? The preliminary analysis carried out in this paper has provided us with a vague idea that it takes between 70-80 days. This measure is neither very precise nor even informative to evaluate production performance. Still, questioning how long it took and attempting to find a preliminary answer made us aware of something very important. That the apartment, being

[4] Ford, H. (2010). *My Life and Work – An Autobiography of Henry Ford*. Greenbook Publications, llc (August 1, 2010).

treated as the unit of our investigation, was something that lied empty without being processed for most of the time during the inventory phase. If we were to use car manufacturing as an example of the same phenomenon, it would be as if the final assembly line was very long and at all times contained many cars waiting without being processed any further. The finding puzzled us, to the point that we thought there are two main problems by doing it this way. First, it might give the project the impression that it is busy and being on track, while the truth is, no apartment is completed yet and will not be in a long time. Second, that as long as the apartment lied empty one may come to think of it as ready for the next crew, while the fact could very well be that it contained hidden problems which were not detected before the apartment was further worked on.

We want to reduce the amount of time an apartment lies empty without being processed as waiting is waste – also when there is work waiting for people. Can work be structured differently so that the processing of the apartment can go on with less downtime? The question relates to defining how the production line should look like for the inventory phase. It implies, for our part, to do discrete analyses together with the main subcontractors. For instance, on how tasks can be put together in ways that allow for the trades to switch operations between them so that work becomes less fragmented and the number of returns are fewer for each crew. To be more concrete, why is it so that the trade worker doing the duct work has to go back to connect the extractor hood to the cabinet above the oven when the kitchen installer can do it in no time? What if the ventilation man, as a return favour to the kitchen guys, put the spice rack up in the same cabinet after installing the duct going down to the extractor hood? We also want to sort out if work can be divided more fundamentally based on it going vertically or horizontally, so that for instance the work in shafts can be started on earlier without interrupting the remaining inventory work. This would definitely help to compress the inventory phase, and likewise secure a more balanced – and less peaked – manning situation. Our point to make is this; that there are possibly several alternative ways to complete an apartment, and that reducing its downtime can be a very instructive measure to reach the most effective, and least wasteful one.

CONCLUSIONS

In this paper, the production of housings is considered from a manufacturing viewpoint. A preliminary study is carried out of the inventory phase in a housing project, using some elementary findings to clarify certain characteristics of this form of production in relation to automotive production as representative to the manufacturing type. The paper has shown that although miles apart in how they appear, the two production forms are useful to compare to trigger new thoughts about how to further improve the construction production. In particular, by using the apartment as the production unit, which is expected to bring about a more dedicated mindset in the work force around quality and completions – for the sake of the residents as well as the subsequent trade; a more expedient design of the apartment that allows for the end user to add qualities and make changes to a certain point limited by the standardized solutions chosen to make way for a repetitive production process, and; a growing awareness around what time is spent for to reduce the amount of time the apartment lies empty without being processed.

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STREAM 22: PROPOSING NEW APPROACHES

Serugga, J., Kagioglou, M., and Tzortzopoulos, P. (2019). "A Predictive Method for Benefits Realization Through Modelling Uncertainty in front end Design." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1321 - 1332
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A PREDICTIVE METHOD FOR BENEFITS REALISATION THROUGH MODELLING UNCERTAINTY IN FRONT END DESIGN

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ABSTRACT

Many projects continue to fail to deliver intended benefits amid uncertainty in benefits realisation (BR) programs. This is more so in Front End Design (FED) where processes remain not only understudied but also informal yet reliant on knowledge sharing. As a result, there is an emergent need for new decision support tools to support benefits delivery processes. The paper addresses uncertainty with FED processes as a way of facilitating decision making as an enabler to benefits delivery of construction projects using uncertainty modelling. The paper adopts a Dempster-Shafer approach using probability theory. This is combined with Quality Function Deployment for user and design requirements capture and management. A conceptual model is suggested that forms a basis for future validation and evaluations in action research in various contexts. The Paper introduces a novel approach to uncertainty modelling in FED to support decision making. The Dempster-Shafer Bayesian based approach also contributes to new ways for capturing contextual influences to benefits realisation.

KEYWORDS

Benefits Realisation, Dempster-Shafer Theory, Uncertainty Modelling.

INTRODUCTION

Bradley (2016) has defined BR as *'an outcome of change, which is perceived as positive by a stakeholder'*. As such, BR is aimed at delivering satisfaction to the end-user in terms of benefits and utility, also called *'Value-In-Use'* (Sweeney et al., 2018). It's therefore apparent that the process of identifying requirements and managing them is a waste reduction process. There are still major challenges in AEC in the delivery of intended benefits in many projects (Burger et al., 2019, Bradley, 2016). This failure of delivery of project core objectives has been attributed in part to complexity and uncertainties inherent within many projects (Burger et al., 2019); and insufficiencies in applied BR decision support frameworks (Bradley, 2016). Moreover, research into uncertainty particularly in a lean project delivery system (LPDS) is still widely understudied. Some isolated process conceptual studies such as bidding (Aslesen et al., 2018), improving reliability in processes (Javanmardi et al., 2018) have been limited and specific. Recently, some authors such as Torp et al. (2018) have attempted to add to the existing body of knowledge looking

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at uncertainty into management integration in Last Planner System (LPS) of planning and control to improve benefits delivery success. At the sametime, authors continue to argue for renewed emphasis on benefits delivery away from traditional focus on project processes (Smyth, 2018) and tasks and activities (Kagioglou and Tzortzopoulos, 2016). Chesbrough et al. (2018) on the other hand argue that sometimes the issues arise out of deliberate *'conceptual ambiguity'*. Moreover, Bolar et al. (2017) highlights challenges in integrating end-users to collaboratively facilitate delivery of project benefits through requirements management. Such research reinforces the position that such factors as these affect the knowledge base that guides decision making resulting in unplanned reworks, over processing/production, 'making-do' and inventory among other wastes prevalent in FED processes .

Through BR, AEC processes are able to extend the notion of benefits beyond the immediate organisational/portfolio/program interface to collaborative processes involving end-users and other stakeholders, etc. in value co-creation.

In this paper, a conceptual benefits optimisation method is presented on the basis of quantified uncertainty modelling. The method provides a first step in the development of a novel approach to improve BR in Front end Design (FED) perspective. In so doing, BR processes can gain from decision support employing a combination of requirements capture using the Quality Function Deployment (QFD) – management and Design Requirements (DRs) transformation (Akbaş and Bilgen, 2017, Yazdani et al., 2017); Utility Theory (UT) for utility of benefits analysis (Keeney and Raiffa, 1993); and the Dempster-Shafer theory (Dempster, 2008, Shafer, 1976); in conjunction with Saaty (2001) Analytical Network Process (DS/ANP) for uncertainty modelling. The combined toapproach are able to combine requirements management and knowledge uncertainty modelling for decision support.

According to literature, processes can be optimised as part of the wider planning, monitoring and control process either through (i) analysis, (ii) inspection, (iii) demonstration, (iv) testing or (v) certification (Kukulies and Schmitt, 2018). Parts of this process are seen in lean practice in the LPS (Torp et al., 2018, Kim and Ballard, 2010) and application of BIM (Bataglin et al., 2017) to support decision making. The suggested optimisation processes proposed in this paper is at the planning stage in FED processes with two process aims: 1) Assessment and analysis of BR processes in meeting the delivery of intended benefits and 2) Identify FED deficits potentially impeding the delivery of these benefits. The two aims are interrelated in the fact that while the first draws relation between User Requirements (URs) and Design Requirements (DRs) and their potential conflicts and interdependences, the second sums up what might not go right in the process. The second aim therefore captures the non-value adding processes that affects delivery of intended benefits. Optimisation processes will in themselves bear costs and benefits relating to time and resources. For this reason, the proposed method employs QFD to refine and model information relating to user requirements and how they relate to design requirements and capture any interdependences between the various parameters to reduce on resource use. Bolar et al. (2017) study using QFD and Hidden Markov Modelling (HMM) changing end user expectations to address the challenges of end-user integration construction processes. Yazdani et al. (2017) describe the importance of sound supply chain selection in delivery of green aims for organisation and proceed to use QFD & MCDM to apply it to green supplier selection to improve organisational competitiveness. UT on the other hand is employed to analyse the utility of the benefits themselves and the nature of the decision maker again contributing to better refined information for the DS/ANP analysis. Uncertain information relating to context, opinions from stakeholders and related risks is still able to be analysed alongside the refined information. The reality according to Kukulies and Schmitt (2018) for design processes is fraught with incompleteness of information and knowledge (see **Error! Reference source not found.**).

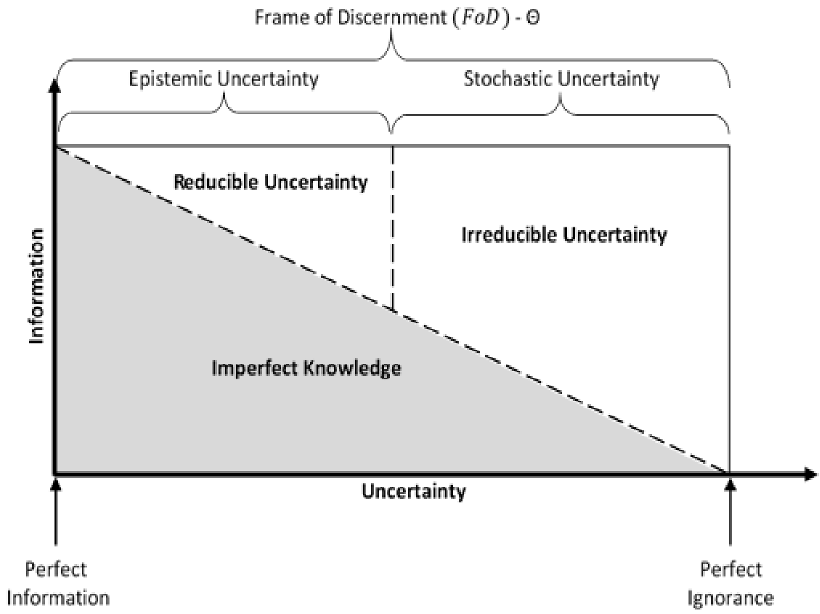

Figure 54 Relationship between Knowledge and Uncertainty(Adapted from Kukulies and Schmitt (2018)

Decision making process for example is unable to fully anticipate all the preference structures for all of the benefits. FED processes are therefore unable to definitively pronounce on all utilities and ultimately on value across the entire decision state space. This results in a three-part state space in **Error! Reference source not found.** (Kukulies and Schmitt, 2018). The fully known part of perfect information where decision making is able to pronounce itself on the outcomes, the partially describable part of imperfect knowledge which accounts for most of the reducible uncertainty; and finally, the indescribable part of perfect ignorance. The latter part is dominated by epistemic uncertainty. All these parts define the Body of Evidence (BoE) during uncertainty analysis.

BENEFITS REALISATION

A successful BR program aims to define benefits through management of stakeholder and end user requirements for implementation collaborative (Del Águila and Del Sagrado, 2016, Horkoff and Yu, 2016). BR cycle is thus a key element in FED for its overarching and collaborative approach between organisational strategy and end-user and stakeholder processes. Horkoff and Yu (2016) point to the fraught FED process in which requirements modelling is difficult; knowledge intensive (Del Águila and Del Sagrado, 2016), characterised by *'imprecision and ambiguity'* (Muñoz-Fernández et al.).

Problem Statement

Lean wastes affect production processes and in FED in particular waste in design processes will negatively impact projects leading to downstream project *dis-benefits*. This can be through unplanned reworks, making-do, transportation and motion or over processing and over production and even through inventory. AEC projects continue to fail to deliver on their intended objectives as a result. Numerous authors ague some problems in downstream processes can be traced back to FED (Kukulies and Schmitt, 2018).

In AEC, FED continues to be less understood, yet its processes are essential in capturing the elements that help shape the intended benefits both through user requirements management and design requirements transformation. It's also an important stage in setting collaborative aims for the project. Kagioglou et al. (2000) earlier highlighted wider challenges more generally in process planning among AEC projects that not only continue to be unlinear, but also largely *'uncoordinated and highly variable project processes'*. More recent research points to opportunities in FED. For example, by adopting a value co-creation approach Fuentes and Smyth (2016) and Smyth et al. (2018) separately argue that project benefit from information and knowledge sharing among collaborating multidisciplinary teams. However, FED processes are still largely little studied, remain highly unstructured and are prone to influences of both personal and contextual dynamics resulting in uncertainty across the entire project delivery cycle (Austin et al., 2001). These challenges precipitate in for example unplanned reworks (Koskela et al., 2013) , and *'making do'* (Koskela, 2004) , in FED processes that will result in delays and extra costs for the former and might affect the scope and quality of the project all affecting its intended benefits in the latter. Controlling these wastes according to authors can improve the BR cycle. For example, any needs for unplanned reworks can be detected early on; while uncertainty relating to designs processes without the full information can be assessed. Similarly, complex and over designs should be assessed for their contribution to the benefits cycle.

In the lean world, the LPS for planning and control (Javanmardi et al., 2018, Salazar et al., 2018, Torp et al., 2018, Kim and Ballard, 2010), choosing by advantages (CBA) - (Nguyen et al., 2009), Virtual First-Run Study (Nguyen et al., 2009), Language Action Perspective (Salazar et al., 2018) and BIM (Aslesen et al., 2018) have been widely applied to support planning, control and decision making. The works by Cortes et al. (2018) present some interesting perspectives in Multi Criteria Decision Making (MCDM) using CBA in delivering project benefits. However, there doesn't appear any evidence of accounting for uncertainty in the application of the tools. Despite the emergent body of research in BR, current methods are limited in supporting decisions on selection of critical benefits for optimisation and analysis; particularly on a quantitative and mathematical basis.

FRONT END DESIGN AND UNCERTAINTY

Definitions for uncertainty are varied and broad. Uncertainty in the context of this paper is that relating to fluctuations in knowledge and information lending to Klir (2004)'s definition as *'the appearance of an existing information deficit'*. Uncertainty categorisations on this basis are captured in **Error! Reference source not found.** to include stochastic – that relating to physical and nature events. This kind of uncertainty is non reducible in the sense that any further new information is unlikely to reduce it. This can involve such elements as nature or context specific physical features. For example, any further information about weather patterns may not necessarily change reduce the uncertainty related to it in FED. On the other hand, is epistemic uncertainty – that relating to knowledge deficit that's reducible. This essentially captures knowledge deficits and limitations in understanding relating to a *'phenomenon, a system or its environment'* (Kukulies and Schmitt, 2018). An example is knowledge of the location of glazing depending on the hemisphere is essential in improving design for maximum solar gain.

UNCERTAINTY MODELLING

Current lean approaches have largely adopted qualitative approaches to uncertainty management in AEC processes more generally; see (Javanmardi et al., 2018, Salazar et al., 2018, Torp et al., 2018). In mathematical modelling, various models of uncertainty modelling exist but mainly probability based and classed as levels 1 and 2 (Kukulies and Schmitt, 2018). In the first level, simplistic approaches such as Monte-Carlo sampling are used to model known stochastic distributions for the unknown yet dependent target value with a yet unknown distribution. The process therefore aims to calculate a distribution function of the dependency of the input variable and the target value. This type of modelling however fails to capture uncertainties relating to stochastic and epistemic uncertainty arising out of deficit in knowledge, data sets, conflicting information and even conflicting personalities. These uncertainties can however be accounted for by level 2 modelling which is a lot more complex. Epistemic uncertainties are also considered in the Frame of Discernment (FoD). Kukulies and Schmitt (2018) contribution is an highlight to this emergent body of research to employing uncertainty modelling in bring stability to design process through reducing unplanned reworks. The Dempster-Shafer Theory is used for this paper's proposed methodological approach.

THE DEMPSTER SHAFER THEORY OF UNCERTAINTY

Current MCDM methodology is insufficient to account for actions spaces of imperfect knowledge (Hua et al., 2008). Today, many research approaches make use of Bayesian theoretic of conditional probability and related adaptations like the Dempster-Shafer (DS) theory (Dempster, 2008, Shafer, 1976); to account for uncertainty in decision making (Hua et al., 2008, Beynon, 2005). The key importance of the DST according to many authors such as Denœux et al. (2018), among others is its ability to account for uncertain and unknown knowledge areas through providing the Frame of Discernment (FOD) and the basic probability assignment (BPA) to facilitate uncertainty information modelling. Incomplete BoE is assigned basic probability assignments (bpa) to describable and partially describable focal elements and the indescribable/FOD all assigned as DS mass functions $[m(.)]$ in an action space (Denœux et al., 2018). The following is the preliminaries of the DST.

A finite non-empty set of mutually exclusive set of acts is denoted as $\Theta = \{S_1, S_2, \dots, S_i, \dots, S_n\}$ is called the Frame of Discernment (FOD). The power set 2^{N} is the full set denoted as $2^{\Theta} = \{\emptyset, \{S_1\}, \{S_2\}, \dots, \{S_N\}, \dots, \{S_1, S_2\}, \dots, \{S_1, S_2, \dots S_i\}, \dots, \Theta\}$. The mass function on the other hand is a set from $m(.): 2^{\Theta} \rightarrow [0,1]$ such that $m(\emptyset) = 0$, and $\sum_{A \epsilon 2^{\Theta}} m(A) = 1$. $m(A) > 1$ captures the strength of belief/evidence in a benefit proposition and is called a focal element – essentially an alternative benefit for analysis while $m(\Theta)$ is the level of ignorance meaning the non-discernible weight of evidence among the focal elements. In a BoE with n as set of focal elements in a BoE

$m(.)$ defined as $s_1, s_2, \ldots, s_n$, with corresponding weights of $b_1, b_2, \ldots, b_n$ respectively, according to Beynon (2005), the BoE could be represented as:

$$m(s_i) = \frac{b_i p}{\sum_{j=1}^{d} b_i p + \sqrt{n}}, j = 1,2,\ldots,n \; and \; m(\Theta) = \frac{\sqrt{n}}{\sum_{j=1}^{d} b_i p + \sqrt{n}} \tag{1}$$

Where p is the weighting for the criteria and Θ the FoD. The basic probability assignment (bpa) can also be represented by a belief function $Bel\,(A) = \sum_{\emptyset \neq B \subseteq A} m(B)$ and a Plausibility function $Pls\,(A) = \sum_{B \cap A \neq \emptyset} m(B)$. For two independent mass functions $m_1 and\; m_2$, the Dempster rule of combination can in this case be used to combine the two as follows:

$$m(A) = m_1 \oplus m_2(A) = \begin{cases} 0, & A = \emptyset \\ \frac{1}{1-k} \sum_{B \cap C = A} m_1(B) m_2(C), & A \neq \emptyset \end{cases} \tag{2}$$

Where k is defined as:

$$k = \sum_{B \cap C = \emptyset} m_1(B) m_2(C) \tag{3}$$

k is also a normalisation constant reflecting the degree of conflict between $m_1 and\; m_2$

UNCERTAINTY BASED BENEFITS REALISATION PLAN

FED is information intensive, iterative and relies on knowledge to define and manage user requirements, transform these into design requirements that deliver the expected benefits. Thus, feedback mechanisms are part and parcel of the process to enable information refinement from design optimisation processes such as analysis, data fusions, and design drawings including schemas, concepts, 3D-models and other imagery in the definition of benefits. These activities are what links the BR and uncertainty modelling. This link has yet to receive the required scrutiny in research and academia. The two conceptualisations i.e. BR on one hand and uncertainty modelling on the other are in the main discussed separately if at all in a FED perspective. The proposed model links these two conceptionalisations presenting a new method that can support prediction of *(dis)* benefits starting at a project's FED.

UNCERTAINTY BASED BENEFITS REALISATION PLANNING MODEL

Error! Reference source not found. is the proposed uncertainty based Benefits Realisation Planning for FED.

What's intended in the model is for the methodology to draw on the link between benefits realisation processes in FED and related uncertainty and uncertainty modelling using the DS/ANP theory. The seven Step methodology employs various tools for information capture, management, modelling, optimisation and iteration. This includes following steps:

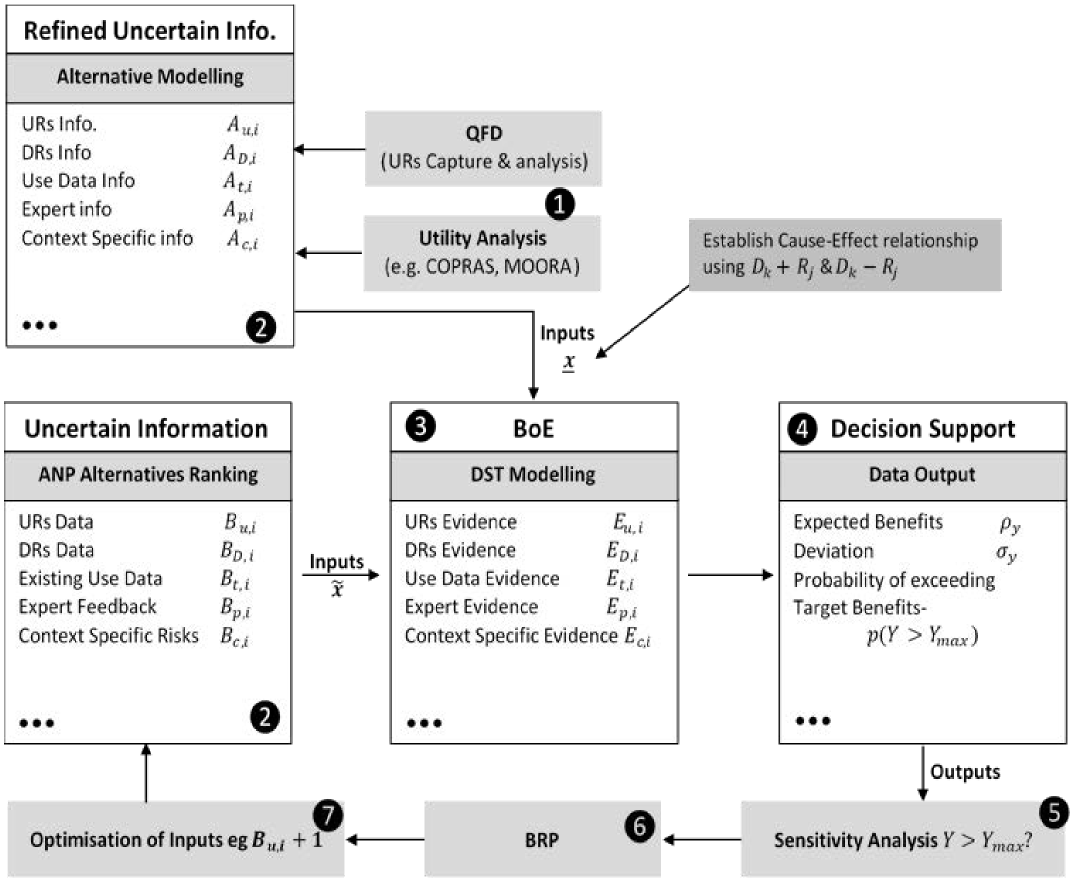

Figure 55 A conceptual Approach to Uncertain Based Benefits Realisation Planning

Step 1 – Define both refine-able and raw data and target benefits and related information. In this step, it's important that information able to support a BR and BRP process is gathered relevant to the specific analysis. Some of this data is able to be refined using pre-analysis modelling tools seen below while other information can be treated as raw data. Multiple variables can be dealt with even with varying lower level attributes. The project core purpose is perhaps the starting point in definition of potential benefit variables plus higher and lower level goals. BR has a particular focus on change management at the organisation-portfolio-program interface where some of these goals will already be defined. Stakeholder input in just as important so a collaborative approach can best serve this approach in defining scope, costings and delivery times while end users can be invaluable in guiding on user desires for example. Any approach to BR has first and foremost to set parameters that define the degree to which benefits can be achieved and how these can be planned and optimised. Secondly, risks to achieving these benefits have to be defined in the same light including identifying critical non-value adding processes. FED processes aim to manage URs and transform these into design requirements. As such it's important that in this stage, QFD is suggested as a useful tool to identify both URs and corresponding DRs on the basis of the expected benefits of the project.

Step 2- Model Input data as refine-able and uncertain variables ready for DS/ANP modelling. This is part cleaning process where some data can be pre-modelled prior to input into the DS/ANP model.

The proposed model suggests the use of QFD, Utility analysis employing the Complex Proportional Assessment of alternatives (COPRAS) and multi-objective optimization on the basis of ratio analysis (MOORA) to refine and rank URs and DRs using first a QFD analysis that yields ranking for URs and follow on comparison with identified DRs. data can be capture and pre-modelled for example as user benefits information. This is adopted through use of House of Quality (HOQ) importance weighting for the matrix (Yazdani et al., 2017). The three methodologies are not discussed in this paper owing to the limitation of scope. However, their combination contributes to the refined set of data to run alongside the uncertain data from other raw sources. Rankings for URs and DRs basing on a weighting can be obtained and the utility of benefit established among alternatives. Decision makers are adjudged to have propensity for maximisation of Utility of benefit. For utility to be maximised or minimised, equation (4) captures the scenarios when l is the objective to be maximized and r is those to be minimized For $x \in X = [x \geq 0]$:

$$Max\ E[U(x)] = U(y_1x, y_2x, \ldots, y_lx),\ Min\ E[U(x)] = U({y'}_1x, {y'}_2x, \ldots, {y_r}'x) \qquad (4)$$

The matrices U and G in Equation (5) capture the URs interdependences (Sahu et al., 2018) and DRs pairwise comparisons respectively.

$$U = \begin{bmatrix} 0 & y_{12} & \cdots & y_{1j} & \cdots \\ y_{21} & 0 & \cdots & y_{2j} & \cdots \\ y_{31} & y_{32} & \cdots & y_{3j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nj} & 0 \end{bmatrix}, G = \begin{bmatrix} 1 & x_{12} & \cdots & x_{1j} & \cdots \\ x_{21} & 1 & \cdots & x_{2j} & \cdots \\ x_{31} & x_{32} & \cdots & x_{3j} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & 1 \end{bmatrix} \qquad (5)$$

G is normalised by $X = k.a$ where $k = \max_{1 \leq i \leq n} \left(\sum_j^n a_{ij}\right)^{-1} (j = 1,2,\ldots,n)$ and thereafter through matrix transformation computing for the total relation matrix $T = X(I - X)^{-1}$ to establish for each criterion how it's ith criterion is influenced by its jth (Sahu et al., 2018). Ranking are obtained by $D_k + R_j$ where $D_i = \left[\sum_{j=1}^n t_{ij}\right]_{nx1} = [t_i]_{nx1}, (i = 1,2,\ldots,n)$ and $R_j = \left[\sum_{i=1}^n t_{ij}\right]_{1xn} = [t_i]_{nx1}, (j = 1,2,\ldots,n)$. At the end of this step, two sets of data in steps 2 should be defined forming the BoE.

Step 3 – Define the Uncertainty Modelling parameters and Model the variables in the DS/ANP model. This step is the application of the DS/ANP modelling process outlined briefly in section 0. In so doing, the process establishes firstly uncertain information from the previous step from the various sources about the yet undetermined benefit(s) as model input variables. Secondly, draw relation between the benefit(s) information and inputs on a quantitatively. Thirdly, establish and analyse the uncertainty using one of the various methods such as $u(\{b_i\}) = Pls\ (\{b_i\}) - Bel\ (\{b_i\})$ or more elaborate methods of dissonance, such as the Generalised-Hartley method or Average Width within the BoE to the extent of delivery of the intended benefit(s). Lastly, develop decision support basing on the results to attempt to reduce the uncertainty or validate the conditions for benefit(s).

Step 4 – Produce and Analyse Preliminary Results. This phase involves setting threshold parameters for analysis of the results. Combined evidences from the BoE are collected alongside their uncertainty calculations from the FOD. Rankings can for example aim to define Expected Benefits (ρ_y), deviation (σ_y), and defining the probability of any assessed parameters of exceeding Target Benefits- $p(Y > Y_{max})$. This step is important in the definition of a BRP on the basis of results from the DS/ANP modelling.

Step 5 – Carry out Sensitivity Analysis: In this step, depending on how far the uncertainty in an alternative is from the threshold, a sensitivity analysis can be carried out to establish what's the most contributor is to the uncertainty. By identifying such intricate information about a specific uncertainty, it's possible to model the decision support process to best meet the required benefits. It might suffice that more reliable information is needed in which case uncertainty in a benefit will be reduced. Alternatively, new data as evidence on a given specification can have the same desired effect. The BRP can thus engage with the process of reducing uncertainty to influence the true utility of benefit.

Step 6 – Define the Benefits Realisation Planning (BRP) program on the basis of the results from the sensitivity analysis as part of a feedback process with information about modelled uncertainties. The BR process established benefits to be analysed from a set of alternative parameters. It might suffice that uncertainty modelling reveals irreconcilable results to the level that data from data sources cannot be refined any further to support uncertainty reduction. In this case its prudent that the BRP has room to take account of this data and consider redefining the benefit in question. Conversely if the data supports the BoE in the benefit(s) then the BRP can adopt the results as decision support.

Step 7 – Iterate over uncertain information for results that do not meet criteria as new input variables. These results can then form part of a new iterative analysis as additional input variables that will yield a higher value weighted BoE in regards to the benefit. The whole analysis process can thus be updated potentially leading to improved values of uncertainty about the benefit. Should the results improve to meet or exceed the threshold, they can be adopted in the BRP. If they don't, then the process can iterate over the previous steps again.

CONCLUSIONS AND FURTHER RESEARCH

The proposed model presents a predictive mechanism for BR on the basis of uncertainty modelling. Waste among FED and AEC processes in general will affect the level and quality of information and knowledge that results in uncertainty among processes and ultimately affecting the delivery of project intended benefits. Current BR practice doesn't quantifiably account for this uncertainty yet the challenges remain in knowledge management in design processes. At the same time, uncertainty modelling promises a unique opportunity for predictive modelling using the DS/ANP approach that's gaining wide appeal among many other sectors of industry and new frontiers in AI. The proposed uncertainty based BR methodology is on the basis of existing concepts and methods such as QFD, UT and ANP. These methods and tools are used to improve some data while the model still accepts raw uncertain data to be compared alongside in establishing the BoE. The DS Bayesian theoretic is used to account for the FoD that accounts for the uncertainty within a BoE and assigning Belief and Plausibility mass functions. The results are dependent on quality input data during BRP mechanism a major challenge to the method for it to support improved delivery of planned benefits in FED. None the less the proposed method promises a practical basis for decision support for project management when implemented as an IT based system (BR Evaluation App) and also for validation and evaluation action research. This novel approach to uncertainty modelling presents opportunities for deep state understanding of design process to provide that significantly improves for decision making. Further evaluation in various project contexts will aim to assess the effectiveness of the method to assess how contextual factors influence the nature of decision making on the basis of context. It will also help draw comparisons of any improvements from the proposed methodological application as opposed to existing practice in terms of the results.

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AHP AND CBA APPLICATION TO LAYOUT DESIGN: A CASE OF CLASSROOM LAYOUT ASSESSMENT

Vijayalaxmi Sahadevan[1] and Koshy Varghese[2]

ABSTRACT

Arriving at a consensus in design decisions is challenging owing to the presence of diverse and multidisciplinary stakeholders with multiple design objectives. The literature on AEC design decision making have reported Analytic Hierarchy Process and Choosing by Advantages as two commonly used multi-criteria decision-making techniques for evaluation of design alternatives. However, the existing literature has mainly focused on choosing between material or technology and the comparison of the two techniques to assess the suitability for their application to non-spatial aspects of AEC design problem. The current work seeks to investigate the suitability of CBA and AHP to a layout design problem. A decision-making exercise involving a hypothetical case of evaluation of three classroom layouts was conducted. A set of criteria for design evaluation which was derived based on a previous study on stakeholder design values was used in the exercise. Conclusions were drawn based on the operationalization of the two techniques rather than a direct comparison of the results obtained from the two techniques.

The findings from the study indicate that CBA aids in defining a robust set of design criteria, sub-criteria and attributes and facilitates a collaborative decision-making process. On the other hand, AHP provides a structured approach for eliciting individual participant judgments. The benefits and limitations with respect to the operationalization of the two techniques are discussed in detail.

KEYWORDS

Choosing by advantage (CBA), set based design (SBD), analytic hierarchy process (AHP) and target value design (TVD)

INTRODUCTION

The requirement definition phase of Architecture, Engineering and Construction (AEC) designs is typically complex in nature involving tacit information and multiple decision points. Arriving at a consensus in design decisions is challenging owing to the presence of diverse and multidisciplinary stakeholders with multiple and conflicting objectives. Design values can provide motivational,

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broader range and long- term goals for AEC design and these values can further aid as criteria in decision making.

Lean philosophy bases its foundations on value maximization and waste minimization. Further, lean literature discusses value in AEC design in a number of contexts such as the Transformation Flow Value (TFV) theory (Koskela 2000), Target Value Design (TVD), Choosing by Advantages (CBA), etc. Although the concept of value has been reiterated in the lean literature, a common definition and categorization of design values have not emerged.

Prior studies on value-based design decision making have mainly focused on Multi- Criteria Decision Making (MCDM) techniques and their suitability to AEC design problem. CBA is an MCDM technique which has been applied to a range of choice problems. In material selection problem, CBA has been applied in choosing between rebar for beam-column joint (Parrish and Tommelein 2012), exterior wall assembly (Arroyo et al. 2012), ceiling tiles (Arroyo et al. 2013; Arroyo et al. 2016), insulation material (Arroyo et al. 2015) etc. Other applications include selection of bidder in public-sector (Schottle et al. 2017), fall protection system (Karakhan et al. 2016), etc. Similarly, the technique of AHP has been applied to problems such as the selection of equipment for construction (Shapira and Golderberg 2005), assessment of pipeline design (Dey 2003), etc.

Arroyo et al. (2014), Arroyo et al. (2015) and Parrish et al. (2015) argue that CBA technique is superior to Analytic Hieararchy Process (AHP) in the context of AEC design based on comparative studies between the two techniques. In the aforementioned studies, several factors related to the operations involved in both the techniques were used to highlight the advantages of CBA over AHP using the example of a material selection problem. The key advantages included context specificity and transparency. In addition, a few technical limitation of AHP were discussed.

In the current study, preferences between layout needs to be assessed. The characteristics of layout selection are different from material and technology selection problem. In Layout selection a user is concerned with experience within the space and this experience in relation to the space is difficult to visualize. As a result the outcomes from the options are intangible in nature due to which the evaluation of layout needs to be done using abstract criteria. Therefore, the study of the effectiveness of the application of the two MCDM techniques for evaluating spatial design needs further exploration.

A study on stakeholder values in the design of university campus buildings (Sahadevan and Varghese 2018), led to a framework for evaluating design alternatives. The framework proposes the use of MCDM technique by using stakeholder values as criteria for design decision making. The decision problem in the above study was concerned with assessing layout design alternatives. However, before applying the framework to a campus layout level, it was decided to conduct a smaller scale study to assess the suitability of the two techniques to a layout problem.

The objective of the paper is to study the suitability of the two techniques to a classroom layout design problem. The study does not attempt to compare the rankings obtained from the two techniques, but rather draws its insights from the observations made during the operationalization of the techniques.

The next section of the paper summarizes the AHP and CBA techniques. The paper then discusses the methodology adopted for the current study and the outcomes of the study followed by discussion and conclusions section.

AHP AND CBA METHODOLOGY

ANALYTIC HIERARCHY PROCESS

AHP is a widely used MCDM technique applied in various areas in deciding between solution alternatives. AHP is a mathematical tool which requires decision makers to provide pairwise comparisons at each criterion level to arrive at weights for each criterion. AHP is particularly useful in cases of conflicting criteria and can consider both subjective and objective criteria for decision making (Saaty 1980). This is the basic advantage of using AHP over cost-benefit analysis, as criteria with different units can be used for comparison, unlike cost-benefit analysis where all criteria have to be in monetary terms. The technique aids in arriving at an optimum solution considering the various criteria.

The technique of AHP is found to be suitable for this problem due to the presence of conflicting design criteria in the design evaluation problem. The other advantage of using AHP is that it does not require a statistically significant sample size. The use of expert data in AHP analysis can be representative of a group in the sample data (Golden et al. 1989). Figure 1 summarizes the steps involved in the framework.

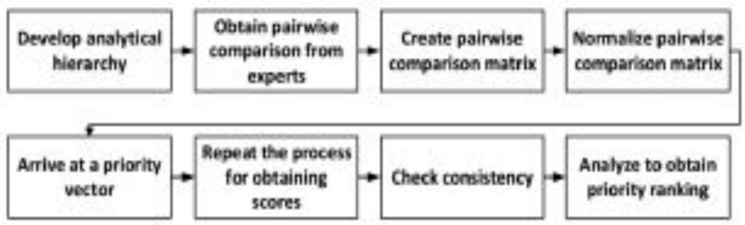


Figure 1: Steps in AHP

In AHP, a decision problem is decomposed into a hierarchy of criteria and alternatives. The information is arranged in an analytic hierarchy. The AHP operation yields relative rankings of the alternatives.

CHOOSING BY ADVANTAGES

Lean literature advocates CBA for design decision-making problems. CBA was developed by Jim Suhr (1999) to compare the advantages of alternatives. The technique is based on criteria of alternatives and stakeholder preferences for the advantages. CBA consists of a tabular method for choosing between mutually exclusive alternatives with unequal costs.

The CBA vocabulary includes the terms alternatives, factor, criterion, attribute, and advantage. The meanings of the above terms are as follows:

- Alternative – a possible decision
- Criteria – a decision rule or guideline as per decision makers

- Attribute – a characteristic or quality
- Factor – a container for criteria, attribute, advantages, importance and other types of data (Suhr, 1999)

The steps involved in CBA are as summarized in Figure 2 (Arroyo 2014):

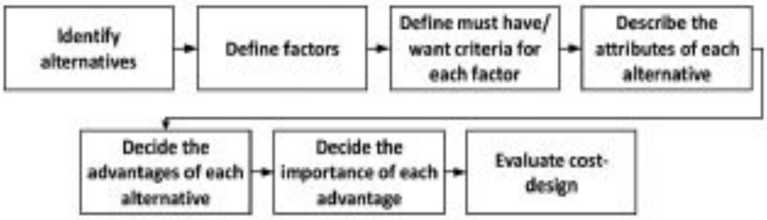


Figure 2: CBA steps

For CBA implementation a group of relevant stakeholders who influence the design needs to be selected who will be the decision makers in the process.

CRITERIA FOR LAYOUT EVALUATION

The application of MCDM necessitates a systematic identification of criteria for decision making. The set of design values from a previous study on university campus design (Sahadevan and Varghese 2018) were used as criteria for applying the two techniques. The criteria of constructability and schedule were not considered in this study as the influence of these criteria on the classroom layout decision was assumed to be insignificant. Table 1 summarizes the design criteria that were used for the study.

Table 1: Design Criteria

Sr. No.	Design Criteria	Description
1	Functional	Provision of all types of requirements, acoustics, efficient planning of spaces, availability of charging points
2	Image	The visual appeal of the design
3	Sustainable	The embodied energy of materials used in construction
4	Social	Opportunities created for interaction among users
5	Flexible	Ease of converting the space for a different utility purpose
6	Design quality	Efficient utilization of available spaces or functional efficiency
7	Health	Ergonomic considerations

Figure 3 illustrates the hierarchical framework for AHP analysis for single criteria level problem.

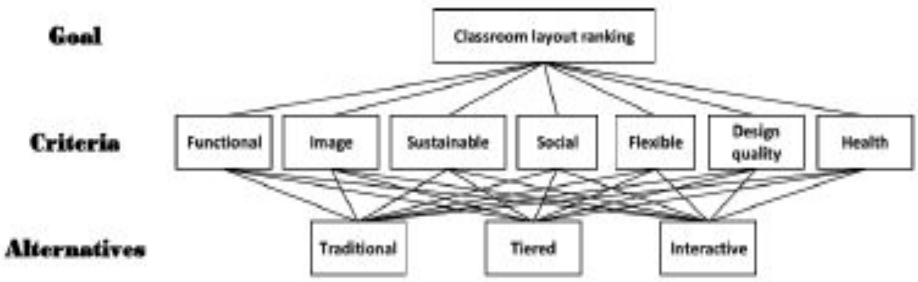


Figure 3: Analytic Hierarchy at three levels

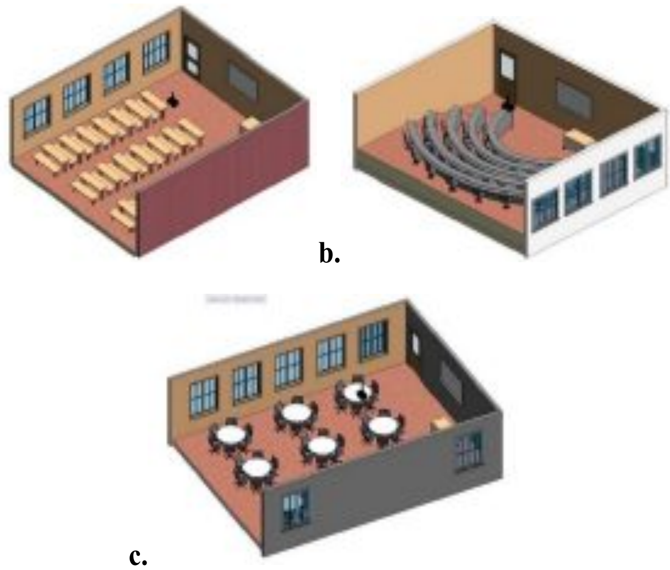
RESEARCH METHOD

The aim of the current work is to assess the suitability of AHP and CBA to layout design evaluation based on their operationalization to a classroom layout problem. The problem was concerned with design layouts for post-graduate courses for an engineering institute. Three layout alternatives were developed whose features are summarized in Table 2.

Table 2: Features of the three layout alternatives

Category	Layout 1	Layout 2	Layout 3
Type of classroom	Traditional	Tiered	Interactive
Capacity (seater)	42	45	45
Area (sq.m.)	119	110	141
Cost (₹)	6,95,000	12,57,000	8,00,000
Embodied Energy (GJ)	1401	2995	1123
Reverberation time (s)	0.34	0.28	0.5

It was assumed that the classrooms were designed for engaging courses which are conceptual and discussion oriented for a class strength of a maximum of 40 students. The location of the building housing the classroom was assumed to be Chennai-India for all the three alternatives. A Revit model (Figure 4) was developed for the three design solutions which aided in visualization as well as material take-offs.



a. **b.** **c.**

Figure 4: Revit model of the three layouts a. Traditional, b. Tiered and c. Interactive

The total cost for construction of the classroom and the energy footprint was calculated from the model. The embodied energy values were considered from the Inventory of Carbon and Energy (Hammond and Jones 2008) for construction materials for arriving at the energy footprint. The reverberation time was used as an indicator for the acoustic performance of the classrooms. The reverberation time was calculated using Sabine's reverberation equation and was found to be within permissible limits for all the three alternatives (Sabine 1964).

Since the study did not aim to compare the results obtained from the two studies, the research design did not necessitate conducting both the exercises with a single group. On the contrary, this avoided the participants from getting influenced by the judgments made from a previous exercise. The following broad steps were used to conduct the study:

i. Four experienced faculties were chosen for the AHP exercise whereas a group of 17 Ph.D. scholars participated in the CBA exercise.
ii. Both the groups were briefed with the design features of the three alternatives and subsequently, each participant was asked to rank their layout preference based on individual ad-hoc judgment.
iii. The participants were familiarized with the CBA and AHP vocabulary and procedures.
iv. The participants were asked to list down and discuss the criteria with which they would evaluate the layout of the classroom.
v. AHP / CBA sessions were conducted individually for the AHP and as a group for CBA. The session was audio recorded for analysis after the study. The AHP analysis was done using a standard commercial software.

One of the challenges in AHP implementation was obtaining consistency in the data. AHP data with an inconsistency above 10% cannot be considered for analysis forcing the researcher to either repeat the process with the particular participant or altogether eliminate the data point. The major challenge in conducting the CBA exercise was co-locating all the decision makers. The findings from the two exercises are discussed in the next section.

RESULTS

Prior to starting the exercise, a brainstorming exercise was conducted to identify whether the identified criteria (Table 1) were comprehensive enough for evaluating the design alternatives. The discussion did not yield any additional criteria other than the ones mentioned in Table 1.

AHP RESULTS

Table 3 summarizes the rankings given by the four respondents for the three alternatives based on individual ad-hoc judgment.

Table 3: Individual judgment

Decision Maker	Rank 1	Rank 2	Rank 3
Faculty 1	Tiered	Interactive	Traditional
Faculty 2	Tiered	Traditional	Interactive
Faculty 3	Interactive	Traditional	Tiered
Faculty 4	Tiered	Traditional	Interactive

The outcomes of this rankings indicate that majority of the faculty (three out of four) preferred tiered classroom over the other two options and three out of four faculty gave rank 2 to the traditional classroom. The results in the form of scores obtained from the AHP analysis are summarized in Table 4.

Table 4: AHP scores

	Traditional	Tiered	Interactive
Faculty 1	0.280	0.332	**0.388**

Faculty 2	0.275	0.315	**0.41**
Faculty 3	0.07	**0.707**	0.223
Faculty 4	**0.742**	0.183	0.075

Inconsistency in all the four cases were below 10%. The AHP scores indicate that AHP yielded different rankings compared to the individual judgments. For example, faculty 1 and 2 preferred tiered classroom over the other two based on individual judgment. However, the AHP exercise resulted in the interactive classroom as rank 1 in both the cases. Similarly, as per the AHP score faculty 3 gives high preference to tiered classroom although the faculty had given rank 1 to interactive classroom and rank 3 to tiered classroom based on ad-hoc judgement. Faculty 4 ranked the three classrooms in the order of tiered over traditional over interactive however the AHP analysis indicates high preference to traditional classroom. The reasons for this variation from the individual judgement is discussed in the discussion section.

CBA RESULTS

Figure 5 summarizes the rankings given by the participants based on individual ad-hoc judgment.

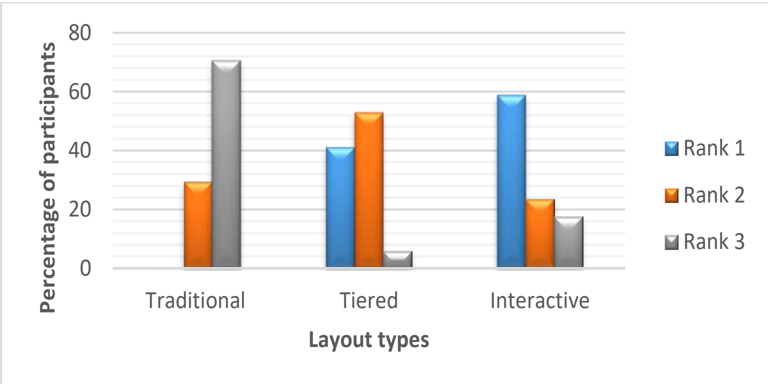


Figure 5: Rankings based on individual participant intuition

58.8% of the participants gave rank 1 to interactive classroom, whereas the remaining 41.2% gave tiered classroom rank 1. Almost 70% of the participants gave rank 3 to traditional classroom. From the results, it can be said that the majority of the participants prefer interactive over tiered and traditional classroom. As all the participants are Ph. D. students, these judgements are predominantly from the user perspective.

CBA Table:

The following Table summarizes the CBA exercise.

Table 5: CBA summary

Factors	Alt.1: Traditional		Alt.2: Tiered		Alt.3: Interactive	
1. Functional **1a. Provision of all classroom requirements** **Crit.: Higher is better**	Att: Provided		Att: Provided		Att: Provided	
	Adv.:	IofA:	Adv.:	IofA:	Adv.:	IofA:
1b. Acoustics **Crit.:Reverberation time (s) within permissible limits**	Att: 0.34 (within permissible limits)		Att: 0.28 (within permissible limits)		Att: 0.5(within permissible limits)	
	Adv.:	IofA:	Adv.:	IofA:	Adv.:	IofA:
1c. Planning of spaces & circulation **Crit.: Better ability to walk around the classroom**	Att: Some circulation space		Att: Less circulation space		Att: More circulation space	
	Adv.: Some ease for users to move around in the classroom	IofA:20	Adv.:	IofA:	***Adv.: More ease for users to move around in the classroom***	IofA:100
1d. Electrical layout **Crit.: Better accessibility of charging points**	Att: Adequate accessibility		Att: Adequate accessibility		Att: Adequate accessibility	
	Adv.:	IofA:	Adv.:	IofA:	Adv.:	IofA:
2. Image **Crit.: More appealing is better**	Att: Some orderly arrangement		Att: Orderly		Att: Least appealing/ could get disorderly	
	Adv.: Less visual appeal	IofA:30	Adv.: Visually appealing	IofA:90	Adv.:	IofA:
3. Sustainable **Crit.: Embodied Energy (GJ), lower is better**	Att: 1401		Att: 2995		Att: 1123	
	Adv.:1594	IofA:50	Adv.:	IofA:	Adv.:1872	IofA:60
4. Design quality **Crit.: More the area (sq. m.) was considered better for the user**	Att: 119		Att: 110		Att: 141	
	Adv.:9	IofA:30	Adv.:	IofA:	Adv.:31	IofA:90
5. Social **Crit.: Higher interaction opportunities are better**	Att: Low interaction opportunities		Att: Moderate interaction opportunities		Att: High interaction opportunities	
	Adv.:	IofA:	Adv.: Somewhat social	IofA:50	Adv.: More social	IofA:90
6. Flexible **Crit.: Ease of future adaptability to changes, higher is better**	Att: Can be modified with some ease		Att: Cannot be modified easily		Att: Can be modified with greater ease	
	Adv.: Somewhat adaptable	IofA:40	Adv.:	IofA:	Adv.: More adaptable	IofA:60

In the CBA exercise, the criterion of ergonomics was not considered as the group was not able to arrive at a consensus on objective attributes for judging the alternatives due to the subjective nature of the criteria. The advantage of ease of circulation was considered as the paramount advantage. The results of the CBA exercise are summarized in Figure 6.

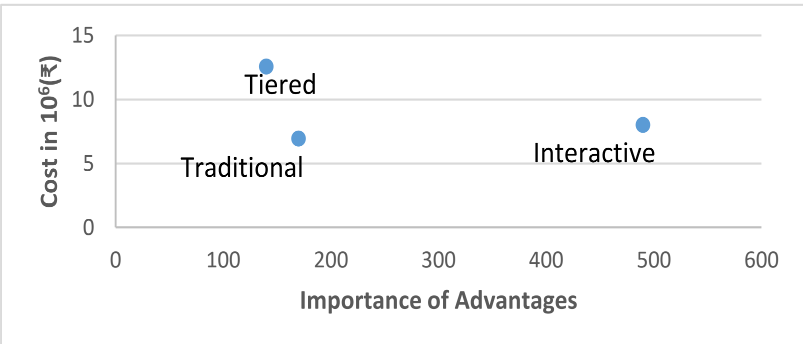


Figure 6: Cost v/s IofAs

As can be observed from the graph, the interactive classroom has the highest IofA of 490 with a cost of ₹ 8,00,000. The traditional classroom has an IofA of 170 with the least cost of ₹ 6,95,000. Both individual rankings and the CBA outcomes show that the group preferred interactive classroom over the other two alternatives. The IofA of the interactive classroom is way higher compared to the other two alternatives. Further, the cost – IofA graph indicates that although the traditional classroom cost is least among the three, the interactive classroom is the best option as an increase in cost by ₹ 10,50,000 yields advantages which is more than twice of the traditional one.

As the exercise was conducted for a hypothetical case, participants were required to provide inputs based on knowledge and experience. It goes without saying that practitioners as participants in the study would provide realistic inputs in terms of criteria and attributes as opposed to non-practitioners due to lack of on-field experience which is the limitation of the study. Another limitation was the presence of a large group (17 members in the case of CBA) which can lead to chaos affecting the decision-making process as opposed to a smaller group which is easier to control.

DISCUSSION AND CONCLUSIONS

Role of individual preferences in decision making:

As discussed earlier the AHP scores indicated variation in the faculty rankings between the ad-hoc opinion of faculty and their AHP computed preference. The AHP scores of faculty 1 and faculty 2 indicate their preference towards interactive type of classroom in contrast to their ad-hoc opinion in which both the faculty gave rank 1 to tiered type of classroom. As per the AHP scores, the interactive classroom scored high due to the 'social' and 'flexible' criteria. Both faculty 1 and 2 handle courses which are pedagogically interactive and involves group discussion. The AHP process ensured that the individual preference of the decision makers for all the criteria is elicited thereby ensuring a more holistic representation of their actual preference.

The variation in the judgments of faculty 3 and 4 can also be similarly explained. Although, faculty 3 gave rank 1 to interactive classroom, the AHP score indicates high preference towards tiered type of classroom. This was due to the high weightage given by the faculty to 'functional' and 'image' criteria. The faculty predominantly engages in lecture-based courses which does not involve student interaction. Faculty 4, gave rank 1 to tiered classroom during ad-hoc judgment but showed high preference towards traditional classroom. Faculty 4 also engages in lecture-based courses which does not involve group activities.

Upon discussions with the faculty, it was revealed that the faculty gave ad-hoc judgment depending upon the type of courses they handle and other factors such as the ease of control of the audience. From the AHP analysis it was observed that the criteria of 'social' and 'flexible' influenced the final outcome of the process which were not considered during the ad-hoc judgment. The AHP process required that the faculty give their preferences for all criteria mentioned in Table 1 aiding in the inclusion of all relevant criteria in decision making.

Soundness of decision making:

The soundness of the two techniques in layout decision making are discussed below using four important factors reported by Arroyo et al. (2015).

- **Consistency**: Arroyo et al. (2015) have discussed how removal of certain non-differentiating criteria can lead to rank reversal in AHP. It goes without saying that CBA is beneficial with respect to this factor. However, there is no explanation in the existing literature concerning the quality of decision by AHP if only differentiating criteria are used. The question whether AHP decision can be made more sound by considering only differentiating factor needs further exploration.

- **Context- specific**: Arroyo et al. (2015) discuss the limitation of AHP citing that factors' weights are obtained from experts without specific alternatives. While CBA process is solely based on context specific attributes, AHP weights in the current work were obtained by considering the available alternatives which makes the judgment context specific.
- **Transparency of trade-offs within and among factors:** Arroyo et al. (2015) discuss about linear trade-offs in AHP operations being unrealistic when concerned with criteria which do not exhibit linear increments of performances. CBA on the other hand is not dependent on such assumptions. These assumptions are certainly a draw-back of AHP and better methods of choosing criteria and eliciting preferences needs to explored.
- **Subjectivity:** In the current work it was found that agreeing on advantages for a subjective criterion such as image was a challenge as there were strong and clear differences in the opinion of participants.

Some additional factors from the current study are summarized below.

- **Collaboration and transparency:** While, the use of AHP in the current work illustrated how individual preferences influence decision making, CBA facilitated collaborative and transparent decision making which is a necessity in design decision-making. However, the dynamics of the decision-making group has an influence on the time and effort expended in reaching a consensus on attributes as well as on individual IofAs. In typical design situations where diverse stakeholders are trying to maximize their objectives, it can be challenging to arrive at a consensus. As the scale of the problem increases, so does the complexity of the design attributes rendering the technique even more challenging to implement. In case of AHP, aggregation of individual judgments for arriving at group consensus and its influence on design decision making needs further exploration.
- **Abstractness of criteria:** An important criterion in the layout of the classroom and furniture layout is ergonomics. Due to the subjective nature of this criterion, obtaining consensus on advantage and importance of advantages is challenging.

Ease of operationalizing of the techniques: As the AHP technique involves obtaining individual preferences and scores, the participants need not be co-located and the individual judgements can be aggregated to analyze the group judgement. After the initial brief, the participants took ten to fifteen minutes in eliciting the weights and scores. The CBA exercise is collaborative and necessitates the co-location of all decision makers involved with the design. The CBA exercise took three hours which was much longer compared to the time spent by a participant in AHP. Thus, it can be stated that AHP can be operationalized with relative ease as opposed to CBA wherein the decision makers are required to invest more time and effort. However, in the current study the longer time taken to arrive at a decision can be attributed to the larger size of the group (17 members) involved in the exercise.

CONCLUSIONS

From the discussions, it can be concluded that AHP aids in capturing individual preferences in design decision making. AHP was found to be easier to implement in case of subjective and abstract criteria. Although, AHP is based on individual judgment it provides structure to decision making and hence it is easier to operationalize. The disadvantages of AHP with regards to consistency and trade-offs call for further exploration. In order to make informed decisions, it is essential that design decisions are made collaboratively. CBA allows decision makers to arrive at sound criteria and sub-criteria and indulge in collaborative and transparent decision making. In order to have a fair comparison between the two techniques similar number of participants is warranted which is a limitation of the study.

FUTURE WORK

The benefits of both the techniques need to be harnessed to arrive at a robust method for layout design evaluation. Therefore, a CBA-AHP framework which combines the characteristics of the two techniques needs to be explored further.

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DESIGNING MUNICIPAL WASTE MANAGEMENT PROGRAMS USING CHOOSING BY ADVANTAGES AND DESIGN STRUCTURE MATRIX

Catalina Perez[1] and Paz Arroyo[2]

ABSTRACT

Designing public environmental policies is not an easy task. Decision makers must consider multiple social, environmental and economic aspects in order to achieve sustainable solutions. They must also manage interrelated information and preferences of different stakeholders to ensure that the policy suits the community and accomplishes its goals. This research study focused on analyzing the design process of environmental public policies using the Choosing by Advantages (CBA) decision system integrated with Design Structure Matrix (DSM) to make complex decisions. A case study involving the redesign of a waste collection program was conducted, where three complex decisions were made using the CBA method. Researchers proposed using DSM to decrease negative iterations by finding the optimal order of decisions. Using DSM helped to decrease the number of iteration loops, and document the assumptions to make the process more transparent. Future work should measure the impacts of using CBA together with DSM to make decisions in the formulation process of public environmental policies.

KEYWORDS

Waste, choosing by advantages, design structure matrix, negative iteration, sustainability

INTRODUCTION

Designing a new policy related to environmental management is a difficult task for decision-makers due to the amount of information and the involvement of multidisciplinary fields (Buzuku, Kraslawski, & Kässi, 2016). Moreover, it is necessary to include citizens and the community's visions about the program during the planning and design stages (Renn, 2006). In particular, Municipal Solid Waste (MSW) management is a complex problem that addresses multi-trajectory, non-linear, and dynamic interrelated components of a system that must consider different aspects such as social, economic, and environmental dimensions to achieve its goals (Hoornweg & Bhada-Tata, 2012).

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The complexity of designing waste collection programs also lies in the many variables that must be addressed, where every variable has several options associated with it. Decision-makers must put special emphasis on the design stage since variables design directly impacts the effectiveness of the program and its participation rate (Renn, 2006).

Traditional practices cannot define and describe the complexity of the problem in early stages of the design process because of its uncertainty (Buzuku, Kraslawski, & Harmaa, 2015). Moreover, these practices usually lack the capability to perform sustainability analyses in early stages of design development. All these failures result in an inefficient process of retroactive modifications to the final solution (Azhar, Carlton, Olsen, & Ahmad, 2011).

Incorporating conflicting factors with different criteria is required in order to assess possible solutions for sustainability problems. Using multicriteria approaches is needed to support the decision-making process during the design stage. This approach must also be capable of managing stakeholders' preferences and including the community's visions as inputs to make key decisions about the features of the policy. Moreover, designers must consider and manage the interrelated decisions and information that the design process creates, in order to discover the real effects and impacts that the problem generates (Liew & Sundaram, 2009).

The purpose of this study is to establish a systematic approach to design public environmental policies related to solid waste management that consider and manage interrelated decisions and information created during the process. It also allows for the management of stakeholders' preferences and community visions during the design stage. In this context, this paper focuses on the synthesis of methods and techniques such as Choosing by Advantages (CBA) decision system and Design Structure Matrix (DSM) to allow for the management of stakeholder preferences to support interrelated decision-making processes. Researchers conducted a case study where three decisions on redesigning a curbside waste collection program were analyzed. The proposed approach seeks to clarify the decision-making process and avoid negative iterations that are activities and work that do not add value to the final process (Ballard, 2000).

LITERATURE REVIEW

MUNICIPAL SOLID WASTE MANAGEMENT

MSW Management has become a problem since the global impacts of solid waste are growing fast. Among these impacts are high levels of GHG emissions, large occupation of landfill spaces, and contributions to flooding and air pollution that affect public health (Hoornweg & Bhada-Tata, 2012). The global nature of MSW also involves increasing number of links between products, urban practices, and the recycling industry. Therefore, choosing appropriate technology and methods to manage all the diversity encompassed within MSW helps to improve human health and environment, promote reuse and recycling, enhance waste prevention programs, and implement extended producer responsibility collectively (Pires, Martinho, & Chang, 2011).

The complexity and uncertainty of environmental problems arise from the difficulty of addressing social, environmental, and economic dimensions, and from insufficient knowledge presented in the design stage. These impose a need for integration of additional information as it becomes available, and call for decision-making processes that allow for integration of different value judgement and logics (Hove, 2000).

For waste management policies, their effectiveness relies on participation rates, and it is therefore crucial to consider the citizens' preferences during the design process (Renn, 2006). Policy-makers and experts must also participate in order to address different aspects to design for sustainability. Consequently, practitioners need to have a shared understanding of the interactions and interdependencies between social, economic, and environmental goals, their complementarities, and potential policy conflicts and trade-offs (OECD, 2016) in order to design an effective policy focused on sustainable development.

On one hand, the formulation of new environmental public policies implies ~~a~~ re-conceptualizing the role of experts, practitioners, and the community in the production and use of information to support the whole process. Therefore, the formulation process needs a system to manage stakeholders' preferences and support a participatory process. On the other hand, sustainable solutions also demand a re-configuration of complex socio-technical systems (Adrian & John, 2009), thus policy makers must emphasize their consideration of all interrelated information to discover the true impacts of the final policy.

INTERRELATED DECISION-MAKING PROCESS

A multicriteria decision making (MCDM) approach is needed to address high uncertainty, conflicting objectives, multiple stakeholders and their preferences, and different aspects of sustainability (Wang et al., 2009). There are several MCDM methods widely used in design processes such as Weighting rating and calculating (WRC) and Analytical hierarchy process (AHP). However, not all of them can manage the decision-making process in a sustainable manner. Studies that compare WRC and AHP with Choosing by Advantages (CBA) decision system showed that CBA performs better than the others when making sustainable decisions (Arroyo et al., 2015), because the other methods do not consider relevant differences between the alternatives. Additionally, weighting factors are used to hide the trade-offs of the decisions, and thus decision-makers do not fully understand the implication of each criteria. Moreover, CBA is capable of creating a transparent and collaborative environment for making sound decisions in design (Kpamma et al., 2016).

There are several studies which formulate frameworks, guidelines, and assessment approaches to improve the involvement of stakeholders in the design of public policies (Edelenbos & Klijn, 2006; Thabrew, Wiek, & Ries, 2009). However, none of them manage the stakeholders' preferences and deliver value through a decision-making system. Kpamma et al. (2016) used CBA to manage the preferences of users during design stage in the construction industry. As a result, CBA worked as a participative decision method that promoted a collaborative environment among stakeholders. CBA also fostered an atmosphere that enabled knowledge sharing and common understanding of the information created in the design process.

Nevertheless, CBA cannot consider the interrelation of the decisions. Disregarding these interrelations hide the real effects and impacts that the problem generates in the project´s lifecycle (Liew & Sundaram, 2009). With this context in mind, researchers propose using Design Structure Matrix (DSM) to manage interrelated information and decisions. DSM is a tool that allows the user to analyze projects or models with the purpose of decomposing and integrating problems (Browning, 2001). This is achieved by breaking down a system into its elements, tasks, or decisions, understanding and documenting the interrelations of these tasks, and analyzing potential reintegration of them via clustering or sequencing. Resequencing activities aims to identify coupling in the process, thus allowing the design team to try solving iterations problems, isolate uncertainty, and raise the confidence associated with decision-making (Eppinger, Whitney, Smith, & Gebala, 1994). In addition, reorganizing information helps maximize the availability of information, minimize the size of iteration loops, and minimize the number of iterations. There are several studies that focus on applying DSM in the design stage (e.g. Browning, 2001; Pektaş & Pultar, 2006; Tuholski & Tommelein, 2010). All studies had positive impacts on the project's outcomes. DSM helped to document and understand activity dependencies, share available information in early stages of design, put effort into coordination, and expose conflicts due to the interrelation of tasks and planning iterations to reduce wastes. Other studies provide information flow models through DSM (Baldwin et al., 1999; Eppinger et al., 1994) to manage the design process. There are few studies that relate DSM with sustainable policy formulation (Buzuku et al., 2015, 2016). However, these studies hide the trade-offs of the different possible solutions by optimizing the whole system behind criteria that are not necessarily understood by all stakeholders. This study proposes using DSM to identify interrelated decisions, then resequencing them to avoid negative iteration during the design stage. Additionally, it aims to separate the entire problem into approachable tasks, and reintegrate it to define the decision-making process.

RESEARCH METHOD

This research uses a case study to analyse the decision-making process using the CBA method to make decisions regarding the design of municipal solid waste management policies and programs. The case study protocol was: 1) The design team made decisions using CBA decision system, 2) Researchers collected practitioners' feedback about the process to understand how CBA worked for complex decisions, and asked the design team to evaluate CBA compared to their previous experiences, 3) Researchers proposed the use of DSM to improve the process by addressing interrelated decisions and information. 4) With the support of the design team, researchers found the optimal order of decisions to avoid negative iteration in the design process. Finally, 5) researchers compared the design process using CBA together with DSM vs. traditional practices where no formal method was used.

CASE STUDY

The project adopted for the case study was the redesign process of a waste collection program for a city with a population of approximately 275.000. The scope of the program included evaluating redesigning the existing recycling program, designing an organic waste collection program, evaluating redesigning the program of waste collection, defining financing options, cart sizes, depots, and collection frequencies for the different programs.

Specific tasks considered in the process included the development of a variable rate waste utility (PAYT Utility) and evaluation of depots and other waste services.

The main decisions: defining the Recycling Program, Organics Program, and PAYT Utility were made using three separate CBAs. To create alternatives and to define the order of the decisions in the early stages of the design process, the team created a decision tree to visualize and define the information flow. To decide on the list of Factors, multiple stakeholders were consulted by one project manager for each CBA. The project manager for each decision had to decide which Factors to include and which to consolidate into bundles that represented a single common Factor. The team used CBA for each decision through workshops to facilitate the decision-making consensus. The CBA framework was delegated to specific subject matter experts who then populated the Attributes and Advantages of their assigned Factors. The team also created financial models for each Alternative, and the average initial monthly cost for customers was calculated. Costs for each Alternative were then plotted against the Total Importance of Advantages for each Alternative. To ensure that the redesigned system reflected the preferences of the public, an external consultant was hired to assist with the development of a community engagement process, and the analyzed results were used to populate Attributes and Advantages in order to capture the values of the community in the decisions. Finally, practitioners gave feedback on the process through a survey and interviews in order to better understand the advantages and disadvantages of using CBA for making complex decisions related to public environmental policies.

NEGATIVE ITERATION DURING THE DESIGN PROCESS

Researchers gathered the practitioners' comments during the workshops, and used them to understand how to approach failures within the process, and how to improve the implementation of CBA. The main problems were the complexity of the decisions, and understanding which factors to assess in order to find a sustainable solution. The most time-consuming tasks were defining the key decisions to be made before starting a CBA, and defining the factors for every decision. Moreover, the interconnection of information through the process made decisions difficult. CBA is limited due to its disregard for interrelations between the decisions that could bring problems to discover the real impacts of the program due to the amount of information created that is inter-linked in the process (Liew & Sundaram, 2009). CBA approach makes decisions as isolated systems that could increase the iteration process and increase the time it took to make the decisions. Thus, without a tool that manages all the information, the process needed constant review and rework.

Using supplementary tools that address interrelated information could mitigate the impacts of not considering interrelated decisions. To improve the design process for complex decisions, researchers propose using DSM to separate the whole problem in order to better understand the complexity and uncertainty of the process. Then, DSM can reintegrate the process to have all the information available at the time that is needed. First, it is necessary reintegrate the defined decisions through dependency sequence to discover the optimal order of decisions. This helps to maximize the availability of information, minimize the size of iteration loops, and minimize the number of iterations (Austin et al., 2000). Second, a revision of the process must be conducted to understand where the iteration loops and tearing dependencies are, to avoid negative iteration during the design stage. Then, practitioners and decision-makers can see the interrelation of the decisions and consolidate the path the process should follow.

REINTEGRATION VÍA SEQUENCING DEPENDENCY

Due to the complexity of the decisions and the manual design procedure of the decision tree, it was difficult to see some of the relationships between the decisions. The result was a fuzzy decision tree where the dependencies between decisions were difficult to show in one information flow. The decision tree is presented in Figure 1.

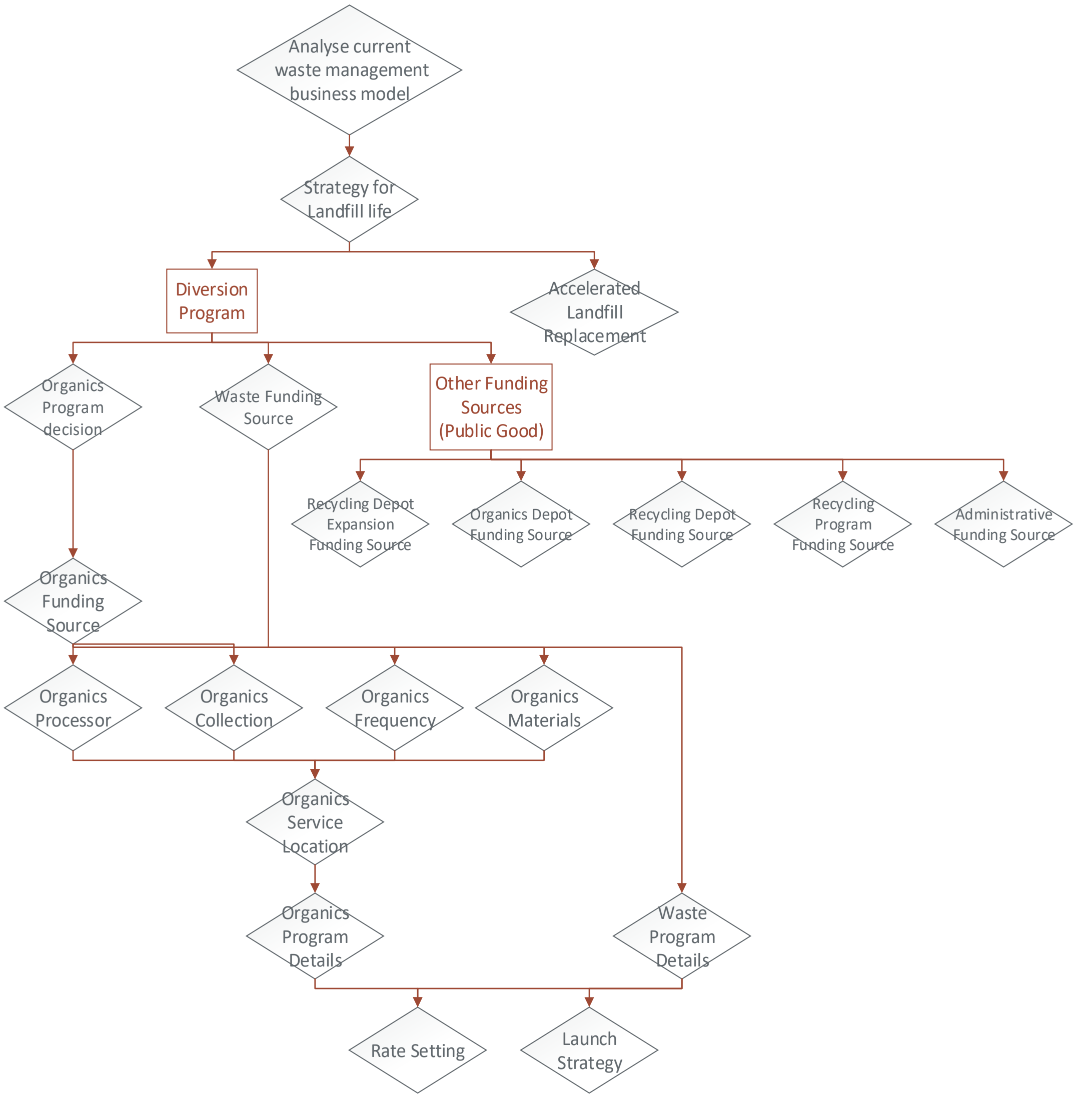

Figure 1: Decision tree of the design process

The tool presents different paths where the information needed to move to the next cluster is not well defined. Not defining a clear path forward could increase the number of iteration loops and the time it takes to make decisions. Also, this type of tool can model parallel and sequential tasks, but cannot model feedback and iteration that is characteristic of the design stage.

Researchers created a DSM to illustrate the dependencies of the problem and find a path that would minimize the number of iteration loops during the design stage. To create the DSM, researchers considered the decisions to be made in an random order, and assigned the dependencies by consulting with an expert on the design team. These are the unified decisions for the three separate CBAs made for Recycling, Organics, and PAYT programs. Decisions to analyze and their dependencies are shown in Figure 2.

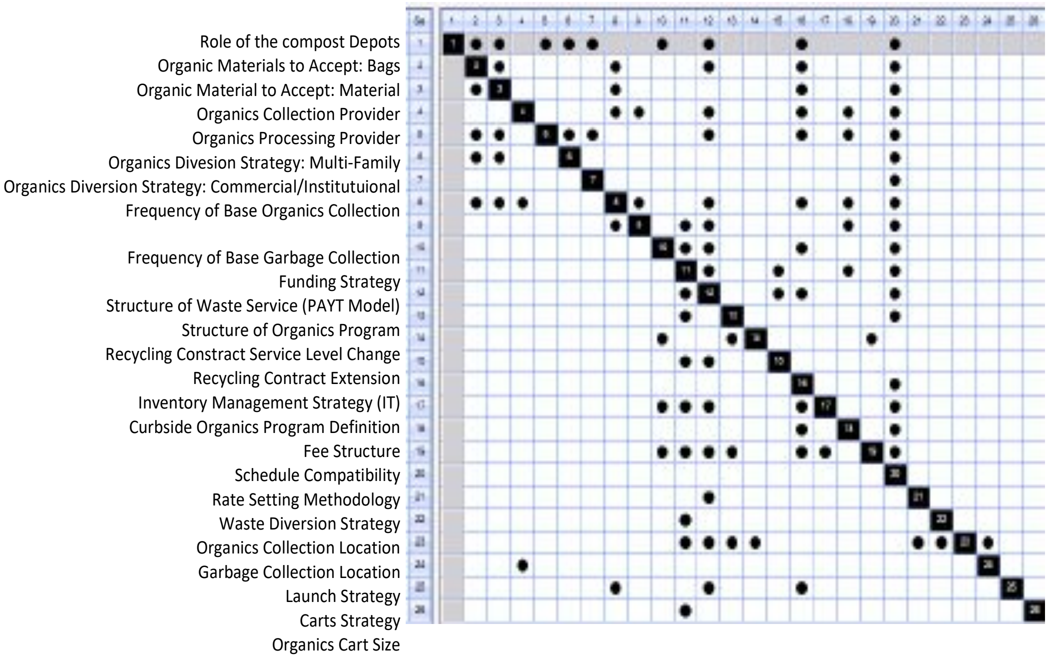

Figure 2: DSM for unified waste utility decisions for a waste collection program

TEARING AND REVIEWING DSM

DSM can reintegrate the decisions through dependency sequence to find the optimal order according the dependencies set before. Figure 3 shows the results of DSM before and after revision (Figure 3a and 3b respectively). The first iteration of DSM shows two iteration loops. The first loop involves decisions regarding making changes to the Inventory Management Strategy (IT), defining the Structure of the PAYT Model, and defining the Structure of the Organics Program. To solve this problem, the dependencies of making changes to the IT Strategy were teared because there was not sufficient time to implement comprehensive changes to the existing IT Strategy according to the results of the other decisions. After this tearing, only decisions regarding the structure of the Organics Program and the PAYT Model are interrelated. Decision-makers can put effort into designing a solution were the two decisions have an optimal performance together. The other iteration loop involved the following decisions: (1) Define role of bags for the Organics Program; (2) Define accepted Materials for the Organics Program; (3) Define Collection Provider for the Organics Program; (4) Define frequency of Organics Collection; and (5) Define Frequency of Garbage Collection. To solve this iteration loop, three assumptions were made before making the decisions. First, in relation with Organics Collection Frequency, the assumptions set were choosing the alternative with lowest cost regardless of interdependent impacts, and tearing the dependency with the definition of Organics' carts size. Second, to solve the interdependencies of Garbage Collection Frequency, the alternative with lowest cost was chosen. Finally, to solve the interdependencies with defining which Material to accept in the Organics program, the decision was made using a separate and less complex CBA that no plastic would be accepted. Tearing these dependencies changes the size of the iteration loops where only two decisions are interrelated in every loop. It helps to have all information available when these decisions are made. Moreover, by illustrating the information flow and marking where the iteration is could prepare practitioners to make interrelated decisions and know what information is needed to make these decisions.

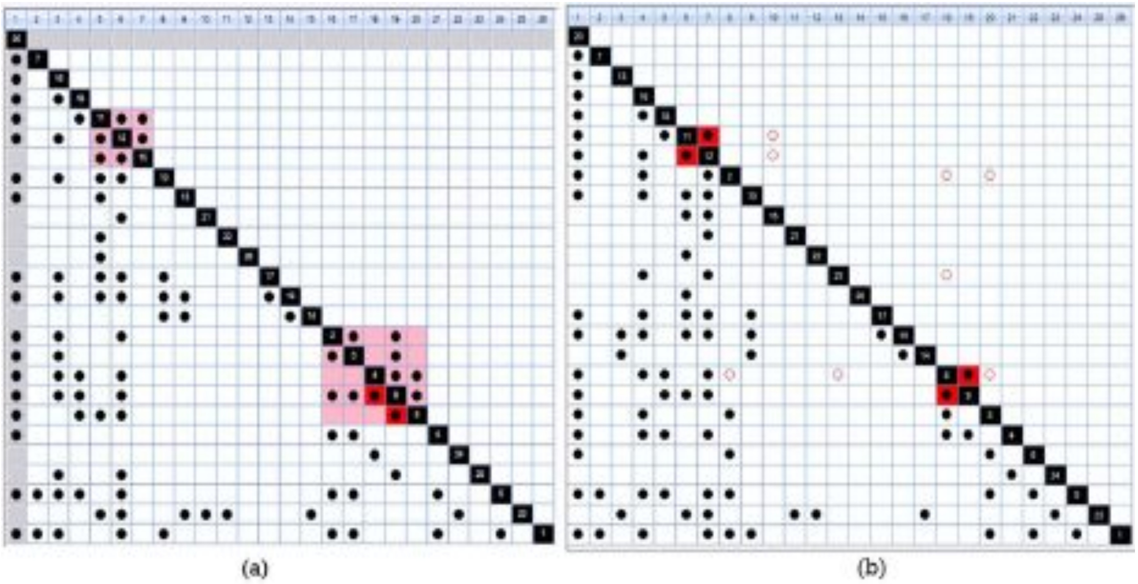

Figure 3: (a) First result of DSM (b) DSM results after revision

DISCUSSION

Using DSM together with CBA allows the user to make interrelated decisions and managing stakeholders' preferences. Additionally, integrating DSM and CBA allows for the documentation of interdependencies among decisions in a fast and simple manner. It also allows for the manipulation of high complexity levels in contrast to traditional tools as decision trees. Therefore, this method would enable practitioners to handle complex problems as a whole, as opposed to traditional practices where interdependencies are not clear for all stakeholders. In addition, DSM permits the documentation of assumptions required to move forward along a linear/sequential path. This makes the process more transparent by registering information that would serve to review the process for an eventual policy modification and for creating reports for the accountability process delivered to the community and the governance. Moreover, the method identifies the optimal order of decisions by not influencing the sequence based on undocumented knowledge. Thus, all information that is needed to make decisions is documented and understood for all stakeholders that participate in the process.

There are other applications of DSM integrated with CBA that can solve problems of negative iteration, but are not discussed in this work. Clustering the factors that practitioners must assess could decrease the time it takes to define the factors of the CBAs. This analysis could avoid excessive time in the definition of the condensed factors by nreaking down the problem. Then, a reintegration of the factors via clustering sequence could avoid duplicated factors and improve the consensus on what practitioners should evaluate when choosing the best alternative to meet the goals of the program.

CONCLUSIONS

This work contributes to the body of knowledge by using CBA together with DSM for make complex decisions to formulate environmental public policies. In particular, three decisions were made to redesign a waste collection program. CBA allowed practitioners to assess multiple aspects in Organics, PAYT Utility, and Recycling Program decisions to achieve sustainable solutions. Preferences of the community and municipality were included in the assessment, along with environmental and economic factors to ensure that the program suited the features of the community and accomplished the goals of the governance. Nevertheless, CBA is limited due to the fact that it does not consider interrelated decisions that impact the process as an excessive time in the definition of the decisions and Factors. To solve this problem, researchers proposed using DSM to find the optimal order of decisions to decrease the size of the iteration loops and decrease negative iteration during the process. The method proposed helped to find the optimal order of decisions according to their dependencies, document assumptions to move forward along a linear path, and identify iterative loops of decisions. Then, practitioners and decision-makers could put forth special effort in finding optimal solutions for two decisions without disregarding their interrelation. The limitation of the study resides in that the results of the implementation of CBA and DSM are based on interviews using a case study, thus its impacts in terms of time or cost savings are not possible to evaluate accurately. Future work should measure the impact of using CBA together with DSM to know if negative iteration decreases during the design stage. Future work should also test using DSM to clustering Factors and define them without constant rework, especially for complex decisions where factors are interdependent.

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recommendations expressed in this paper are those of the authors and do not necessarily represent the views of the people involved in the design process

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A PROPOSED LEAN DECISION-MAKING PROCESS FOR BUILDING ENERGY RETROFITS

Xiaosu Ding[1], Kristen Parish[2]

ABSTRACT

Buildings are one of the largest contributors of greenhouse gas emissions and, in the United States, they are the largest energy users. To combat these emissions, policy makers suggest retrofitting older buildings to achieve better energy performance. (The authors define retrofit as any changes to an existing building that improve the building's ability to perform or extend the building's life.) Despite consensus that buildings *should* be retrofit, building owners may struggle to identify how to retrofit their building. This paper addresses this gap by providing a proposed lean process, rooted in Choosing by Advantages (CBA), for selecting among potential energy retrofit options.

In this paper, the authors present the energy retrofit decision-making process recommended by the U.S. Department of Energy and compare it to those used in practice on case studies completed in the last five years. The authors identified two shortcomings in the implemented processes: first, the decision-making processes only consider the designers' perspective on energy and cost savings with little involvement from other stakeholders, and thus, they may ignore the needs, desires, and opinions of others with non-design backgrounds; second, these processes consider more design alternatives than may be realistic for a building owner given budget and schedule constraints.

To make the process leaner, the authors propose a new energy retrofit decision-making process, rooted in CBA, that addresses the previously-identified shortcomings. This process involves more stakeholders in the decision-making process. Moreover, this process helps decision-makers focus on the most promising design alternatives, thereby supporting better use of time and increased likelihood of a successful retrofit.

KEYWORDS

Building energy retrofit, multi-criteria decision making, choosing by advantage (C BA), design science, work flow

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INTRODUCTION

Buildings impact the environment, society and humans. Buildings are estimated to use about 40% of the total energy worldwide and produce 30% of anthropogenic green gas (GHG) (United Nations, 2009) throughout their lifecycle. Over a building's lifecycle, the operation stage is responsible for most of the energy and water use, as well as for the bulk of the greenhouse gas (GHG) emissions. Thus, reducing the environmental impact of buildings represents an opportunity to mitigate the impacts of climate change, and one method to reduce impacts is to retrofit existing buildings. The United States Department of Energy (US DOE) defines an energy retrofit as, "an opportunity to upgrade the energy performance of commercial building assets for their ongoing life. Often retrofit involves modifications to existing commercial buildings that may improve energy efficiency or decrease energy demand." (US DOE, 2019)

Indeed, policy makers recognize the value of retrofitting existing buildings when they develop goals for building energy consumption. For example, the California Energy Efficiency Strategic Plan proposed that: "50% of commercial buildings will be retrofit to Zero Net Energy by 2030" (DNV GL, 2017). While nearly every building offers the potential to improve its energy performance, not every building is a good candidate for an energy retrofit, particularly if the building is nearing the end of its useful life (Maslesa et al., 2018).

In this paper, the authors present the energy retrofit decision-making process recommended by the U.S. Department of Energy. The authors compare this to the decision-making processes used in practice, as documented in building energy retrofit case studies. Then, one new decision-making process is proposed incorporating the method of Choosing by Advantages (CBA) (Suhr, 1999; Kpamma et al., 2014), which proves to be a better decision-making tool than weighting tools for an energy design problem (Correa et al., 2017).

The rest of this paper is organized as follows: the authors present the energy retrofit decision making process recommended by the U.S. Department of Energy in the literature review section. The methodology section discusses how the authors review and summarize case studies; the authors then summarize case studies and their common decision-making process features. The authors propose a new energy retrofit decision-making process rooted in CBA. The authors also compare the new decision-making process with those in case studies and U.S. DOE; finally, the paper closes with a discussion of conclusions and future work.

LITERATURE REVIEW: ENERGY RETROFIT PROCESS

A building energy retrofit project is often complex and made of multi-steps, in some cases addressing multiple building systems (e.g., lighting and heating). Figure 1 illustrates the U.S. Department of Energy's energy retrofit process (Hendron, R.; Leach, M.; Bonnema, E.; Shekhar, D.; Pless, 2013; Hendron, Leach, Bonnema, Shekhar, & Pless, 2013). Figure 1 illustrates a five-step process, where the first three steps relate to how to decide what energy retrofit(s) to implement. The first step, goal setting, involves determining the energy goals for the project, which can either be absolute, i.e., "the office spaces in this building will consume 85 kWh/square meter/year" or relative, i.e., "the office spaces will realize energy consumption reductions of 20%." Following goal setting, the DOE process moves to "action creating," where designers develop a set of energy efficiency measures (EEMs) that can be installed in the building to meet the goals. Notably, this step involves designers and owners, but rarely building users or constructors. Next, the designers evaluate the EEMs they developed during the "action creating" step, and determine a set of EEMs they feel make the most sense for the building, based on financing available for the retrofit, the goals, and the cost-effectiveness of the EEMs. Surprisingly, the step "action creating" is ahead of "Financing options evaluation" and there is no loop to circle back to the original design (action plan). Moreover, after evaluating financing, say, to meet the budget requirement, the design is done and the process moves on to the "implementation approach," where the retrofit is constructed; "project completion" includes commissioning the retrofit and closing out the project.

Figure 1: Energy retrofit process recommended by U.S. Department of Energy, created based on the energy retrofit guide (Hendron, R.; Leach, M.; Bonnema, E.; Shekhar, D.; Pless, 2013)

Figure 2 presents a more detailed view of the "action plan creating" step in Figure 1. Figure 2 illustrates the "Staged Approach to Energy Efficiency Upgrade" (Hendron, R.; Leach, M.; Bonnema, E.; Shekhar, D.; Pless, 2013; Hendron et al., 2013). Designers review the existing building's performance and first try to improve what is already there ("existing building commissioning"). Then, designers develop retrofits for specific systems designed to reduce the building's load on the energy grid (load-based retrofit measures"). Finally, designers consider the air and water systems, and then the heating and cooling systems, to develop additional EEMs that may synergize well with the load-based retrofit measures. For example, if a load-based retrofit measure calls for installing more efficient lighting systems, the heating and cooling retrofit may down-size the existing air conditioning units, given that the lights now create less heat in the building. The designers follow the flow chart and study the potential retrofit measures step by step, and all retrofits will be included in the "action plan" from Figure 1 if the financing evaluation proves feasible. Therefore, the energy retrofit decision-making process recommended by the U.S. Department of Energy leads designers and building owners to go over the pre-defined energy systems (like the lighting and cooling systems) one by one and identify their energy saving potentials. After analysing the costs and benefits for each system, the designers develop an energy retrofit plan.

It could be convenient to apply this process for making energy retrofit decisions. However, with the process' simplicity, there could be three potential problems. First, the decisions may be limited to the pre-defined energy retrofit choices, which could impact the performance of the energy retrofit. Second, there is no involvement of stakeholders from different backgrounds (e.g., building occupants or constructors) who could make contributions (e.g., recommendations, criticisms) to the projects. Finally, the evaluation system considers only the financial benefits, rather than also including other benefits, like improved occupant comfort or productivity.

Figure 2: A staged approach to Energy Efficiency Upgrades recommended U.S. Department of Energy, created based on the energy retrofit guide (Hendron, R.; Leach, M.; Bonnema, E.; Shekhar, D.; Pless, 2013)

METHODOLOGY

For this article, the authors searched the Web of Science (WoS) for papers using "decision-making" and "building energy retrofit" as keywords. This search yielded literature used to collect information about the decision-making processes **actually used** for making building energy retrofit decisions, as documented in energy retrofit case studies. The authors only considered papers published in the last five years to limit the scope of inquiry. Table 1 lists the results of these searches.

Table 1: Results of Literature Search

Search terms	Number of research papers	Number of case studies
"Building energy retrofit" and "decision-making"	53	30

The authors reviewed the case studies and compared the decision-making processes used in each to summarize an energy retrofit decision-making process. In every case study, we assessed the following:

1. How building energy performance after retrofit was predicted;
2. How decision-makers evaluated the financial costs and benefits;
3. Who made the final decision on what to implement in the retrofit and how they selected those retrofit measures.

After reviewing and summarizing the decision-making processes, the authors look for shortcomings in these processes; that is, the authors looked for waste in the case studies. In the event that retrofits did not meet their goals, the authors conducted a root cause analysis () to determine why energy targets were not achieved. These observations formed the basis of the authors' proposed process. The authors sought to mitigate the failures of the current process through developing a new, CBA-based decision-making process for developing and selecting EEMs for energy retrofits.

CURRENT STATE: THE ENERGY RETROFIT DECISION MAKING PROCESS

Figures 1 and 2 illustrate that designers need to consider retrofit measures in pre-defined building systems, determine those that are financially advantageous, and then move forward with a retrofit. This suggests that the energy retrofit decision-making process comprises three important features:

1. How to predict possible building energy performance after retrofits;
2. How to evaluate the financial costs and benefits;
3. How to make the final decision, that is to select the retrofit measures.

CASE STUDY REVIEW

In this section, the authors analyse thirty (30) case studies from literature to find out how these three features manifest in practice. This analysis allows the authors to plot the basics of the energy retrofit decision-making processes documented in the literature of the last five years.

Table 2 lists the three features of each case study. First, there are two ways to calculate the energy performance, energy codes and energy modelling. By using energy codes, the researchers used the guidance and codes to estimate the potential energy consumption after energy retrofits. For example, EN ISO 13790 was applied to calculate the energy consumption of existing and future buildings (Qian Wang, et al., 2017). On the other hand, more researchers chose energy models to simulate the energy consumption following an energy retrofit. One popular energy modelling software is "EnergyPlus," which predicts the performance of energy retrofit measures from multiple case studies (Ashrafian et al., 2016; Mauro et al.,2017; Tagliabue et al., 2018; Qinpeng Wang et al., 2017).

Table 2: Approaches for Energy Prediction, Cost Evaluation, and Selection of EEMs

Predicting Energy Consumption (post-retrofit)	Cost Evaluation Methods	Methods to select EEMs for installation
Energy code	Life cycle analysis	Selecting all measures
Energy simulation model	Payback period	Weighting
	Net present value	Optimization

Second, most case studies (23 of 30) used financial models to evaluate the retrofit's economic performance, although in the other case studies, authors simply calculated the energy savings number, as was suggested in the US Department of Energy guides described in the previous section. The authors note three popular approaches for financial evaluation: life cycle cost (Amiri et al., 2018; Becchio et al., 2016; Jafari 2017; Qian Wang et al., 2014), payback period (Aguacil et al.,2017; Ashrafian et al., 2016; Tahsildoost et al., 2015), and net present value (Becchio et al., 2016; Hosseinian et al., 2017; Senel Solmaz et al., 2018; Qinpeng Wang et al., 2017). All of these approaches focus on the economic benefits of the life-long service of the building, say, the energy savings from daily operation subtracting the initial cost of retrofit projects.

Finally, different methods were used to make the final decision of what EEMs to include in the retrofit. In some studies, the candidate retrofit plans were simply ranked based on the energy or cost saving (Ashrafian et al., 2016; Becchio et al., 2016; Fregonara et al., 2017; Hosseinian et al., 2017). Other case studies used weighting methods to find the most applicable retrofit plan, where Analytic Hierarchy Process (AHP) is one popular tool (Amiri et al., 2018; McArthur et al., 2016; Rocchi et al., 2018; Si et al., 2018; Si et al., 2016; Zheng et al., 2019). Finally, a few case studies had multiple choices in every retrofit measure; these case studies used optimization algorithms to find the best EEM combination for the final plan (Mauro et al., 2017; Senel Solmaz et al., 2018).

OBSERVATIONS FROM CASE STUDIES

After reviewing the energy retrofit decision-making process, the authors note several observations. Unlike the retrofit process recommended by the U.S. DOE, most case studies documented exploring multiple energy retrofit measures, especially when they used energy simulation software. In fact, with energy modelling, the designers can predict the building performance after retrofit. With more retrofit options to choose from, more variables would be considered and thus, the decision-making tools that allow designers to make selections among a larger and more complex design space become all the more important. Finally, when reviewing case studies, it seems that even when designers consider a more complex design space, with multiple retrofit measures that may be interdependent, the decision criteria remain relatively simplistic, based exclusively on the economic variables (i.e., benefits and cost).

The authors identify two shortcomings from the US DOE and case study decision making processes. First, the decision makers focus on the economic variables and do not pay enough attentions on needs from the stakeholders of different backgrounds. Second, based on the idea of the weighting or optimization, designers need to create a large design space to cover every possible design and compare them. In this way, efforts (energy modelling and cost analysis) could be wasted on design alternatives that may easily be deemed infeasible from others' perspectives; for example, the procurement staff for the building may quickly rule out an alternative, based on the fact that there is only a single vendor of that system, which violates procurement rules.

LEANER RETROFIT DECISION-MAKING PROCESS

Considering the aforementioned shortcomings, the authors propose a leaner retrofit decision-making process that enhances the involvement of stakeholders and supports more holistic review of alternatives, rooted in CBA (e.g., Kpamma et al., 2014; Sound- et al., 2015). Figure 3 shows this process; it uses CBA in a design charrette environment (Correa et al., 2017). The words in chevrons describe the energy retrofit process; text below maps the process to the CBA process and vocabulary (Koga, 2008).

The first three (3) steps are preparation phases for the decision-making charrette (in Step 4). In step 1, the stage-setting phase of CBA is performed and the project team determines who should participate in charrettes (i.e., form the decision-making team). The building owner builds the decision-making team, which should include stakeholders with different backgrounds, like designers, owners, users, and contractors. This team works together to develop alternatives, factors, and criteria (as described in Suhr, 1999). In this phase, the decision-making team will also learn CBA if they do not already know it.

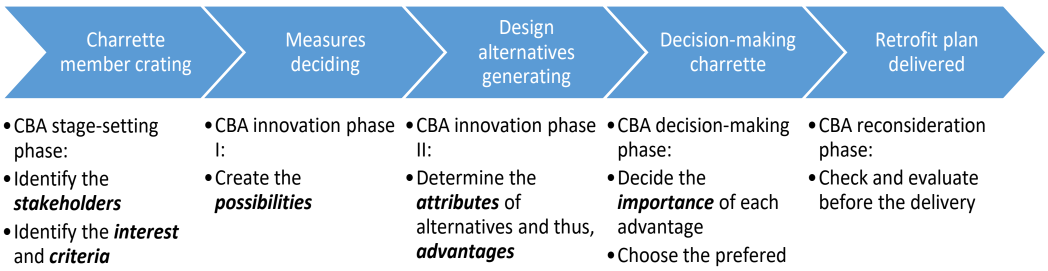

Figure 3 the proposed energy retrofit decision-making process

In Step 2, the team determines factors and alternatives (in this case, energy retrofit measures). Designers would likely provide the bulk of the alternatives, but other team members can also provide alternatives. When the retrofit measure alternatives are collected, the decision-making process moves to Step 3.

In Step 3, members may propose different decision factors for the decision-making charrette (note cost will likely be one of the factors). During this step, the design team builds the energy model with different retrofit measures implemented to estimate building energy performance with any combination of retrofit measures (the building performance is an *attribute* of an alternative). The team can work together to identify the attributes of each alternative, and assess advantages from these attributes. In this step, any alternative without advantages will be removed. The total number of alternatives are limited to twenty (20) for the decision-making charrette. If design alternatives cannot meet the requirements of decision-making team, the process can loop back Step 2 and generate new retrofit measure alternatives.

In Step 4, the design team hosts a decision-making charrette to decide the final energy retrofit plan. In the charrette, every team member will independently assess the available design alternatives with importance of advantages (IoA) (Correa et al., 2017). At the end, the final retrofit plan is decided by the trade-off between the cost and IoA.

In the final step, the energy retrofit plan is delivered for construction.

COMPARISON OF PROPOSED AND DOE PROCESSES

Compared to the U.S. DOE decision-making process for energy retrofits, the leaner decision-making process could meet the requirements of different stakeholders (owners, occupants, contractors, designers and so on). Moreover, rather than only focusing on only energy savings and cost, the proposed process offers an opportunity to consider additional factors, like occupant comfort, in the comparison of retrofit measure alternatives. Finally, in including more stakeholders in the alternative generation process, the proposed process supports inclusion (and exclusion) of alternatives that may be outside of the traditional design considerations.

Using CBA, decision-making efforts are leaner because they focus on evaluating all alternatives and deciding the most promising design alternatives in the decision-making charrette. In fact, designs that do not have any advantages would be removed prior to the decision-making charrette. This seems better than the processes in literature because the latter processes may waste resources on alternatives without advantages when investing the resources uniformly into every alternative.

In fact, the CBA decision-making process is proven to have a better performance than the decision-making process of "weighting, rating and calculating" (Correa et al., 2017), and the latter type of process is used by most of reviewed case studies in literatures.

CONCLUSION AND FUTRUE RESEARCH

In this paper, the authors presented the energy retrofit decision-making process recommended by the U.S. Department of Energy and compared this to decision-making processes documented in case studies published in the last five years. Two shortcomings are found in these processes: first, the decision-making processes only consider the design about the energy savings and costs with little involvement of different stakeholders, and thus, they may ignore the opinions from other backgrounds; second, too much time could be spent on the design alternatives that would be infeasible, as they do not have any advantages.

To make the process leaner, the authors presented a new energy retrofit decision-making process that leverages CBA. With this new process, the stakeholders from different backgrounds can get involved in the decision-making process or even make contributions to the set of retrofit design options. Moreover, most decision-making efforts are used to evaluate and compare promising design alternatives in the decision-making charrette. Therefore, the final retrofit may have better performance.

For future work, the authors plan to evaluate the performance of the proposed decision-making process in upcoming energy retrofit projects. This will allow the authors to determine whether or not this process yields advantageous energy performance compared to other processes. Finally, in piloting this process, the authors can refine the decision-making process as required.

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CONNECTIONS BETWEEN MASS CUSTOMISATION PRACTICES IN HOUSING AND LEAN PRODUCTION

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ABSTRACT

The understanding of customers' needs and preferences in housing is complex. In order to respond to this, housing companies should be able to offer a higher product variety while ensuring cost effectiveness. Mass customisation (MC) has been suggested as an effective strategy for balancing the fulfilment of clients' needs and at the same time keep costs and delivery time within acceptable limits. Several MC practices have been associated to Lean Production (LP), such as reducing lead time, increasing value by systematically capturing customer requirements, and increasing output flexibility. The aim of this paper is to identify a set of MC practices in housebuilding, discuss their underlying concepts and principles, exploring their connections to LP. The identification of common concepts and principles between LP and MC can support the definition of the MC strategy for housing companies and also the adaptation of best practices to different organisational contexts. Results are based on a literature review and a case study developed with a Brazilian house-building company. The main contribution is better understanding trade-offs between productivity and flexibility with the aim of improving value generation in housing projects.

KEYWORDS

Lean construction, mass customisation, housing.

INTRODUCTION

Mass Customisation (MC) is an organisational strategy that aims to offer products that fulfill customers' requirements, potentially adding value, through flexible process and

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structure, with costs and delivery time similar to mass production (Pine, 1993; Hart, 1995; Jiao, Ma, & Tseng, 2003; Fogliatto, da Silveira, & Borenstein, 2012). The main challenges in the application of MC for housebuilding companies to are capturing customers' requirements (Barlow & Ozaki, 2003; Tillmann and Formoso, 2008; Martinez et al., 2017) and keeping the balance between offering variety and maintaining housing affordability (Martinez et al., 2017) without affecting the efficiency of the production process (Nahmens & Bindroo, 2011). In the last 20 years, several studies have proposed ways to overcome this challenge in manufacturing. Furthermore, previous research suggest the combination of different practices and strategies to deliver mass custom goods (Ferguson, Olewnik, & Cormier, 2014; Fettermann, 2013; Piller, Moeslein, & Stotko, 2004).

Koskela (2000) states that the consolidation of lean production has played a key role in the emergence of MC in the beginning of the 1980s, based in the value generation perspective. Piller, Moeslein, & Stotko (2004) describe that the use of the concept of value generation in different production systems and strategies, such as agile, lean and MC, have the common goal of increasing cost-effectiveness and ability to react to heterogeneous and constantly changing market demands. Agile and Lean are also considered as enablers to mass customisation (Fogliatto et al., 2012). However, exploring the relationship between agile, lean and mass customisation is a significant research gap yet to be addressed (Fogliatto et al., 2012). Although the combination lean and MC have been raised in the literature its implications have not been addressed in detail still (Stump & Badurdeen, 2012). According to Nahmens and Bindroo (2011), in the house building industry the combination of lean and MC are particularly interesting due to the challenges provided by its context of application, and can be regarded as way to achieve and maintain continuous improvement and efficiency in operations and strategic levels. Moreover, there is a lack of discussion on which are the specific relationship between MC and Lean concepts and limited empirical evidence on how those connections can enable MC and ease the implementation of related practices.

The aim of this paper is to identify a set of MC practices in housebuilding, discuss their underlying concepts and principles, exploring connections to Lean Production. The identification of common concepts and principles can support the definition of MC strategies for housing companies and also the adaptation of good practices to different organisational contexts.

MASS CUSTOMISATION

The implementation of MC depends on fundamental changes in the product development process, so that the diversity of customer requirements is systematically considered, and opportunities for cost savings created (Ferguson et al., 2014; Fettermann, 2013; Piller et al., 2004). These changes depend on the coordinated efforts of three different areas: Customer Integration, Product Design and Operations (Ferguson et al., 2014; Rocha, 2011; Schoenwitz, Potter, Gosling, & Naim, 2017). Customer integration is concerned with understanding the demand for customisation by capturing customers' requirements and translating them into product specifications, customer-supplier interaction process, tools and the solution space definition (Ferguson et al., 2014; Rocha, 2011). The product design area involves developing design concepts and solutions, including product architectures and product-service systems, based on the customisation units chosen by customers (Ferguson et al., 2014; Rocha, 2011). Operations can be regarded as a way to produce and deliver customized goods by managing production and supply chains to ensure that the costs and time are below a certain limit. Rocha (2011) recommends that the definition of the strategy should begin from the core categories which outline the MC strategy to then proceed to other areas above mentioned.

In house-building, several MC practices and approaches have been presented in the literature (e.g. Rocha, 2011; Schoenwitz et., 2012; Shin et al. 2008; Tillmann and Formoso, 2008; Noguchi & Hernández-Velasco, 2005; Barlow and Ozaki, 2002; Naim and Barlow, 2002). Fetterman (2013) defines practices as methods, tools, techniques, which can be combined to support the introduction of changes in the product development. When translated into abstract ideas, practices can be transferred from different contexts and cultures to be applied (Lillrank,1995). This practical-theoretical reflection is necessary to transcend the mechanical repetition of the existing (Arís, 1998) enabling improvement through critical thinking and reflection (Franco, 2003 apud Amorim, 2018).

According to Balow (1998), MC can be enabled by agile production systems, which aim to respond to the constantly changing market demands by delivering high-quality products and reducing costs and product development process time. The same author argues that agile systems can be regarded as an extension of the lean production philosophy. Furthermore, Pine II (1994) and Barlow (1998) suggest that there are several connections between MC and Lean Production, such as: (i) just-in-time, which contributes to the reduction of waste and stocks; (ii) pull production, which enables the production of goods pulled by customers' orders; (iii) economic batch, in which each product customisation is done by reducing the setup and change over times, responding rapidly to frequently changing customers desires and expectations. Additionally, in both approaches there is a need to manage the supply chain, and to enhance collaboration between stakeholders in orderv to deliver a product that fulfill the customers requirements (Naim & Barlow, 2002).

In the housing context, the adoption of lean principles combined with MC strategy has been seen a way to reduce the trade-offs of improving value for customers through variety and increasing productivity through standardization (Nahmens & Bindroo, 2011). The same authors highlight that even though both MC and Lean construction seek for production efficiencies, lean is not focus on increasing product variety. However, the perspective of the production as a flow and flexibility of the production system can support the offer of high product variation, which is a key feature of MC (Nahmens & Bindroo, 2011). Additionally, Martinez, Tommelein and Alvear (2017) state that the combination of lean production system with IT can enable the application of MC in affordable housing by reducing lead time, improving communication and shared information.

The challenges for implementing lean principles in MC contexts can increase according to the degree of customisation and level of customers involvement in manufacturing (Stump & Badurdeen, 2012) as well as in housing (Nahmens & Bindroo, 2011). Thus, the understanding of the connections between MC practices and Lean principles in this research was perceived as an opportunity to comprehend the underpinning ideas from best practices in order to ease their application in different contexts, and apply it on a specific case study. Additionally, identifying these connections can provide some insights of the potential benefits that the construction companies can achieve by applying practices related to a specific decision category and lean principles.

RESEARCH METHOD

The methodological approach adopted in this research was Design Science Research, which aims to build innovative solution concepts for classes of real world problem and, at the same time, make scientific contributions to a specific field of knowledge (Kasanen, Lukka, & Siitonen, 1993; Lukka, 2003). In this research, the practical problem addressed was how construction companies can address the productivity-flexibility trade-off and improve cost-benefits through mass customisation strategies. The main theoretical contributions relate to describing relationships between MC decision categories and Lean concepts and principles.

The research process was divided into three stages: (i) understand the problem and identify MC practices in the literature; (ii) assess practices used in an empirical study; (iii) reflect about underlying ideas, analysing the connections between MC and Lean.

A set of practices was identified in a literature review focused on mass customisation in the construction industry. The practices were extracted from academic publications, and further categorized according to core functional areas in the companies, their country of application, authorship, etc. Based on the classification of practices, MC decision categories were identified.

In the second phase, an empirical study was undertaken about a house building company from the South of Brazil (Company A). This company has over 20 years of experience, mostly in the upper middle and in the middle-class segments. The provision of customized housing projects as part of the competitive advantage of the company was one of the key elements for its selection for this empirical study. The company has a business unit dedicated to the customisation of housing units, that addresses a set of market segments with different levels of choice. This study addresses a relatively new product line in which the company provides a limited offering to fulfill customer's choices. Focusing on the line that fits the most the MC approach, where the productivity-flexibility trade-off must be managed closely, in order to improve the value generation to customers without substantially increasing costs and lead time.

The third stage of the study involved analysis and reflection of the empirical study and literature review findings.

Multiple sources of evidence used: (i) 11 semi-structured interviews with architects, managers and other professionals from company A; (ii) 4 open-ended interviews with professionals involved in the customisation process; (iii) analysis of documents related to the customisation process, mostly related to the solution spaces adopted in different projects; (iv) participant observation in planning and control meetings, and in one customisation event promoted by the company; and (v) 3 meetings to discuss the customisation process map and improvement opportunities.

RESULTS

IDENTIFICATION OF BEST PRACTICES IN THE LITERATURE

Based on the literature review approximately 100 MC practices in housing were identified in different countries, e.g. Japan, United Kingdom, Germany, Brazil, Ecuador, Mexico and South Korea. Practices were classified into several decision categories, which were divided into four groups: core categories, product design, customer integration and operations. The main decision categories are presented below, some of which were proposed by Rocha (2011), and others emerged as part of the literature review carried out in this investigation.

The core categories are related to the establishment of the MC strategy and definition of product variety, are they: (i) Solution Space (adapted from Rocha (2011)), (ii) Strategy and customisation level (adapted from Rocha (2011)), (iii) Assessment and feedback and (iv) communication of the information about customization. The solution space is a set of customisation units (i.e. the customizable attributes of the product and their range of options) and rules for combining them to be offered to customers, which outlines the definition of product variants in a MC strategy (Rocha, 2011; Salvador; Holan; Piller, 2009). When proposed by Rocha (2011) the solution space and customization units were two different decision categories. However, a fusion of this decision categories is proposed due to their interdependency, once there is no solution space without customization units and the customization units need to be combined in solutions space in order to be offered to customers. The second decision category is related to the MC Strategy and level of customization, the level or taxonomies of customisation refer to the strategy that companies adopt to satisfy different markets through the value chain (Fogliatto; Da Silveira; Borenstein, 2012). It is related to the customer order decoupling point (CODP) and product variants definitions, providing a holistic view of the process. Additionally, this category relates to the company's competitive strategy and position in the market. The second adaptation proposed is the consideration of the level of customization to be a core concern for the establishment of the customization strategy, rather than what was proposed by Rocha (2011) to be only related to production.

The new core categories defined based on the literature review and researchers insights from the empirical study are (iii) Assessment and feedback and (iv) Communication of customisation information. The third core decision category mentioned addresses the need for defining the approaches to assess customers demand for customisation to establish a solution space accordingly and to evaluate the delivered product after occupancy to understand emerging and evolving requirements. Additionally, it is necessary to establish how is this information will be used to feedback the PDP. It is strongly related to Customer integration and value generation. The fourth core decision category is related to one of the key issues in companies that implement MC that is the improvement of the information flow between departments to facilitate collaboration and increase value generation (Barlow, 1998; Martinez et al., 2017; Tillmann & Formoso, 2008). This decision category embraces practices that promote transparency and continuous improvement, by making relevant customisation information available to stakeholders along the product development process.

Customer integration related practices are: (i) Visualization Approaches (Rocha (2011)) (ii) Configuration Sequence (Rocha (2011)) (iii) Customer interaction and relationship. The visualization approaches are related to the Definition of how and to whom (i.e. customer, company or both) customisation units will be displayed (Rocha, 2011). There are three types of approaches: collaborative, transparent and Do-It-Yourself (Rocha, 2011). This category of decision is also related to the existing interface with clients and provided information about the process for customers. The second decision category related to the customer integration practices is the configuration sequence, which involves the establishment of the sequence of customisation units or decisions to be made by customers in the product configuration process in order to define variants (Rocha, 2011). The sequence is deeply influenced by the level of customisation and customisation units available. The third decision category mentioned in this group, was proposed in this research, and is related to the definition of the approaches to interact with clients along the product configuration process and the development of a relationship with customers to achieve loyalty.

The decision categories related to operations and supply chain proposed by Amorim (2018), strongly related to different lean principles, are: (i) Supply Chain Management, (ii) Production Planning and Control Emphasizing Pull Production, and (iii) Production System Flexibility. The supply chain management decision category is related to increasing the output flexibility and transparency, simplify by reducing the number of parts, reduce the batch size and lead time, and improve value generation (Koskela, 2000). The second decision category in this group is concerned with controlling production and managing information flows according to the release of customer order. The company must align the production planning and control system with the customisation offered to customers to be able to deliver customised housing units. According to Koskela (2000), pull production can bring benefits such as increasing the output flexibility and transparency, and reduce the lead time.

ANALYSIS OF THE CUSTOMISATION STRATEGY OF COMPANY A

Company A's Customisation Department is responsible for the definition of the solution space for each project. At the conceptual stage, customisation units (i.e.: customizable attributes and their available options) of the housing unit layout and finishings to be offered to customers are discussed with the Product Development Department. Subsequently, the layout customisations units and deadline for customisation decisions are defined by the Project Launch Committee. An event involving several departments of the company is carried out for each new conceptual design a brief that is delivered to architecture designers.

After the project launches into the market, clients will choose a layout option when buying the units. The customisation department is responsible for processing that information and delivering it to the construction site. Simultaneously to sales, customisation units related to the finishings are defined by the customisation team. These customisation units are later offered to clients in an event, named "first visit", in which clients visit a housing unit prototype. During the event, a customisation guide is delivered to customers so that they can choose alternatives from a kind of choice menu. Afterwards, customers have to sign an additional contract concerned with the customisation of housing units and this information is processed and summarized to be delivered to the production management team. Finally, the customisation team performs periodic construction site visits to check the fulfillment of the customer order.

Assessment of the practices in company A

From the set of practices identified in the literature, only 75 were assessed in this empirical study, excluding the 25 design related practice, since the design of the projects for company A was done by subcontracted architectural and engineering firms. An assessment was made on the degree of implementation of practices, according to a 5 points scale: applied, partially applied, not applied, improvement recommended, recommended. **Error! Reference source not found.** presents an overview of the degree of implementation of practices according to decision categories. This assessment was based in the multiple the sources of evidence of the study, especially in the semi-structured interviews and the analysis of documents.

The customer interaction and relationship category had the highest degree of implementation, mainly due to the creation of several communication channels with customers, which allows a follow up to be carried out until project delivery. Additionally, company A applies 2 practices from the set available for communication of customisation information: (i) produce a list of the necessary materials and labour costs for product change to customers and cost estimators; and (ii) visits to the construction site by the customisation team to check the compliance of the product with customisation orders.

Moreover, there were some practices related to visualization approaches to inform customers about the available customisation units and the standard product specifications by interacting with a product prototype. The practice applied regarding production planning and control emphasizing pull production was the use of postponement strategies, through additional work on the delivery. This is done by the offer of additional customisation units to customers related to finishing and furniture among others, after the housing unit is handover, operationalized by the customisation department by coordinating different suppliers.

Many improvement opportunities exist in Company A in the implementation of MC practices: in eighth of the nine decision categories analysed, the full or partial adoption of practices was higher than 50%. Several best practices related to the "information flow along the customisation process" decision category were found in the literature. However, most of them are not found in the Company A. This low rate of application reflects the lack of integration among departments involved in the customisation process, as revealed during the semi-structured interviews. The decision category "assessment and feedback" is another example of improvement opportunity for Company A. Although several best practices were found in the literature, the degree of implementation in that company was very low. In fact, the solution space for each market segment was usually proposed relying in the customisation team expertise only.

Furthermore, the improvement recommended (rose) and recommended practices (red) (**Error! Reference source not found.**) were proposed according on the identified opportunities found in Company A. The most critical decision categories to be addressed were assessment and feedback, communication of customisation information, solution space and production planning and control emphasizing pull production. In those categories, there were practices that could be used in the specific context of Company A.

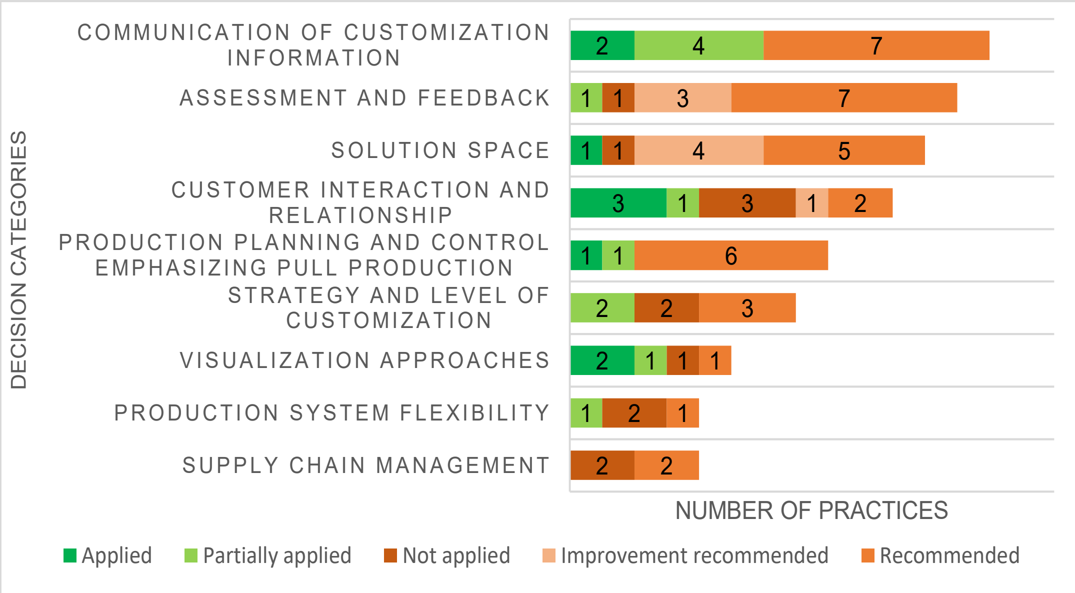

Figure 56: Degree of implementation of practices according to decision categories

Examples of practices and improvements recommended for Company A are briefly described in Table 24. For instance, one key issue identified during the empirical study was that many customers would only be aware that they could customize their housing unit during the "first visit" event. Thus, one of the recommendations made to the company was to inform their clients in product leaflets about how the customisation process occurs and the available solution space to the project. This recommendation can increase the impact of the customisation strategy of the company in attracting potential customers. Another measure that can contribute to the dissemination of the customisation strategy is the development of an informative and advertising area about customisation on the company website.

Table 24: summary of improvement opportunities and recommended practices

Improvement Opportunities	**Examples of Recommended practices**
Map Customisation process for low-end projects	Systematically map the product development process aiming to find process improvement opportunities.
Add a description of customisation process and solution space to product catalogue	Use of catalogues as tool to advertise and inform customers about customisation.
Align the solution space definition with customers' demands	Identify the demand for customisation to define the customisation units and delimitate the solution space.
	Definition of a limited solution space to offer to the clients and
Increase collaboration between	

departments and involvement in the definition of the solution space	to achieve scale economies.
	The definition of customisation units should balance customers' perceived value with their production costs.
Improve Market research and Post occupancy assessment methods	Monitor the product in use to capture requirements and feedback the product development process.
Increase the communication between sectors involved in customisation	Devise a communication channel to collect and share data about customers' configuration order, monitor its evolution and ease communication within departments

DISCUSSION

According to the literature review, MC and Lean Production share a common ground in many aspects. Indeed, during the process of obtaining an in-depth understanding of the MC practices and decision categories, several connections to Lean concepts and principles emerged, such as the strong relationship between the solution space definition and the value generation concept and the use of pull production to reduce productivity-flexibility trade-offs. In Figure 57 the a set of relationships between MC practices and Lean Production concepts are summarized, according to decision categories. It is noteworthy that the core decision categories for defining the MC strategy are the ones which present the largest number of connections to Lean concepts: communication of customisation information (7), solution space (7), and strategy and level of customisation (6).

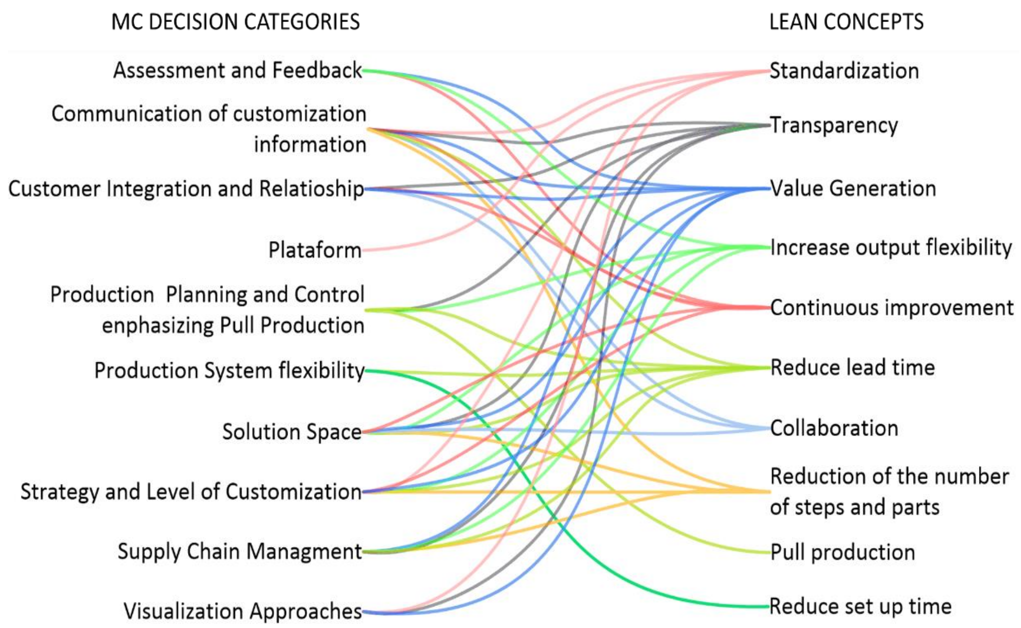

Figure 57: Mass customisation decision categories and Lean Concepts Sankey diagram

For example, the communication of customisation information is related to standardization of information flows, increasing transparency by showing clearly the customers' orders along product development, and ensuring that customers' requirements are achieved along this process improving value generation. Additionally, it relates to collaboration among the different departments of the company to create trustworthy shared information, contributing also to reduce the lead time, continuous improvement, and reduction of the number of steps and parts. Other decision categories shown more specific connections to Lean concepts, such as the use of pull production, is only related to the production planning and control decision category, while production system flexibility is only related to the reduction of the lead and setup time.

Finally, it is interesting to note that the value generation concept is the one with the largest number of connections to different decision categories, which is coherent with Koslela (2000)'s statement that the emergence of MC is based on this concept. Another noteworthy fact, is that the practices and decision categories related to operations and focusing on the efficiency were easier to connect with the lean principles, corroborating Nahmens and Bindroo 2011 and Stump & Badurdeen, 2012 findings.

CONCLUSION

This paper has discussed a set of decision categories for the implementation of MC in house building, and has explored the underlying ideas extracted from MC best practices from different countries that have been reported in the literature. This set of decision categories have been built on previous work (Rocha, 2011), being especially extended in the customer integration and operations groups. In this research, some new decision categories were proposed, such as "communication of the customisation information" and "assessment and feedback". In addition, this paper made contributions towards establishing relationships between the decision categories and practices.

From a practical perspective, this set of decision categories were useful for assessing the MC strategy adopted by a house building company from Brazil, and identify some improvement opportunities. From a theoretical perspective, several connections were established between decision categories and Lean Production concepts, which can be helpful for adapting some of the practices to different contexts.

Although this paper explored some relationships between MC decision categories and lean concepts and principles, there are several opportunities for further development of research studies on the scope of decisions and best practices adopted by house-building companies. Another relevant future research area is the use IT and BIM based tools to support customers' requirement management, visualization approaches, and collaborative processes related to MC, in order to improve decision making and make information flows more effective along the product development process.

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PLENARY PAPERS (5)

Koskela, L., Tezel, A., and Patel, V. (2019). "Theory of Quality Management: its Origins and History" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1381–1390. DOI: https://doi.org/10.24928/2019/0259. Available at: <www.iglc.net>.

THEORY OF QUALITY MANAGEMENT: ITS ORIGINS AND HISTORY

Lauri Koskela[184], Algan Tezel[185], and Viranj Patel[186]

ABSTRACT

Purpose: Determination of the theoretical and philosophical foundations of quality management, as they have evolved and changed over time.

Methodology/Approach: Conceptual and historical.

Findings: At the origin of the quality movement, Shewhart defined quality through an account of production (later called value generation theory), and suggested the scientific model (later to be named as Plan-Do-Check-Act cycle, PDCA) as the epistemology for improving quality. Somewhat later, Deming recommended ideas falling into process ontology as applicable in the quality context. These prescriptions were not presented in terms of theory, epistemology or ontology but through examples. Perhaps partly for that reason, in subsequent developments these prescriptions were often forgotten or rejected. Especially, the ISO standard for quality management rediscovered the original PDCA epistemology only in 2015. Thus, the degeneration of the original theoretical and philosophical foundation seems to be one of the longstanding problems in the area of quality.

On the other hand, it has turned out that the value generation theory of production is a partial theory. As the success of the lean movement indicates, production should also be seen through the flow theory. The achievement of quality can, for its part, also be explained through this flow theory of production. However, there has been very little theoretical work both regarding production and quality, and thus the integration of theories on production has not been achieved. Lacking theoretical evolution is another long-standing problem that arguably has hindered the progress of quality.

Research implication: The findings call for a sustained effort to explicate and develop the theoretical and philosophical foundation of quality management.

Originality/Value of paper: It is widely perceived that quality as a managerial focus has lost its attraction in the last two decades. In this presentation, the argument that weaknesses of the theoretical and philosophical foundation of quality have contributed to this lack of attraction is forwarded.

KEYWORDS

Quality management, production, theory, ontology, epistemology.

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INTRODUCTION

There is an influential school of thought in management studies contending that all or at least most managerial methods are fashions or fads, having their lifecycle similarly to living organisms. From this perspective, quality seems to have passed its heyday, as indicated by the frequency with which quality related terms are being used in published books (Figure 1). Indeed, the decline of the quality movement is visible in many ways. It is stated that "during the first 10 years of the new millennium, the term TQM seems to have lost its attractiveness in Western parts of the world" (Dahlgaard-Park 2011). The ISO 9000 quality standards are bitterly criticized (Seddon 1997, Hoyle 2007), and the benefits to be derived from their implementation are debated. Hoyle (2007) writes:

> "…resultant confusion [around ISO 9000]. The standard could have been written better but it is unfair to put all the blame on the standard. The standards bodies, certification bodies, accreditation bodies, training providers, consultants, software providers and many others have contributed to this confusion. Commercial interests have as usual compromised quality. We have followed like sheep, pursued goals without challenging whether they were the right goals but most of all we have forgotten why we were doing this. It was to improve quality, but clearly it has not."

What are the causes of this apparent decline? We posit that the usual ways of looking at the history of quality are not helpful for perceiving such causes. Namely, typically such history is structured according to the contributions of gurus of quality (Zairi 2013) or according to different approaches to quality (Juran 1995). Such foci are not helpful for understanding the underlying theoretical and philosophical assumptions of quality or for examining whether they are adequate.

In this presentation, the argument that weaknesses of the theoretical and philosophical foundation of quality have contributed to this lack of attraction is forwarded. The paper aims at the determination of the theoretical and philosophical foundations of quality, as they have evolved and changed over time, and at explanation of the decline of the quality discipline through those foundations.

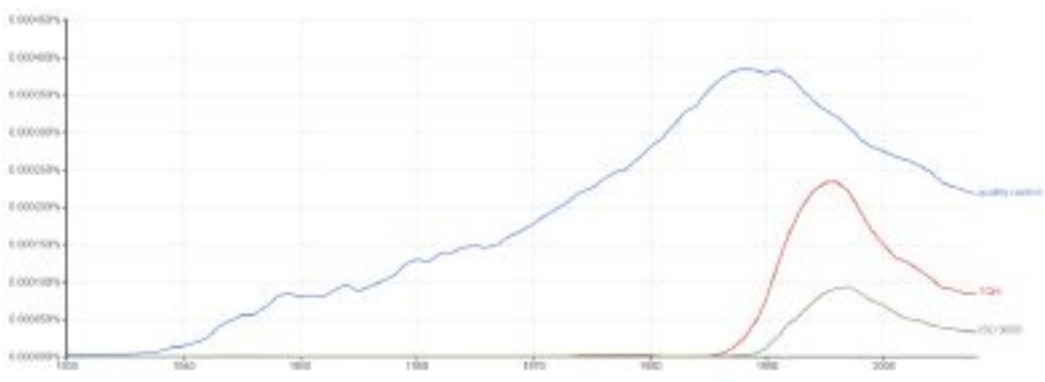

Figure 1. The frequency of the word strings "quality control", "TQM" and "ISO 9000" in books published in English in 1930 – 2008, according to Ngram.

THEORY OF QUALITY MANAGEMENT: THE ORIGINS

Scott and Cole (2000) claim that the quality effort is not readily linked to a well-identified, clearly specified set of ideas and practices but, rather, appears as a loosely coupled collection of orientations and practices. We disagree with this judgement. The seminal authors on quality have presented influential theoretical and philosophical starting points for quality. Unfortunately, those starting points fall outside the usual paradigms of management scholars, and they have failed to spot them.

It is thus deserved to ask from where the theoretical and philosophical ideas of quality management can be found. We contend that there are three promising places:

- First, quality is usually, although not always, related to man-made artefacts that have been designed and produced. Thus, it seems natural to expect that the concept of quality is related to or embedded in concepts and theories of production.
- Second, for maintaining and improving quality, information and knowledge are needed. From where should that be acquired? The discipline studying such matters has traditionally been called epistemology. So, it can be expected that that the concept of quality would entail epistemological considerations.
- Third, for perceiving and acting for the sake of quality, a conception on what is out there in the world is needed. The discipline studying such matters is ontology. It can be expected that the concept of quality would entail ontological considerations.

In the following, the three identified topics are explored.

THEORY OF PRODUCTION

It is well-known that Shewhart started the quality movement through his statistical quality control. In his seminal book (Shewhart 1931), he related quality to design and production in the following way:

> Looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kind. […]
>
> The first step of the engineer in trying to satisfy these wants is therefore that of translating as nearly as possible these wants into the physical characteristics of the thing manufactured to satisfy these wants. In taking this step intuition and judgement play an important role as well as the broad knowledge of the human element involved in the wants of individuals.
>
> The second step of the engineer is to set up ways and means of obtaining a product which will differ from the arbitrarily set standards for these quality characteristics by no more than may be left to chance.

The conceptualization of production used by Shewhart has later been named value generation model (Koskela 2000). In contrast to two earlier conceptualizations of production, the transformation model and the flow model (Koskela 2000), the value generation model introduces the customer into theorizing on production.

EPISTEMOLOGY

On which knowledge basis envisaged Shewhart "setting up ways and means" to achieve quality to happen? Arguably, the existing scientific and engineering knowledge related to any particular production process has to be used. However, the novelty advanced by Shewhart was that additionally, the scientific method (Shewhart and Deming 1939) is to be used:

> In this sense, specification, production, and inspection correspond respectively to making a hypothesis, carrying out an experiment, and testing the hypothesis. These three steps constitute a dynamic scientific process of acquiring knowledge.

This idea contrasts with the attitude in engineering sciences according to which engineering proceeds from scientific knowledge towards application. This contrast has time-honoured roots – it has been characterized as the difference between Platonic and Aristotelian epistemology (Koskela & al. 2018). In the context of engineering, Platonic epistemology starts from reason (and in extended sense, from existing knowledge) and deduces prescriptions to be pushed towards the world. Instead, Aristotelian epistemology emphasizes observations made on the world and induction of new knowledge based on them.

ONTOLOGY

Deming, a close collaborator of Shewhart, presented his ontological views in his book "Out of the crisis" (Deming 1982):

> Every activity, every job is part of the process. A flow diagram of any process will divide the work into stages. The stages as a whole form the process. The stages are not individual entities…

Further (Deming 1982):

> Work comes into any stage, changes state, and moves on into the next stage. Any stage has a customer, the next stage. The final stage will send product or service to the ultimate customer, he that buys the product or the service. At every stage there will be:
>
> Production – change of state, input changes to output. Something happens to material or papers that come into any stage. They go out in a different state.
>
> Continual improvement of methods and procedures, aimed at better satisfaction of the customer (user) at the next stage.
>
> Each stage works with the next stage and with the preceding stage toward optimum accommodation, all stages working together toward quality that the ultimate customer will boast about.

This represents process metaphysics (Rescher 2000), characterized by its focus on temporal developments, and relations between phenomena. It starkly contrasts to the more well-known thing metaphysics, which directs attention to (relatively) stable things and their composition (Koskela & Kagioglou 2005, 2006).

SUBSEQUENT DEVELOPMENTS IN THE MAINSTREAM UNDERSTANDING OF QUALITY MANAGEMENT

How have the discussed theoretical, epistemological and ontological starting points influenced the evolution of quality ideas?

Shewhart embedded the notion of quality into a conceptualization of production as value generation to the customer. This became almost a mantra in the subsequent quality movement. It is clearly visible in the suggestion of Juran (1999) to distinguish between quality as q, freedom from defects, and quality as Q, overall satisfaction of the customer. Also, the ISO 9000 quality standard strongly emphasizes these matters. The quality methodologies have developed in correspondence with the evolution of the concept of quality. The focus has changed from an inspection orientation (sampling theory), through process control (statistical process control and the seven tools), to continuous process improvement (the new seven tools), and to designing quality into the product and process (Quality Function Deployment).

As a production paradigm, the quality movement originated in Japan. Quality issues were attended to by the Japanese industry under the guidance of Deming, Juran and Feigenbaum. The quality movement in Japan soon evolved from mere inspection of products to total quality control (or Total Quality Management). Here, the term total refers to three extensions (Shingo 1988): (1) expanding quality control from production to all departments, (2) expanding quality control from workers to management, and (3) expanding the notion of quality to cover all operations in the company.

This Total Quality Management approach that originated in Japan was aligned to the epistemology proposed by Shewhart. The key indication for this is the position given to the scientific experimentation, in the form of the Plan-Do-Check-Act cycle. Thus, for example, Spear and Bowen (1999) described the epistemology of the Toyota Production System with almost the same wording as Shewhart: "whenever Toyota defines a specification, it is establishing sets of hypotheses that can be tested. Thus, the scientific method is followed." However, Spear and Bowen seem not to have been aware of the prior work by Shewhart and Deming – they do not cite them.

More generally, Dean and Bowen (1994) contended that in Total Quality Management, there are three basic principles and respective practices and techniques. These principles are: (1) customer focus, (2) continuous improvement, and (3) teamwork. These neatly correspond to the underlying theory of quality as discussed above:

- Customer focus is compatible with the value generation model of production.
- Continuous improvement is compatible both with Aristotelian epistemology and process metaphysics.
- Teamwork is compatible with process metaphysics.

Thus, the theoretical and philosophical starting points as defined by the seminal thinkers on quality have clearly been influential in the subsequent evolution of the quality movement, at least when it comes to the shaping of Total Quality Management. However, in closer examination, two problematic tendencies become visible: (1) independently from the quality movement, quality practices and techniques have been developed based on another theory of production, (improvement outside the starting points) and (2) the original starting points are forgotten or misunderstood (deterioration).

QUALITY BASED ON THE FLOW THEORY OF PRODUCTION

In parallel to the early development of the mainstream quality ideas, quality started to be developed from different starting points. Here, an account from the Web site of Toyota is illustrative (Toyota 2004):

> When Taiichi Ohno became manager of Final Assembly in the Manufacturing Department of Toyota Motor Corporation in 1945, he faced a huge challenge. Toyota had become highly inefficient during the Second World War, and Kiichiro Toyoda's Just-in-Time system had collapsed completely.

> Just-in-Time dictates that parts are delivered to the right part of the assembly line, at the right time and in the right amount. However, for this to work effectively, Ohno realized that another factor had to be controlled: quality. Parts must be flawless and defects must be eliminated before progressing along the line. This is when jidoka, the second pillar of what would later become the Toyota Production System, entered the picture.

This overall account of the developments can be corroborated through other sources (Ohno 1988, Shingo 1986). There are two aspects calling for attention. First, quality is embedded in the flow conceptualization of production (Koskela 2000): quality was needed – not primarily for the sake of the customer, but for realizing the Just-in-Time system that is designed based on prescriptions derived from seeing production as flow. The reduction of temporal variability is a key principle according to the flow model. This contrasts to the reduction of variation related to dimensional and functional attributes of parts, as implied by the doctrine of the value generation model.

Second, an examination of the concept of *jidoka* reveals that quality was approached from inside production, and generic tools, such as source inspection and fool-proofing mechanisms, *poka yoke*, were promoted for ensuring zero defects in produced parts (Shingo 1988). This contrasts to the mainstream quality thinking that looks at quality as an outcome of production, and assumes the rectification of a quality problem to be one of a kind, separate from general improvement of production.

All in all, this seemingly led to a more aggressive and effective elimination of defects than in the case of mainstream quality movement. Tellingly, Hino (2005) writes about quality at Toyota:

> The requirements of ISO 9000/QS 9000 were more than satisfied by practices and systems Toyota had established through its TQC/TQM activities, including policy deployment, management by functions, top management diagnoses, process control, design review, document control, quality audits, and quality education and training. ISO 9000/QS 9000 was unnecessary for Toyota, moreover, because it was incomplete: It did not deal with cost, one of the two pillars of management.

This superiority of a quality concept based primarily on the flow model of production suggests that anchoring quality to the value generation model is too narrow and restrictive starting point.

EPISTEMOLOGY

After the heyday of total quality management, the wider implementation of quality ideas in the industry has been supported by the ISO 9000 series of quality standards, first published in 1987 and revised in 1994. These standards contained a prescriptive approach to quality: they stipulated which kind of documents should be prepared for the quality system. This represents Platonic epistemology (Koskela et al. 2018): existing knowledge is pushed to the world. The Aristotelian element was more or less absent. Cogently, a book guiding on the implementation of the ISO standard contained just this one line on PDCA, nothing more (Badiru 1995): "Deming's PDCA cycle, for example, is a simple model to implement".

A new version of the ISO standard was published in 2000; it contained prescriptions on continual improvement of the quality management system (Hoyle 2001). Unfortunately, the wording gave the (probably unintended) impression that the object of continual improvement is the quality management system rather than the organization and its productive activities. All in all, continuous improvement based on the PDCA cycle was sidelined in quality efforts based on the ISO standard. A telling example is provided by a recent PhD work, where the author could not find even one case where identified quality problems would have led to improvement action in the studied organizations that followed the mentioned standard (Taggart 2016).

It is only the newest version of the standard (ISO 9001:2015) that takes a much less procedural approach and stresses the application of the PDCA cycle at all levels of an organization. Ironically, a seminal idea, presented more than 80 years earlier, was thus finally rediscovered by the quality movement.

Generally, the reception of this epistemological foundation of quality has been strangely mixed. On one hand, there are attempts to define a science of improvement based on the PDCA cycle (Langley et al. 2009). On the other hand, a recent popular management book (Syed 2015) discusses learning from mistakes without any reference to the corresponding established ideas and techniques, like PDCA, used in quality efforts. While these ideas attract enthusiastic followers, who deepen and operationalize them, at the same time they seem to be unknown to many.

ONTOLOGY

The practical import of the metaphysical (or ontological) starting points for quality management is in the emphasis on relationships between different things and processes, and on continuous change, especially continuous improvement (irrespective of the source of improvement).

Not all developments in the quality methodology have subscribed to these emphases. Business process design (or re-engineerig) emerged as a popular tool for quality. In Harrington's (1991) influential book on business process design, only 2 % of the pages (5 and a half pages out of 274) are addressing continuous improvement. It may be that this inability to embrace continuous improvement has cultural reasons (de Oliveira & Nisbett 2017): in Western thinking, there is an expectation of lack of change, whereas East-Asian thinking assumes states of the world to be subject to constant change as interconnected parts engage in dynamic, mutual influence. The observations of the Japanese Imai (1986) support this:

> "It dawned to me that there might be different kinds of change: gradual and abrupt. While we can easily observe both gradual and abrupt changes in Japan, gradual change is not so obvious a part of the Western way of life. How are we able to explain this difference?"

Business process redesign contained another related feature that goes against the original assumption behind quality. Armistead and Rowland (1996) state: "…business processes can be broken down into a hierarchy of smaller processes which share the same characteristics". This is an analytical approach, closely related to thing metaphysics. The general direction of examination is towards breaking up entities into their constituent parts, whereas no or little attention is given to relations between entities (or their parts).

As evident from Deming's characterization of the implications of dividing the productive effort into tasks (presented above), a central consequence of process metaphysics is that collaboration between tasks (operatives, firms, etc.) is the default situation, rather than an exception. This idea has not been properly acknowledged in the ISO centred quality approach. A list of quality principles has been developed in connection to ISO standards, and the latest version includes the following: Customer focus, Leadership, Engagement of people, Process approach, Improvement, Evidence-based decision-making, Relationship management (International Organization for Standardization, 2015). While most other original starting points of quality are well represented, the important issues of collaboration and teamwork are in practice covered regarding the relations between a firm and its suppliers and other stakeholders only – not inside the firm.

DISCUSSION

At the origin of the quality movement, Shewhart defined quality through the value generation theory of production, and suggested the scientific model (later to be named as Plan-Do-Check-Act cycle, PDCA) as the epistemology for improving quality. Somewhat later, Deming recommended process ontology as applicable in the quality context. These prescriptions were not presented in terms of theory, epistemology or ontology but through models and verbal arguments. Perhaps partly for that reason, in subsequent developments these prescriptions were often forgotten or rejected. Especially, the ISO standard for quality management rediscovered the original PDCA epistemology only in 2015. In turn, an acknowledgement of the implications of process ontology has been partial at best. Thus, the degeneration of the original theoretical and philosophical foundation seems to be one of the longstanding problems in the area of quality. Arguably, the situation that these epistemological and ontological starting point have been implicit has contributed to these problems.

On the other hand, it has turned out that the value generation theory of production is a partial theory. As the success of the lean movement indicates, production should also be seen through the flow theory. The achievement of quality can, for its part, also be explained through this flow theory of production. However, there has been very little theoretical work both regarding production and quality, and thus the integration of theories on production has not been achieved. Lacking theoretical evolution is another long-standing problem that arguably has hindered the progress of quality management.

CONCLUSION

There is a perception that quality as a managerial focus has lost its attraction in the last two decades. In this presentation, the argument that weaknesses of the theoretical and philosophical foundation of quality have contributed to this lack of attraction has been forwarded, along with supporting evidence.The findings call for a sustained effort to explicate and develop the theoretical and philosophical foundations of quality.

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DEVELOPING A CONCEPTUAL MODEL FOR VALUE DELIVERY IN VALUE SHOP CONFIGURED CONSTRUCTION PROJECTS

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ABSTRACT

Value configuration is a term from the business literature that describes how companies are rigged for delivering value. The paper argues that modern day construction projects adheres to a value shop configuration rather than a value chain configuration. Where the focus of the value chain is the transformation of inputs into products, the focus of the value shop is to (re)solve customer problems.

The main theoretical foundation of Lean Construction for understanding value delivery is the Transformation-Flow-Value (TFV) theory of production. While this provides a solid basis and model for understanding value delivery in value chain configured construction projects, it comes up short with regards to value shop configured projects.

The paper presents a newly developed conceptual model for the value delivery in value shop configured construction projects, and shows how it can be beneficial vis-à-vis the TFV theory with regards to understanding the fundamentals of value delivery in value shop configured construction projects

KEYWORDS

Lean construction, theory, value delivery

INTRODUCTION

In the last few decades there has also been a shift in focus of project management from just delivering scope on time and on budget to delivering value (Laursen and Svejvig 2016). Within Lean Construction, value has always been central. However the topic of value is not without issues. While there is no contention that the goal of projects is to deliver value (Emmitt et al. 2005), there is no agreement of what value is (Drevland et al. 2017a; Salvatierra-Garrido et al. 2010) or whom we should deliver value to (Drevland and Tillmann 2018). We would argue that the fundamentals of value delivery in modern day construction projects is poorly understood. Furthermore. we would argue this is at least partially due to not having s suitable conceptual model of value delivery.

In general, models represent reality in some way or form (Gregory 1993; Meredith 1993). Models can have different levels of abstraction. On one end of the scale we find

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iconic models, which are physical representations of objects or systems, such as scale models. In these, there is a one-to-one relationship between every part of the model and the real object or system it represents. On the other end of the scale we find pure conceptual models, where the elements of such models do not necessarily have a real-world equivalent (Gregory 1993).

While the literature is ambiguous with regards to what constitutes a conceptual model, we defer to Greca and Moreira (2000) 's definition. According to them, a conceptual model is an "external representation created by researchers, teachers, engineers, etc., that facilitates the comprehension or the teaching of systems or states of affairs in the world".

The literature contains little in the way of conceptual models of the value delivery process that takes place in projects. What exists on the subject mostly falls into one of two categories; 1) those that treat projects as a black box and 2) those that are very closely tied to specific tools and models such as Value Management (e.g. Kelly 2007). The one notable exception is Koskela's seminal Transformation-Flow-Value (TFV) theory of production, which is a cornerstone of the LC theoretical body of knowledge. However, we will in this paper argue that the TFV-theory is inadequate for fully understanding value delivery for the *value configuration* that modern construction projects employ.

Value configuration is a term from the business literature used to explain how companies are rigged with regards to delivering value to their customers. Following the method section, the paper starts by introducing the concept, and the different archetypes of value configuration, in detail and contextualising it for construction projects. Next, we give a brief overview of the TFV-theory and present arguments for it being inadequate for fully describing value delivery in construction projects. Thereafter, we present a new conceptual model for the value delivery in construction projects. Finally, we discuss the model's aptness versus the TFV-theory.

METHOD

This paper is anchored in the pragmatic research paradigm. This paradigm "sidesteps the contentious issues of truth and reality, accepts, philosophically, that there are singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the 'real world'" (Feilzer 2010). Within the pragmatic paradigm "inquiry aims at utility for us rather than an accurate account of how things are in themselves", and truth is here seen as a matter of useful belief (Rorty 1999).

The conceptual model presented later in this paper has been developed through abductive reasoning. Abduction is an alternative form of inference to the more traditional induction and deduction. The term was first coined by the pragmatist philosopher Charles Sanders Peirce (Burks 1946). Pierce refers to it as the logic of discovery, the only logic that can truly create new theoretical knowledge (Peirce et al. 1994).

VALUE CONFIGURATION

In his seminal book *Competitive Advantage: Creating and Sustaining Superior Performance*, Porter (1985) introduced the concept of *value chain*, which he describes as a representation of the collection of activities that are performed in a company to design, produce, market and deliver the company's product.

Porter argues that the general value-creating logic of the value chain model is valid for all industries. This notion is challenged by Stabell and Fjeldstad (1998), who argue that the value chain concept has several shortcomings with regards to describing the value creation taking place in many companies. One of their examples is that of banks:

> *"Our experience is that value chain analysis frequently results in either postulating deposits as the 'raw material' that the bank's primary activities transform into loans, or postulating that all primary banking activities collapse into a single major activity class: operations. In either case, the chain model cannot deal explicitly with both lenders and borrowers as bank customers. The*
>
> *value chain metaphor obscures the competitive logic of banking by focusing attention on transaction-processing unit costs, with little attention to interest spread and risk management."*

Stabell and Fjeldstad (1998) further argue that the value chain is but one of three generic *value configurations*. The other two being *value shop* and *value network*. The attributes of each of the three models are summarized in Table 1. While these value configurations are intended to describe how value is created in companies, we would argue that they are also applicable for describing projects as value delivery systems.

Value network configured companies deliver value linking their customers together, for example, telecommunication providers. For construction projects, there are no analogue to this. However, we would argue that the other two configurations have analogous project delivery models.

The value delivery logic of traditional project management and traditional design-bid-build delivery resembles the logic of the value chain. The scope is locked at the outset of the project, and optimisation is matter minimising inputs in delivering this output. Conversely, modern project delivery approaches, such as Lean Integrated Project Delivery, are more open ended at the outset and focused on fulfilling the client's purpose rather than delivering a locked scope. We would argue that such delivery models can be considered to be value shop configured.

Table 25 Overview of alternative value configurations (Stabell and Fjeldstad 1998)

	Chain	Shop	Network
Value creation logic	Transformation of inputs into products	(Re)solving customer problems	Linking customers
Primary technology	Long-linked	Intensive	Mediating
Primary activity	• Inbound logistics • Operations • Outbound logistics • Marketing • Service	• Problem-finding and acquisition • Problem-solving • Choice • Execution • Control evaluation	• Network promotion and contract management • Service provisioning • Infrastructure operation
Main interactivity relationship logic	Sequential	Cyclical, spiralling	Simultaneous, parallel
Primary activity interdependence	• Pooled • Sequential	• Pooled • Sequential • Reciprocal	• Pooled • reciprocal
Key cost drivers	• Scale • Capacity utilization		• Scale • Capacity utilization
Key value drivers		• Reputation	• Scale • Capacity utilization
Business value system structure	• Interlinked chains	• Referred shops	• Layered and interconnected networks

THE TRANSFORMATION-FLOW-VALUE THEORY

According to Koskela (2000), three different conceptualisations of production have been present through the 20th century have been used. He argues that all three are needed and synthesises them to one common theory; the Transformation-Flow-Value (TFV) theory.

The predominant conceptualisation of production has historically been that of a *transformation* of inputs to outputs. Here, it is assumed that the overall transformation can be decomposed into a set of smaller transformations, which in turn can be optimised to improve the whole.

One limitation of the transformation conceptualisation is that it only considers where processing takes place, i.e. the value-adding activities. If a production process is decomposed into smaller transformation activities, then this decomposition will also yield several non-value-adding activities in between, such as transportation, inspection and waiting. This is the focus of the second conceptualisation, *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 minimised or eliminated.

Another flaw of the transformation conceptualisation is that it is prone to sub-optimisation. Neither consequences on downstream operations nor the qualities of the final product are of concern when optimising the smaller tasks. This is the domain of the third conceptualisation, *value*, which is concerned with the realisation of the customers (internal and external) needs.

CRITIQUE OF THE TFV-THEORY

Winch (2006) provides a thorough critique of the TFV-theory. Of special interest is his critique of the unitary value concept implied in the TFV theory, with the focus being solely on the final customer. Winch argues that there are three different value aspects that must be considered:

1. the contribution that the asset created by the process makes to the client's business processes
2. the contribution that the process makes to the supplier's business processes
3. the contribution that the asset makes to society as a whole

Drevland and Tillmann (2018) have argued that there might be even more groups that must be considered, than those who Winch (2006) mention. However, Winch's view is in line with the arguments by Drevland and Tillmann. The salient point here is that the projects as value delivery systems must take into account the value for more than one customer at once.

The TFV-theory does to some extent consider multiple customers. All downstream workstations are considered customers, and the value for those should always be considered. However, the value measurement and optimisation that takes place is always related to the final customer. I.e. better value delivered to a downstream workstation is only interesting insofar as it improves the value delivered to the final customer.

We would argue that the TFV-theory is excellent for explaining and optimising production in cases where the output, that the production system should deliver, is fixed at the outset. E.g. assembly lines or traditionally scope locked projects. However, we would furthermore argue that it comes up short for any project model that can be considered a value shop configuration.

In the TFV-theory, the value to be delivered is simply equated to be what the customer wants in terms of hard requirements. These requirements will be formulated based on some perception of what is valuable at that point in time. Herein lies the problem. The perception of this will be dependent on both the context and the knowledge of the customer (Drevland et al. 2017a). Construction can take a significant time to complete, and the changes in the customer's context could be significant during that time. Furthermore, knowledge can be said to be the key product of any design process (Reinertsen 1997) Thus; the customer's perception will change as the project moves forward and new knowledge is gained. Modern project delivery models, typically integrating design and construction, therefore requires value to be treated dynamically.

Another issue with the TFV theory is that at the core it is a linear model. While it is well suited for a value chain configuration, which has sequential logic, it is not so much so for a value shop configuration, where the main interactivity logic in a value shop configuration is cyclical or spiralling. We would argue that a conceptual model of the value delivery process, of value shop configured projects, should not be purely linear, but rather should have some notion of iterativity.

THE STAKEHOLDER VALUE DELIVERY MODEL

This section presents the Stakeholder-Value-Delivery (SVD) model. The model, shown in Figure 2 is heavily inspired and influenced by Gero's (1990) Function-Behaviour-Structure model of design. However, the model is too fundamentally different to say that it is derived from it.

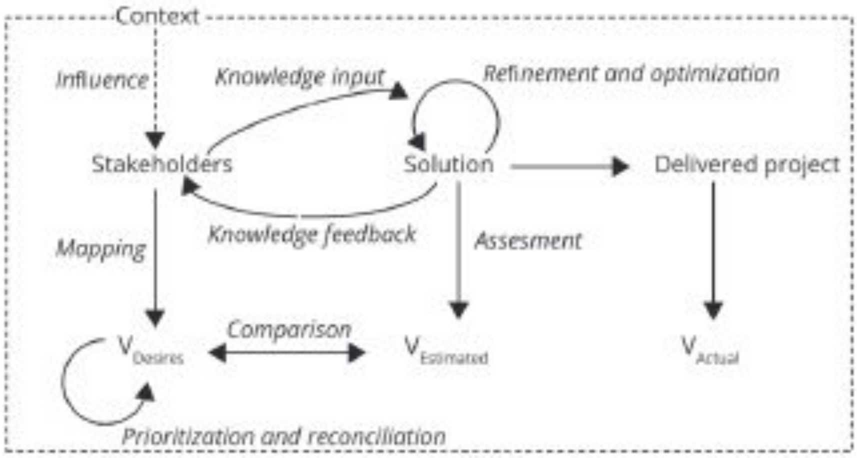

Figure 58 The Stakeholder Value Delivery Model

Stakeholders

Exactly who's value matters in a project is a matter of philosophy (Drevland and Tillmann 2018). However, in general, the goal of any project will be to deliver value to a set of stakeholders. The project, when delivered, will yield V_{Actual}, this being the set of value actually delivered to each stakeholder. The project delivery process then becomes a matter of finding and executing a *Solution* that will lead to V_{Actual} being maximised.

Since V_{Actual} is the set of value for all stakeholder, and there always some degree of value misalignment between these, maximising must necessarily be in accordance to some value philosophy. It is impossible to maximise the value for all stakeholders at once.

According to Drevland et al. (2017a), there are three elements that come into play for a stakeholders perception of value 1) their values, 2) their context, and 3) their knowledge. While peoples values can and do change, especially when dealing with money (DeScioli et al. 2014), we would argue that stakeholders changing values is not a typical nor expected result of the value delivery process. Furthermore, insofar as they do, this can be said to be as a function of new knowledge received from the solution.

Similarly, any change in values caused by something outside of the project can be said to be a matter of a changing context. Values, as such, are therefore not an element of the model.

Context influence

Every stakeholder and the project is surrounded by a context. This context influences the stakeholders' perception of value and the value they desire from the delivered project. For example, hospital projects take a long time to complete. During the project execution, several contextual factors could come into play, such as developments in medical technology or demographic shifts, that would change how the owner would want the final design of the facility.

Mapping

The starting point of the solution process will be an understanding of what is valuable $V_{Desires}$, for the different stakeholders. In the literature, explicit processes that are undertaken to understand stakeholder value are typically referred to as elicitation (Barney et al. 2008; Boehm 2006; Grünbacher et al. 2006; Niazi et al. 2006). The SVD model, however, refers to processes that help form this understanding as mapping. Partially, because this understanding is not necessarily formed by any explicit elicitation. It could, for example, be formed in part by assumptions and general knowledge. Also, because someone's understanding of what is valuable versus what actually is valuable is analogous to a map and the terrain it represents.

Prioritisation and reconciliation

For many projects, especially large buildings and infrastructure projects, there are many stakeholders, and there will inevitably be value misalignments between some of them (Drevland et al. 2017b). In such cases, some sort of prioritisation and reconciliation processes must take place. These could be formal and explicit, or they might be informal and subconscious. However, at some level, somehow, such processes must necessarily take place.

Solution

Given that some notion of $V_{Desires}$, i.e. what is of value for the different stakeholder, formulating a solution that achieves the desired value can be attempted. The form and content of the solution will vary wildly, depending on where we are in the project life cycle. From a pure cost model in early stages to full-blown set of design drawings, execution plans, installation instructions and such in the final stages.

Refinement and optimisation

The solution is iterated on either through refinement or optimisation. We define refinement as taking the solution further forward, i.e. adding elements or details that have so far been abstracted away. Furthermore, we define optimisation as improving the solution at the level that it is. Both refinement and optimisation can be conceptualised as a process of identifying, developing and selecting solution alternatives, as illustrated in Figure 2. There is one key difference. For optimisation, one on the alternatives will be the existing solution and some evaluation of whether iterating on this solution will be worthwhile, i.e. that the expected marginal improvement of the solution outweighs the expected cost of doing the optimisation.

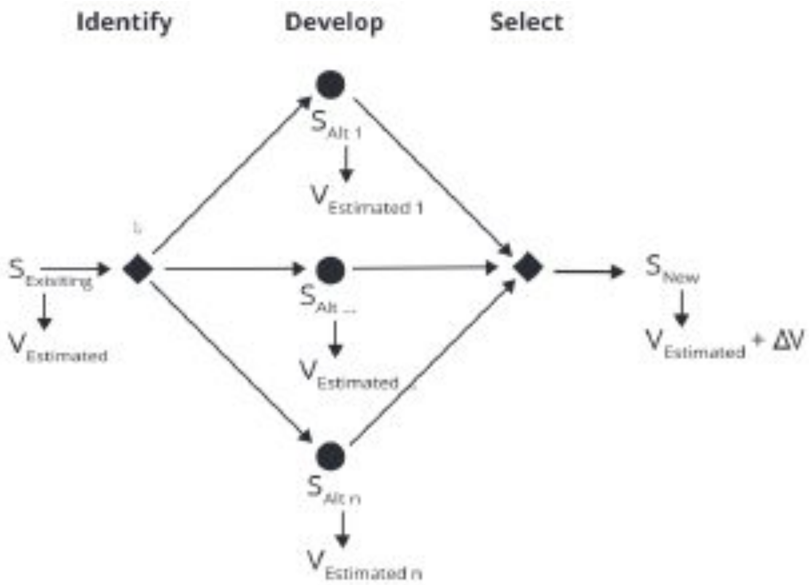

Figure 59 Process of refining or optimising solution

Assessment

The choices that are made during refinement or optimisation will be based on some notion of which alternative yields the most value. $V_{Estimated}$ is the estimate of what value the solution will give. The solution will typically be expressed in terms that are not directly relatable to $V_{Desires}$. For example, a hospital owner will desire a building that is cheap to build and maintain, and fit for purpose, while the design of the building is three-dimensional arrangement of materials and building elements. Thus, assessment categorises any processes related to estimating the impact of the elements that are contained in $V_{Desires}$.

Comparison

Based on a comparison between $V_{Desires}$ and $V_{Estimated}$ the goodness of the solution can be assessed. The results of this comparison will feed into the decision to further refine and/or optimise, as well as setting the target for these processes.

Knowledge Input and Knowledge Feedback

Coming up with the solution requires knowledge possessed by the stakeholders. Those that will design and build the project, as well as those that will own and use it. However, there is also a feedback loop here. The solution process creates knowledge which feeds back to the stakeholders. The perception of value being dependent on knowledge, entails that what is seen as valuable might now have shifted. Thus, ideally the map should then be updated to how the terrain is currently observed.

DISCUSSION AND CONCLUSION

We have in this paper made the case that projects using modern project delivery models should be considered value shop configured. However, this is a somewhat simplistic view that we would argue would not hold up well when faced with reality and the immensely complex nature of construction projects. There are certain aspects of any project, regardless of delivery model, that would benefit from being optimised either through a value chain lens or through a value shop lens. While traditional projects can be said to heavily value shop configured in the execution phase, the early phase will still focus on problem-solving. Conversely, while the problem-solving stretches further out in modern project delivery models, at some point in time, what is to be built will be locked down, and the construction process can be considered sequential.

The TFV-theory provides an excellent foundation for analysing and optimising projects through a value chain lens, but it is ill-suited to do the same when regarding projects through a value shop lens. We propose that the SVD-model presented in this paper can fill that role. Thus, we would argue that the TFV-theory and the SVD-model are complementary rather than competing conceptual models of project value delivery.

Is the SVD-model a good representation of the value delivery process in value shop configured projects? Considering that we are operating within a pragmatic research paradigm, where truth is a matter of useful belief, the question is not whether the model can be said to be a truthful representation of reality in the positivist sense, but rather if it is useful. This question cannot be can fully answered here but is something that must be left to future research. We can allude to how it can have some explanatory powers versus the TFV theory.

A feature of some the most successful tools used in Lean Construction is that they have very fast feedback cycles with regards to the SVD-model loop. Some could even be considered integrated process in the sense that Mapping, Prioritisation and Reconciliation, Knowledge Transfer, Solution and Optimisation, and Assessment are all performed by the same people in in very rapid feedback setting. One example of this is the 3P method which involves getting key stakeholders together and building full-scale mock-ups of facilities, typically using cardboard and tape, and simulating their use. Other examples are Choosing by Advantages for decision making and pull planning for scheduling.

While the TVF-theory can to some extent be used to describe the effects of the use of such tools, it does not have the vocabulary or constructs to explain the fundamental mechanisms that they act upon. The SVD-model on the other hand does. We would argue that this is essential to have these if we want to go beyond the incremental improvements of trial and error, when it comes improving such tools or developing new tools to replace them.

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PRINCIPLES OF MISTAKEPROOFING AND INVENTIVE PROBLEM SOLVING (TRIZ)

Iris D. Tommelein[1]

ABSTRACT

To err is human but people can design and make systems that are less error-prone, and more fail-safe and defect-free than many are today. One such lean design practice is called mistakeproofing (poke yoke). It is integral to the Toyota Production System and successfully practiced in numerous industry sectors. Mistakeproofing is not as widely- nor as intentionally practiced in the Architecture-Engineering-Construction (AEC) industry as it could be. To promote conceptual understanding and adoption, this paper presents 6 mistakeproofing principles. To further spur innovative mistakeproofing practices, it also presents the 40 principles of the Theory of Inventive Problem Solving (TRIZ). Mistakeproofing examples from the AEC industry demonstrate how these two sets of principles can be directly linked to rationalize existing mistakeproofing practices and, in addition, to potentially design “innovative” ones. As such, this paper supports the drive for industry innovation in developing products and processes of greater quality and thereby contribute to construction industry performance improvement.

KEYWORDS

visual management, mistakeproofing (mistake-proofing, mistake proofing), error proofing, poka yoke, Theory of Inventive Problem Solving, TRIZ

INTRODUCTION

To err is human. People can and, despite their best intentions, will make inadvertent errors (mistakes). Recognizing this reality while at the same time aiming to eliminate this source of bad variation, lean practitioners rely on mistakeproofing (also spelled “mistake-proofing” or “mistake proofing”). Mistakeproofing (translated from the Japanese word “poka yoke,” a concept integral to the Toyota Production System) has been successfully practiced in numerous industry sectors. It can be practiced, likewise, in the Architecture-Engineering-Construction (AEC) industry.

Mistakeproofing is “the use of any automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred (ASQ 2019).” It is also known as error proofing or fail safing (these words too may also be spelled as a single word or with a hyphen). The objective of mistakeproofing is to reduce the likelihood that errors will occur and, should they occur anyway, to prevent that they turn into defects.

Where mistakeproofing has been used in other industry sectors (e.g., service sectors such as healthcare, e.g., Grout 2003, Godfrey et al. 2005) it has yielded significant

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benefits. Reasonably one may therefore expect that the AEC industry will benefit from its use as well. Owners, designers, contractors, engineers, product manufacturers—simply: everyone needs to know what and where opportunities exist for mistakeproofing, to gauge what value may stem from it, and to sharpen their thinking about opportunities to mistakeproof what they do (processes) and make (products). Mistakeproofing is relevant and applies to products, steps in operations that make up processes, and projects small and large, simple and complex, and all sectors of the construction industry (e.g., Wood 1986, McDonald 1998).

In an early IGLC paper, dos Santos and Powell (1999) noted that "empirical evidences revealed that the sector makes little use of this approach at the present moment." About a decade later, Tommelein (2008) observed that it was still the case that "mistake proofing appears to not have been […] systematically researched or practiced in the lean construction community" and proceeded by saying that "To raise awareness of opportunities provided by thinking with mistake proofing in mind as a means to build quality into project delivery, this paper summarizes the philosophy that underlies mistake proofing. Examples illustrate how mistake proofing applies to the work done within one specialty trade, how manufacturers and fabricators can design their products so they cannot be constructed defectively, and how architects and engineers may conceive of system designs that are less likely to fail during construction or in a product's life cycle." Now, another decade later, systematic research on mistakeproofing and its application in the AEC industry appears to still be scarce. Some related research has been conducted in the context of visual management (e.g., dos Santos et al. 1998, Moser and dos Santos 2003, Rocha et al. 2018) but a clear presentation of mistakeproofing principles and systematic means to design new practices is overdue.

With the latter in mind, this paper first offers some conceptual background and lays out 6 principles for mistakeproofing. Second, it offers background on the Theory of Inventive Problem Solving (TRIZ), developed to help spur innovative concept generation, and refers to the 40 TRIZ principles. Third, it presents mistakeproofing examples from the AEC industry to illustrate how these sets of principles can be directly linked to rationalize existing mistakeproofing practices and, in addition, potentially design "innovative" ones. The paper concludes by stressing the need to systematically drive industry innovation in developing products and processes of greater quality, and thereby contribute to construction industry performance improvement.

MISTAKEPROOFING

Mistakeproofing is an old concept. It is a practice related to autonomation ("jidoka" in Japanese), with origins going back at least to the late 1800s when Sakichi Toyoda devised a way to detect broken thread and automatically stop a loom to avoid making defective product. The mistakeproofing concept was described by Suzaki (1985) and Shingo (1986), who wrote the book Zero Quality Control. Claiming "Defects = 0 is absolutely possible!" Shingo critiqued the use of statistical process control and was set on eliminating ad-hoc quality control (QC) (e.g., in construction, ad-hoc QC includes punch-list processes and rework that experienced practitioners all too often take for granted but nobody wants).

Shingo noted the need to clearly distinguish errors from defects, that is, to differentiate between causes and effects: "errors will not turn into defects if feedback and action take place at the error stage.” Elimination of defects by mistakeproofing is done by reducing the possibility of errors occurring, by making errors—should they occur—easily detectable, and by mitigating their effects so they would not turn into defects. As a result, mistakeproofing reduces the need for inspection.

Mistakeproofing is based on 6 principles (e.g., Shingo 1986, Shimbun 1988, McMahon 2016) as illustrated in Figure 1 (after Fig. 1 in Godfrey et al. 2005, attributed to Prof. Takeshi Nakajo, redrawn and color-coded by Tommelein). These principles apply to the design of a product (e.g., Norman 1989, Taguchi and Clausing 1990) and related operations. They have an impact at different points in time, when different steps in the operation are performed. Colors in Figure 1 indicate the author’s assessment of the desirability of the intervention. The range spans from dark green, the most desirable type of mistakeproofing, to red, the least desirable type—though still desirable!

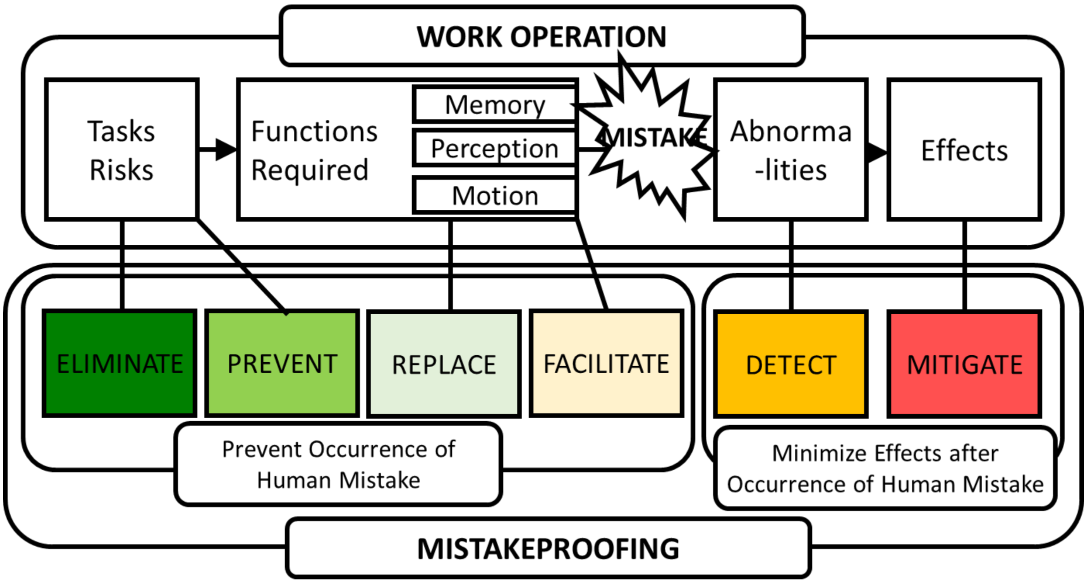


Figure 1: Mistakeproofing Principles Applied to Work Operations
(after Figure 1 in Godfrey et al. 2005, attributed to Prof. Takeshi Nakajo,
redrawn and color-coded by Tommelein)

While planning an operation before it starts, risks associated with the steps that make up the operation are identified and their possible occurence “designed out” so they will be avoided altogether. Mistakeproofing principles to achieve this are:

1. **Elimination** (paraphrased as “don’t do it anymore”) is to remove the possibility of an error occurring in a step by redesigning the product or operation so that the step (or associated product part) is no longer necessary.
2. **Prevention** (“make sure it can never be done wrong”) is to design and engineer the product or operation so that it is impossible to make a mistake at all.

If the operation cannot be designed to guarantee elimination or prevention of the occurrence of errors, then consideration must be given to how errors may manifest themselves in the course of performing the operation. While performing a step in an operation, people involved can rely on their memory, perception, and motor skills to perform not only the step but also to avoid errors. Mistakeproofing principles to support people then are:

3. **Replacement** ("use something better") is to substitute one operation with a more reliable operation to improve consistency.
4. **Facilitation** ("catch people's attention, help them make fewer mistakes") is to use various means (e.g., sensory input) to make steps easier to perform mistake-free.

If the operation can get to a point at which a mistake gets made, the mistakeproofing principle "detection" comes into play.

5. **Detection** ("notice what is going wrong and stop it") is to identify a mistake promptly so that a person can quickly correct it and thereby avoid that the error may turn into a defect.

Finally, if the ocurrance of a defect cannot be prevented, mistakeproofing can help avoid that the situation turns into a disaster, using the following principle:

6. **Mitigation** ("don't let the situation get too bad") is to minimize the effects of errors. Grout (2003) calls this "designing benign failures."

Mistakeproofing will be most effective when applied before a mistake occurs by elimination, prevention, replacement, or facilitation (Figure 1). However, should a mistake occur, it will still be beneficial to the performance of the operation overall to detect that occurrence and mitigate its impact.

These 6 mistakeproofing principles can readily be applied in the AEC industry. Tommelein and Demirkesen (2018) documented 30 examples of mistakeproofing practices in the AEC industry, selected from Tommelein's collection of more than 100. Categorization of those examples based on the 6 aforementioned principles indicates that AEC practitioners tend to resort to facilitation, detection, and mitigation significantly more so than to using principles that aim at designing potential mistakes "out." Methods are needed to systematically design more instances of mistakeproofing. The following section describes one such method.

THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

Knowledge of the mistakeproofing principles will help people recognize practices already in use. Such recognition will inform new practices in that examples can be copied or extrapolated from one application to another. In addition to direct copying or extrapolation, other methods are available to mistakeproof existing products or processes, or to design an altogether new mistakeproofed-ones. The "Theory Inventive Problem Solving" or TRIZ serves as a means to this end (Cerit et al. 2014).

DEFINITION OF TRIZ

TRIZ is a Russian acronym, translated into English as the **Theory of Inventive Problem Solving** (TIPS). This theory was developed by Altshuller, a Russian patent officer who judged- and, from 1946 onward, studied principles to foster innovations (Altshuller 1984, 1997, 1999, Souchkov 2008 rev. 2015). Over a period of time, Altshuller and colleagues compiled not only 40 principles but also developed Algorithms for Inventive Problem Solving (ARIZ) (e.g., Altshuller 1999, Marconi 1998) and related methods to foster innovative thinking. In line with Ikovenko's (2005) suggestion that TRIZ could be used as a Lean Thinking tool and the application of TRIZ in construction (Teplitskiy 2005), the focus in this paper in on using TRIZ principles to rationalize existing as well as design new mistakeproofing examples.

40 PRINCIPLES OF TRIZ

In the course of design, designers face requirements and constraints that often are contradictory, and must then negotiate tradeoffs. In the TRIZ context, designers speak of contradictions. To offer an example from Toyota, engineer Suzuki who spearheaded the Lexus program, became known for his uncompromising stance on seemingly conflicting design requirements (e.g., develop a car that can reach high top speeds, yet have low fuel consumption) known as "Suzuki's YETs" (Liker 2004 p. 43-50).

Altshuller (1999 pp. 287-289) compiled a set of 40 TRIZ principles that serve as a means to resolve contradictions and thereby spur innovative thinking. For brevity, these are not all replicated in this paper. Only 10 TRIZ principles (namely 2, 3.3, 4.1, 6.1, 11, 12, 14, 18, 23.1, and 32.1) are mentioned later in the examples provided. Readers can find all 40 in Altshuller's book (op. cit.) or, with minor adjustments in wording, on the TRIZ40 (n.d.) website.

Innovation using TRIZ principles is a four-step process to inspire thinking outside of the box. Figure 2 shows that it requires (1) a statement of a concern (problem), (2) abstraction to a more conceptual level, (3) followed by the application of a principle, and then (4) specialization to formulate a countermeasure (solution).

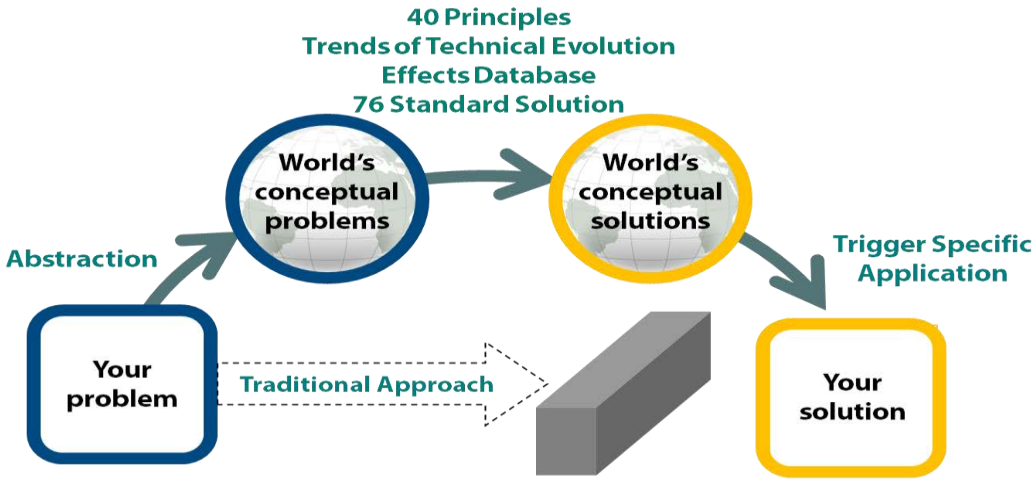


Figure 2: Prism of TRIZ Problem Solving Solutions (Oxford Creativity, (upload.wikimedia.org/wikipedia/commons/thumb/a/a2/Prism_of_TRIZ_Oxford_Creativity.png/640px-Prism_of_TRIZ_Oxford_Creativity.png visited 18 Feb. 2019)

AEC EXAMPLE APPLICATIONS OF MISTAKEPROOFING AND TRIZ PRINCIPLES

With the mistakeproofing mind-set explained, 6 mistakeproofing principles presented, and reference to the 40 TRIZ principles available to rationalize innovations (in this case: means for mistakeproofing), the following examples (Figures 3 to 12) show how these two sets of principles can be directly linked to characterize existing mistakeproofing practices. Each example describes a situation where a concern exists for a mistake to happen. A photo illustrates the mistakeproofing practice and that practice is also described as the countermeasure. In addition, each example refers to one of the 6 color-coded mistakeproofing principles and also to one of the 40 TRIZ principles that (conceivably) was applied.

Image source: Tim Carter - www.askthebuilder.com/which-circular-saw-should-i-buy/ visited 17 Feb. 2019

CONCERN:

- The electrical cord on a power tool limits the worker's working range.
- The cord attached to the tool and any extension cords may get tangled or damaged in use, and create a tripping hazard.

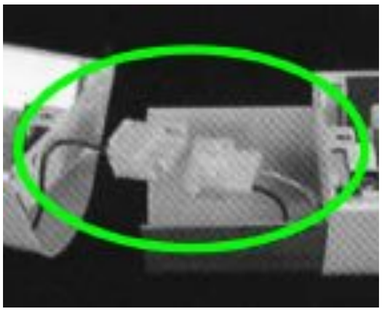
COUNTERMEASURE: Eliminate cord and tripping hazard by using batteries to supply electricity to power tool.

LIMITATION: Relative to corded tools, battery-powered tools tend to have less power and are more limited in capacity.

Mistakeproofing Principle: ELIMINATE

TRIZ Principle 2 Taking Out: Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.

Figure 3: Two Nearly Identical Circular Saws: Corded and Cordless



CONCERN:

- Electrical wires may get connected wrongly.
- Electricians must work at elevation to wire linear light fixtures, which is strenuous.

COUNTERMEASURE:

In the shop, install clips to end the wiring on each fixture. Put on correctly, these clips can snap together in only one way (asymmetry) so that the wires will always be connected correctly. On site, the electrician's installation work at elevation won't take much time nor be as strenuous.

Image source: Finelite (2008). *Estimator and Contractor Guide.* www.finelite.com/contractor/ContractorGd_m.pdf visited 22 April.

Mistakeproofing Principle: PREVENT

TRIZ Principle 4 Asymmetry: 4.1 Change the shape of an object from symmetrical to asymmetrical.

Figure 4: Connection Plug and Wiring of Linear Light Fixture

The methodology the author used was to assess each example and use judgment to classify it by principle. In fact, examples may illustrate multiple principles from each set of principles. The reader can expand on these examples further.

The examples are intended to help readers "learn to see" and recognize mistakeproofing practices in their everyday environment, so they can then leverage that ability to create their own mistakeproofing applications.

CONCERN: The cover for an opening that is rectangular (e.g., a ground excavation), can be turned sideways and fall into the opening. People working underneath inside the opening would be in harm's way.

COUNTERMEASURE: A manhole cover is round because a round object cannot fall through a circular opening of at least the same diameter, no matter how it is positioned.

Image source: McCarthy (2015-01-07) "Why Are Manhole Covers Round?" mentalfloss.com/article/60929/why-are-manhole-covers-round visited 19 Oct. 2016.

Mistakeproofing Principle: PREVENT

TRIZ Principle 14 Spheroidality (Curvature): Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones…

Figure 5: Round Manhole Cover

Image source: Brittany (2015). How to Install a Towel Bar Securely. www. prettyhandygirl. com /how-to-install-towel-bar-securely/ visited 1 Nov. 2017

CONCERN: Mounting a towel bar on a wall requires accurate measurement of the spacing between screws.

COUNTERMEASURE: The towel bar packaging acts as a template to facilitate installation by identifying the location of the drill holes, thereby eliminating the need to measure the distance between screws and then marking the location before drilling holes.

The template is held level and taped to the wall. The location of the 4 drill holes needed are illustrated on the template without requiring any additional work. Use of templates makes it significantly easier and faster to complete the work.

Mistakeproofing Principle: FACILITATE

TRIZ Principle 6 Universality: 6.1 Make a part or object perform multiple functions; eliminate the need for other parts.

Figure 6: Towel Bar Installation Template

CONCERN:
- Welders must bend or reach over and twist their bodies to access connections to be welded.
- Weld material runs down due to gravity.

COUNTERMEASURE: "ConXtech is the first manufacturing facility […] to weld, in a production environment, Hollow Structural Steel (HSS) columns entirely in the horizontal position."
- Welder works at ergonomically comfortable height and can turn by hand the column to the right position.
- Weld material is deposited horizontally.

Image source: www.prweb.com/releases/conxtech/ladbs-approved/ prweb10762433.htm visited 28 Feb. 2019

Mistakeproofing Principle: FACILITATE

TRIZ Principle 12 Equipotentiality: Change the condition of the work in such a way that it will not require lifting or lowering an object

Figure 7: Rotating Jig and Clamps to Hold Welded Steel Element

CONCERN: when using white paint to paint over a white ceiling, it is hard to see which areas have already been painted, so application may be uneven.

COUNTERMEASURE: Additives to the paint make the white paint look pink for as long as it is wet. When it dries, it gradually turns white.

Image source: Glidden® EZ Track Ceiling Paint, kk.org/cooltools/ glidden-ceiling/ visited 3 Oct. 2017

Mistakeproofing Principle: FACILITATE

TRIZ Principle 32 Color changes: 32.1 Change the color of an object or its external environment.

Figure 8: Color-changing Paint

CONCERN: Distracted or sleepy drivers may veer off the road.

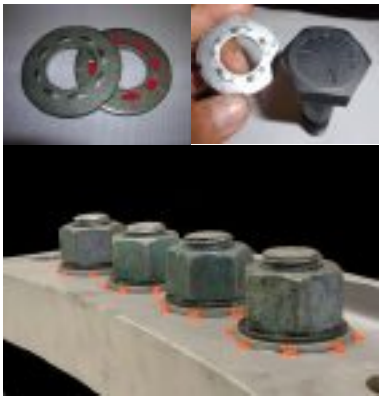
COUNTERMEASURE: Rumble strips cause the vehicle to make a loud noise (auditory feedback) that alerts the driver, who can then avoid running off the road.

Image source: www.rumblestrips.com/resources/research-and-publications/cyclists-and-rumble-strips/ visited 2 Nov. 2017

Mistakeproofing Principle: DETECT

TRIZ Principle 18 Mechanical Vibration: Cause an object to oscillate or vibrate.

Figure 9: Rumble Strip



CONCERN: Structural bolts must have the proper pretension in order to be functional. This tension is achieved by torqueing the bolt however torque is not a reliable indicator of tension.

COUNTERMEASURE: Squirter DTIs are compressible washers that show when a bolt reaches its target tension, independent of torque, by expressing orange-colored material.

Image source: Myhrum, B. (2010). "Simple QA for Wind Turbine Bolts." Windpower, www.windpowerengineering. com/ construction/simple-qa-for-wind-turbine-bolts/

Mistakeproofing Principle: DETECT

TRIZ Principle 23 Feedback: 23.1 Introduce feedback (referring back, cross-checking) to improve a process or action.

Figure 10: Tension Bolt

TRIZ principles (and ARIZ methodology) can also be used to design innovative mistakeproofing practices. Imagine designing a nail gun with a contact sensor that also, like SawStop (Figure 12), gauges the conductivity of the surface it touches. The nail gun should fail to engage upon contact with a person.

CONCLUSIONS

The principles of mistakeproofing have practical and useful application in the AEC industry. While perhaps not so obvious to the untrained eye, quite a few such applications already exist. AEC practitioners should learn to see them. The practice of mistakeproofing construction, itself, needs to be made more visible. Documentation of existing practices will inspire greater adoption. The systematic adoption of mistakeproofing principles is bound to help improve quality performance in the short- and long-term as it has across the board in other industries.

The need to mistakeproof everyday products and processes may seem obvious—or hopefully will appear obvious in hindsight. The generation of new ways to mistakeproof product designs, and steps in operations that make up processes can be supported by drawing on the 40 principles of TRIZ. TRIZ takes a scientific approach to foster innovative thinking and offers methods that can be taught. It should be considered for inclusion in any mistakeproofing curriculum.

CONCERN: Cart (as shown, loaded with ~1,600 kg or 3,500 pounds of glass) may tilt over or collapse due to wheel/caster failure, and crush or kill a worker.

COUNTERMEASURE: Added a “dead man” concept (cicled in red) to each of the 4 corners of the fabricated cart to prevent cart from tilting over or collapsing in case of wheel/caster failure.

Image source: Stoker, I. and Stearns, L. (2017). “Harmon Glass Handling Kaizen-Report Out (Event Dates: 1/12 to 1/14).” Harmon, Inc. Mfg. Facility, Cincinnati, OH, 30 Nov. 2017; Powerpoint slides provided by Chad Hoffmann, 23 pp.

Mistakeproofing Principle: MITIGATE

TRIZ Principle 3 Local Quality: 3.3 Make each part of an object fulfill a different and useful function.

Figure 11: Wheeld Cart with “Dead Man” Legs

Image Source: www.sawstop.com visited 10 Oct. 2018

CONCERN: People use their hands to push material and cut it with the table saw. Their hand may get caught by the blade.

Table saws have blade guards to reduce the likelihood of a hand getting caught, but workers may find these to be impractical and remove them.

COUNTERMEASURE: “The SawStop saw detects contact with skin. The blade carries a small electrical signal, which the safety system continually monitors. When skin contacts the blade, the signal changes because the human body is conductive. The change to the signal activates the safety system.”

Mistakeproofing Principle: MITIGATE

TRIZ Principle 11 Beforehand Cushioning: Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

Figure 12: Table Saw Stop

By presenting sets of principles for mistakeproofing as well as for innovating using TRIZ, and demonstrating how these relate to industry-specific examples of mistakeproofing, this paper aims to encourage broader awareness and use of mistakeproofing in AEC education and practice. It supports the drive for industry innovation in developing products and processes of greater quality and thereby contribute to construction industry performance improvement.

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PREDICTION OF ENVIRONMENTAL PERFORMANCE INDICATORS FOR CONSTRUCTION SITES BASED ON ARTIFICIAL NEURAL NETWORKS

Luara L. A. Fernandes[190], Mércurie J. Rocha[191], and Dayana B. Costa[192]

ABSTRACT

The construction sector still contributes on a major scale to negative impacts on the environment, but it is aware of its responsibility for sustainability in the life cycle of a building. The sector has been using performance measurement, specifically environmental indicators, to monitor and manage its impacts. However, managers have not been using the monitored indicators for any managerial decision because they do not have benchmarks to establish performance targets and evaluate their results. This research is an experimental study that aims to develop an equation for the prediction of environmental performance indicators based on the construction progress. For the development of the study, a database of 15 construction sites in Brazil concerning three environmental indicators (water consumption, energy consumption and construction waste generation) established by the PBQP-H (The Brazilian Program for Quality and Productivity in Habitat) was used. The developed software was written in Python language and the model was built with the use of Artificial Neural Networks. From the application of the resulting equations, managers can obtain a benchmark based on the construction progress in which the building is and promote improvements in their environmental performance as well as use such information in the planning stage.

KEYWORDS

Lean construction, sustainability, waste, construction management, performance measurement.

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INTRODUCTION

Lean construction can support sustainable construction by not focusing only on its accidental benefits for the environment, but also introducing the social and environmental issues as values to reach (Bae and Kim 2007). Lean construction can contribute to more sustainable buildings, since they add value to the customer, intervening at the stages of conception and design and at time of construction, (Carneiro et al. 2012). A more sustainable construction should seek increase value, pollute less, provide support for the sustainable use of resources, respond effectively to the parties involved and improve the quality of life in the present without compromising the future (Silva 2003).

Lean construction implementation on construction sites reduces waste and improves construction flows, providing economic advantages (Carneiro et al. 2012), but it is essential to ensure sustainability, also improve the social and environmental aspects during the lifecycle (Carneiro et al. 2012). Lean construction principles can contribute to the sustainability purposes by eliminating waste (of material) by minimizing resource depletion and pollution and adding value to the customer, with the reduction of these resources, and matching business and environmental excellence (Bae and Kim 2007).

For the management of the impacts, it is necessary to define technological resources and necessary managerial actions, selecting the resources required to be implemented and the deadlines and costs involved (Cardoso and Araujo 2007). In this way, the environmental management of construction sites uses sustainability indicators to monitor the conditions and environmental performance of construction sites (Tam et al. 2006).

In Brazil, there are efforts to define sustainability indicators in different scales of the built environment, which vary widely and are defined based on criteria and methodologies not necessarily replicable (Silva 2007). The PBQP-H (Brazilian Program for Quality and Productivity in Habitat) requires that the certified companies in this Program collect six sustainability indicators, which are: (1) energy consumption throughout the construction (kWh /number of workers); (2) energy consumption at the end of the construction (kWh / m^2); (3) waste generation throughout the construction (m^3/number of workers); (4) waste generation at the end of the construction (m^3/m^2); (5) water consumption throughout the construction (m^3/number of workers); (6) water consumption at the end of the construction (m^3/m^2).

However, just the collection of indicators is not enough to improve environmental performance. Sustainability indicators are generally new, and the main problem is to establish maximum and minimum values (Lopez and Sanchez 2011). Therefore, the purpose of this study is to make a statistical analysis of a database of the three environmental PBQP-H indicators throughout the construction and to develop an equation relating them to the construction progress. The developed equation aims to provide a forecast of these environmental indicators during the construction, supporting the construction industry and firms in the improvement of their environmental performance.

SUSTAINABILITY MANAGEMENT IN CONSTRUCTION

According to Yilmaz and Bakis (2015), sustainability is the use of natural resources in an equilibrium condition that it does not reach decay, depletion and non-renewal, without compromising the development of future generations. The concept fundamentally seeks to promote balance with respect to the human, time and place; in other words, equitable allocation of the world's resources among all nations, living beings, and future generations (Yilmaz and Bakis 2015). Sustainability has become a strategy that led governments to develop policies and corporations to develop strategies (Ratiu and Anderson 2015). The construction industry is becoming aware of the importance of adopting the principles of sustainability in the sector and has been using statistical and computational methods to perform analysis to improve environmental performance.

Sustainable construction is related to the integration of environmental, social and economic considerations into building business strategies and practices (Ogunbihy et al. 2014). It is a holistic process that seeks to maintain the harmony between the natural and constructed environment (Yilmaz and Bakis 2015). Sustainable construction is directly linked to sustainable project management.

According to ISO 14001/2015, it is the role of an Environmental Management System (EMS) to help organizations prevent and control significant impacts to the environment, manage risks and continuously improve environmental performance and productivity. Performance measurement is a strategy that can be used to monitor environmental impacts.

Performance measurement is very important for production management because it provides necessary information to control the process, and makes possible the establishment of challenging and viable goals (Lantelme and Formoso 2000). Indicators can be an efficient tool to measure environmental performance. Sustainability indicators can be defined as instruments that allow the description of environmental, economic and social impacts caused by enterprises (Silva 2007). By monitoring these indicators, regular evaluations and goal control can be performed, since they can highlight any adverse trends in the environmental control process (Tam et al. 2006).

However, for an effective use of monitored indicators, it is necessary reference values. According to La Barre and El-Adayay (2014), one of the most important aspect of performance measurement is the ability to do benchmark. It is the next step for improving efficiency of products and processes (Luu et al 2008).

ARTIFICIAL NEURAL NETWORKS

A machine learning system is a computational program that takes decisions based on accumulated experiences through the effective resolution of previous problems (Monard and Baranauskas 2003). Artificial Neural Networks is an example of an Artificial Neural Network technique. A neural network "is a massively distributed processor composed of simple processing unit, which has the natural propensity to store experimental knowledge and make it available for use" (Haykin 2007). It resembles the human brain in two respects: in the form of acquiring knowledge (from its environment and in a learning process) and in the storage of knowledge (through synaptic weights, which are the connecting forces between neurons) (Haykin 2007).

Neto, Nagahama and Gadéa (2017) point out that neural networks have been widely used in engineering as a solution to complex and non-linear problems. One of the applications is the use of neural networks to extract rules and make a sensitivity analysis, a possibility pointed out with one of the potentialities of the method of Han and Kamber (2001). The search for rules that explain the behavior of observed variables can be seen, for example, in Bortolazza and Formoso (2006), that studied the correlation between root cause frequency and PPC measured weekly in sites that implemented Last Planner. Due to the number of indicators and, therefore, variables produced in the sustainable management of buildings, there is a great potential to develop more studies of this nature.

RESEARCH METHOD

This research is characterized as experimental study, which is, according to Fontelles et al (2009), any research that involves experiments. In this kind of study, the researcher selects the variables that are going to be studied, defines the manner of control and makes the observation of the effects of the research (Fontelles 2009).

This study was developed based on a data collection carried out by the Research Group in Construction Management and Technology [193] . For this paper, data from three environmental indicators (water consumption throughout the construction, energy consumption throughout the construction and waste generation throughout the construction) and the physical progress of construction projects were used. All the indicators used were collected from a monthly basis by the construction projects investigated. The pilot sample used for this paper is composed by 15 construction sites, with different constructive systems, which are concrete walls (5), reinforced concrete (5) and structural masonry (5), from different target public, which are high income (5) and low income (10), and with different building purposes, which are commercial (4) and residential (11). The Figure 1 presents the characterization of the sample.

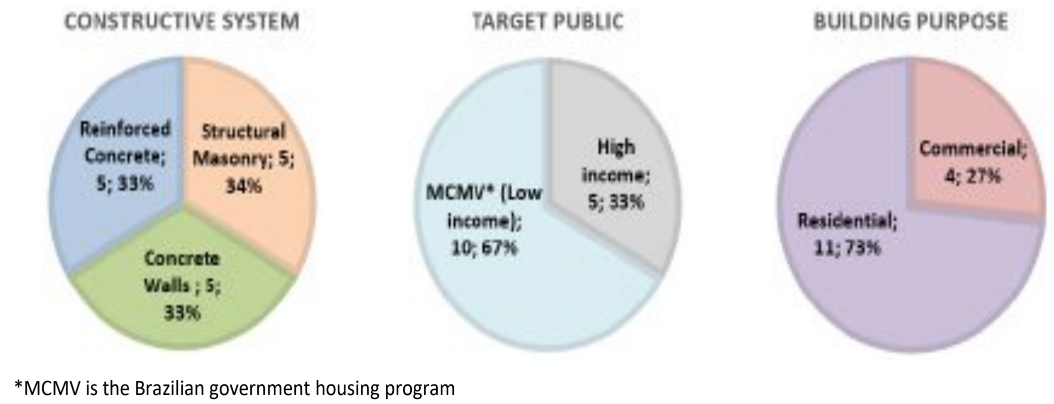

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Figure 1 – Sample characterization

The study was developed from four major steps: (1) Sample analysis, (2) Equation development, (3) Evaluation of the model (4) Final model, as illustrated in Figure 2.

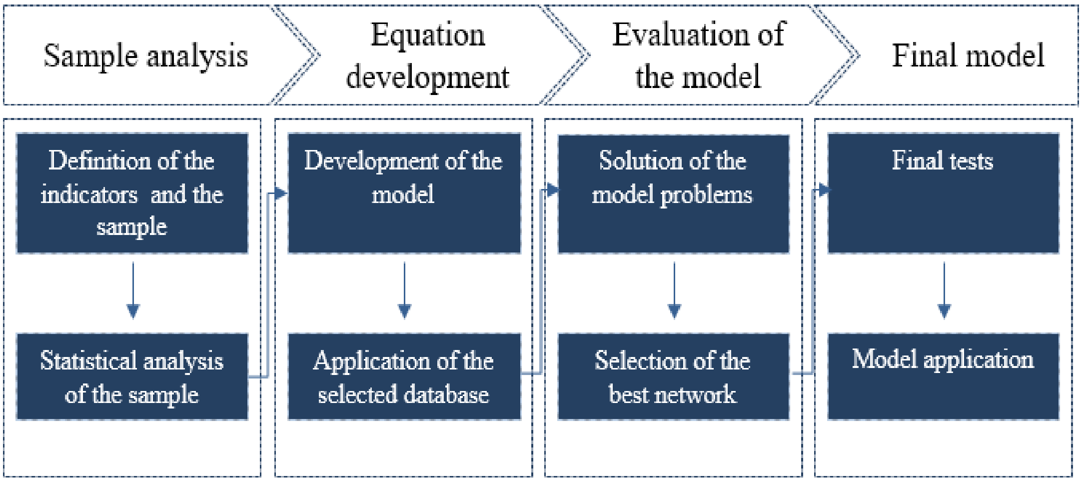

Figure 2 – Steps of the study

The first stage of the study was consisted in defining the indicators and the sample to develop a statistical analysis. Then, a software was written in Python with the use of the scikit-learn library (Pedregosa et al, 2011) and in its implementation was used Multi-layer Perceptron. Only one intermediate layer was applied in the model, considering the good results (Neto et al. 2017). Several network topologies (from one to seven neurons in this layer) were tested respecting the Komogorov-Nielsen theorem (Kóvacs 1996). The transfer functions tested were the logarithmic and hyperbolic tangent.

After these steps, some Artificial Neural Networks were trained in order to predict the sustainability indicators based on the physical progress of the constructions. Table 1 presents the variables in the model and their range of variation.

Table 1 – Variables, representation and range of variation

Variable	Representation	Range of variation
Physical progress	x0	[0;1]
Water consumption	y0	[0;∞)
Energy consumption	y1	[0;∞)
Waste generation	y2	[0;∞)

For this data analysis, cumulative medians of indicators of 15 construction sites were used for each 10% of physical progress (except for the first data range, which was used 5% to analyze the impacts of the activities of the beginning of the construction, and the last data range, which was used 15% due to the proximity to the end of the construction). The data waTable 2 presents the data set used in the model.

Table 2 – Data set used in the study

Construction progress (%)	Water consumption (m^3 / number of workers)	Energy consuption (KWh / number of workers)	Waste generation (m^3 / number of workers)
0-5	0.97	67.21	0.31
5-15	2.71	84.96	0.77
15-25	4.49	101.13	1.29
25-35	5.61	119.24	2.15
35-45	7.09	140.81	2.75
45-55	8.88	158.85	3.37
55-65	10.58	177.66	4.07
65-75	12.13	193.68	4.94
75-85	13.94	212.81	5.77
85-100	16.32	230.62	6.83

RESULTS AND DISCUSSION

This section presents the results obtained from the statistical analysis of the sample and the generation of the model.

STATISTICAL ANALYSIS OF THE ENVIRONMENTAL PERFORMANCE INDICATORS

A statistical analysis of the sample was performed in order to identify the range of construction progress with major impacts and establish some reference values. Regarding to the water consumption indicator, the median values varied between 0.97 m^3/worker and 2.38 m^3/worker. The maximum value for this indicator is associated with the range of construction progress of 85-100%, which may be related to the reduction of the number of workers in the end of the construction, what impacts in the indicator because it consider this variable in its denominator. The minimum value is associated with the 0-5% range of construction progress, what is expected due to the small amount of activities at the beginning of the construction.

For the energy consumption indicator, the median values varied between 16.02 kWh/worker and 67 kWh/worker. It should be noted that for this indicator the maximum value is associated with 0-5% range of construction progress. Analyzing the data, it was noticed that this value is specifically high due the small amount of data for this range (not all the sites have the energy consumption measures in the beginning of the construction) and also due to one construction site that present an extreme indicator in the deployment phase. However, the medium values for all the other construction progress are in the range of 16.02 kWh/worker and 21.57 kWh/worker, presenting a certain regularity of the data.

The waste generation indicator presented median values between 0.31 m^3/worker (range of 0-5% of construction progress) and 1.06 m^3/worker (range of 85-100% of construction progress). This situation is expected because the indicator does not consider soil for waste, which in general is the biggest part of the waste in the beginning of the construction. The fact that the biggest value for the indicator is in the end of the construction is also expected due to the demobilization phase. The complete statistical analysis of the data is presented in Table 3.

Table 3 – Statistical analysis of the sample

	Construction progress	Minimum	Average	Median	Maximum	Standard deviation
Water consumption	0-5%	0.60	1.50	0.97	3.44	1.34
	5-15%	0.29	1.80	1.74	4.50	1.31
	15-25%	0.02	2.43	1.78	10.84	2.67
	25-35%	0.08	2.23	1.12	8.98	2.60
	35-45%	0.50	2.13	1.48	6.31	1.80
	45-55%	0.47	2.23	1.79	7.32	1.91
	55-65%	0.28	2.36	1.70	6.48	1.84
	65-75%	0.14	2.60	1.55	11.66	2.97
	75-85%	0.13	1.95	1.81	3.65	0.90
	85-100%	0.14	2.33	2.38	4.88	1.37
Energy consumption	0-5%	16.13	67.21	67.21	118.28	72.23
	5-15%	0.83	18.06	17.75	37.20	12.64
	15-25%	3.94	29.60	16.17	185.78	38.36
	25-35%	0.73	19.51	18.11	49.65	12.89
	35-45%	7.98	20.86	21.57	44.19	10.16
	45-55%	6.27	19.10	18.04	35.53	9.81
	55-65%	5.50	20.35	18.81	37.28	10.62
	65-75%	5.27	20.68	16.02	42.31	10.62
	75-8 5%	2.94	19.54	19.13	44.37	10.93
	85-100%	1.88	20.59	17.81	47.50	13.45
Waste generation	0-5%	0.13	0.31	0.31	0.49	0.25
	5-15%	0.08	2.78	0.46	34.31	8.74
	15-25%	0.02	4.00	0.52	33.98	9.98
	25-35%	0.09	1.34	0.86	8.99	2.11
	35-45%	0.17	0.80	0.60	2.99	0.75
	45-55%	0.15	1.27	0.63	3.75	1.23
	55-65%	0.18	0.88	0.70	2.36	0.55
	65-75%	0.19	1.09	0.87	3.04	0.77
	75-85%	0.43	1.07	0.83	2.50	0.62
	85-100%	0.25	1.15	1.06	2.34	0.69

EQUATIONS FOR THE PREDICTION OF ENVIRONMENTAL PERFORMANCE INDICATORS BASED ON THE CONSTRCTION PROGRESS

The quality of the trained networks prediction can be measured by the R^2 resulting from the linear adjustment between the values predicted by the network and those values effectively measured; the closer the prediction is to 1 the better. In addition, it is possible to evaluate individually the error of the network in making the forecast for each of the output variables of the database presented during the training, in order to know the errors for the dataset. The closer to 0% errors are, the better the network. The R^2 was evaluated for the 3 output variables together and the error was evaluated for each individually, seeking to identify which could cause errors or deviations in the forecast. The results obtained are presented in Table 4.

Table 4 – Results obtained from the trained networks

Function	R^2	Variable	Maximum negative error	Minimum negative error
		y0	-10.26	5.17
1	0.9996	y1	-1.33	0.86
		y2	-79.97	7.64
		y0	-9.55	21.19
2	0.9998	y1	-1.50	0.96
		y2	-36.31	9.81
		y0	-6.96	4.20
3	0.9999	y1	-0.65	0.50
		y2	-5.92	4.82
		y0	-3.18	2.85
4	1.0000	y1	-0.01	0.01
		y2	-8.46	7.06
		y0	-2.71	1.68
5	1.0000	y1	-0.01	0.02
		y2	-10.33	7.63
		y0	-3.01	3.39
6	1.0000	y1	-0.02	0.02
		y2	-5.41	7.79
		y0	-0.30	1.19
7	1.0000	y1	-0.03	0.02
		y2	-2.26	2.35

It could be verified initially by the R^2 analysis the excellent results presented by the networks, obtaining a numerical value equal to 1.0000 for all the networks with more than 3 neurons in the intermediate layer. On the other hand, the best network, according to Neto et al. (2017), is the network that produces errors of less than 10%, in absolute values, for all output variables. The networks that met these criteria were the ones with 3, 4, 6 and 7 neurons in the intermediate layer. In addition, the best network is the one with the lowest number of neurons possible (Neto et al. 2017), which is the one with 3 neurons. Furthermore, the adjusted equation becomes more complex as the number of neurons increases, so, in this situation, the network with only 3 neurons must be chosen. It should be noted that the prediction of variable y2, waste generation, was especially problematic, indicating a difficulty of the Artificial Neural Networks to recognize a pattern for this variable. This problem can be justified by the fact that managers often do not know effectively the amount of waste, due to inappropriate discards and lack of waste control. The Figure 3, Figure 4 and Figure 5 show the linear adjustment and the error distribution histogram for water consumption, energy consumption and waste generation, respectively.

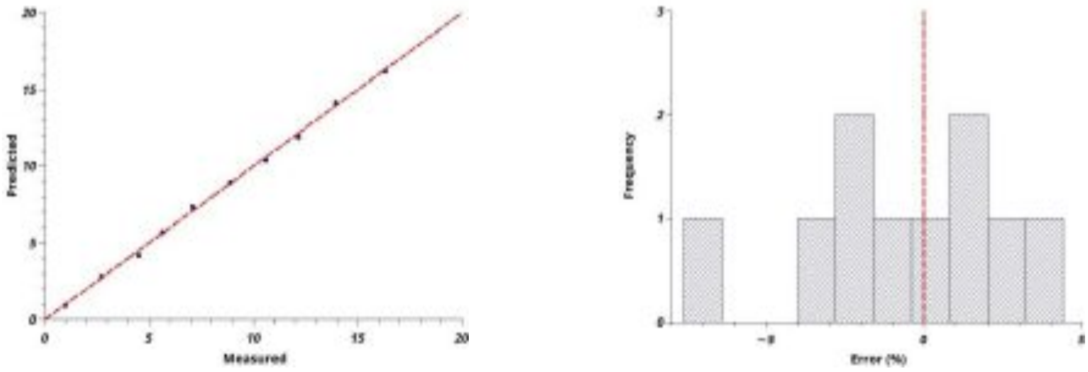

Figure 3 - Linear adjustment and error distribution histogram for the water consumption indicator

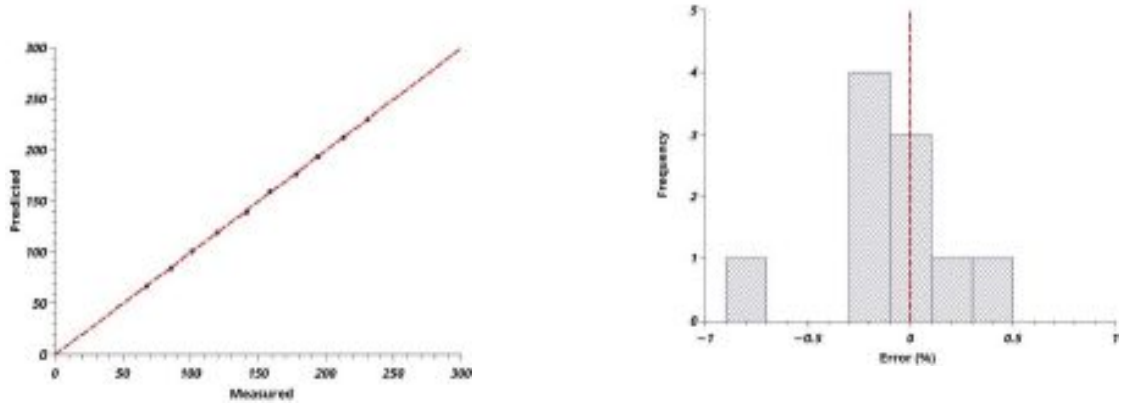

Figure 4 - Linear adjustment and the error distribution histogram for the energy consumption indicator

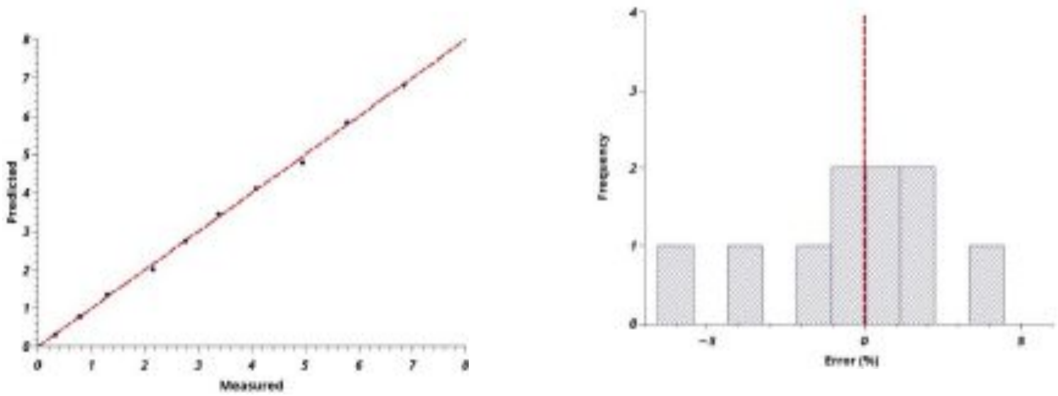

Figure 5 - Linear adjustment and the error distribution histogram for the waste generation indicator

Finally, the equations adjusted for the network are presented in Table 5.

Table 5 – Equations adjusted for each environmental indicator

Water consumption throughout the construction
y0 = -3.5414 + 14.3485/(1 + 7.2142*exp(-4.6260*x0)) + 3.1105/(1+ 46139674.6098 *exp(-21.1366*x0)) + 3.3357/(1 + 1.6709*exp(-27.5809*x0))
Energy consumption throughout the construction
y1 = 26.2729+ 175.9568/(1 + 7.214*exp(-4.6260*x0)) + 19.5838/(1 + 46139674.6098*exp(-21.1366*x0)) + 21.0000/(1 + 1.6709*exp(-27.5809*x0))
Waste generation throughout the construction
y2 = -0.7561+ 6.3319/(1 + 7.2142*exp(-4.6260*x0)) + 1.5226/(1 + 46139674.6098*exp(-21.1366*x0)) + 0.17198/(1 + 1.6709*exp(-27.5809*x0))

From these equations, it is possible for the project managers to forecast environmental indicators based on the construction progress. At first sight, its application may not be simple if it is thought to calculate by hand, but such equations in this format can easily be implemented in some spreadsheet, app or website that automatically calculates the measures taking with single input variable the physical progress of the construction site. The development of this model presents its relevance as it shows a reference so that managers can make managerial decisions and improve the environmental performance of the construction.

CONCLUSIONS

From the results obtained in this study it was evidenced that it is possible to apply Artificial Neural Networks to make correlations between environmental indicators and construction progress, obtaining a predictive model. The data set with the logarithmic transfer function used in the networks presented the best performance, being the network with 5 neurons in the intermediate layer the best for the development of the model. It should be noted that, among the 3 indicators, the waste generation was the one that presented more problem for the calibration of the model.

In addition, the use of median values to represent results of a set of construction sites was observed in this study as an alternative to avoid the inherent variability to the constructive process that appear naturally in the indicators. However, it can be considered a limitation of the study since it does not consider the specificities of each site.

In view of the good performance, it would be advisable to apply the technique to a larger set of data and verify the performance in this situation or even to seek new correlations in order to generate new forecasting models. To cope this limitation, a research project is under development in Brazil aiming to obtain data related to the environmental performance measures presented in this work from at least 100 construction sites national wide. Thus, future studies intent to develop an equation for different constructive methods in residential buildings, in order to achieve a more trustworthy benchmark.

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DAILY MANAGEMENT APPLICATION IN A DAM CONSTRUCTION PROJECT

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ABSTRACT

Brazilian construction companies have sought lean thinking to increase competitiveness in the sector. The initial step for lean implementation is to stabilize the project production system. Many lean tools have been applied to stabilize production, however daily managemet is a lean practice that has been implemented in manufacturing and has little application in the construction. This paper aims to explore daily management in the construction context and evaluate the results of its implementation. Action research was the research method adopted. The research lasted three months and was conducted in three stages: the first for preparation, the second for the implementation cycles and the final for analysis and conclusions. The application evaluated the four fundamental elements of daily management: visual management, teamwork problem solving, help chain, and leadership. Daily management implementation facilitated decision-making and problems were solved more often and in a more structured way with the help chain. Visual boards helped the managers to see the production and productivity deviations. Meeting routines provided a more present leadership in the field and a spirit of team collaboration. The main results of the research were the reduction of project costs, project completion on time and increased project team commitment.

KEYWORDS

Daily management, daily huddle, visual management, action learning/research.

INTRODUCTION

Brazilian construction sector has been facing a crisis that led to a decrease in the number of construction projects. Within this scenario, construction companies further reduced their profit margins to close new contracts (Boshi and Pinho 2018). In a competitive market,

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construction companies have sought ways to reduce their costs, such as investments in technologies, building systems and management methods (Tiwari et al. 2018).

Lean Thinking has been an alternative used to increase the competitiveness of companies due to the fact that it is based on eliminating waste along the value stream, thereby shortening lead times, reducing costs and also increasing product quality. (Womack and Jones 2003).

A basic premise for implementing lean is to achieve basic process stability (Ohno 1997). Some tools have been used to achieve basic stability in the construction environment, such as: value stream mapping (VSM), workplace organization (5S Method), Total Productive Maintenance (TPM), Last Planner System and *Kanban* (Gallardo et al. 2014).

Daily management is a lean practice widely used in manufacturing sector to remove process instability (Liker and Hoseus 2008). In the construction sector there is still no consolidated application of this practice. Therefore, this paper aims to explore the daily management in the construction context and evaluate the results of its implementation.

DAILY MANAGEMENT

Daily management (DM) is a continuous process that ensures that work is done in the right way and in the right time, in order to achieve business success according to the company's strategic objectives (Ferro and Gouveia, 2015). The Daily Management elements are (Liker and Hoseus 2008; Ferro and Gouveia 2015):

- Visual management: Visualization must be simple in order to ensure clarity and focus, and to allow everybody to understand. A simple board is used to expose targets and problems
- Teamwork problem solving: It's necessary to create an environment in which hiding problems is neither acceptable nor possible. The right way to work, which lean thinking advocates for, is exposing problems, effectively solving them, and asking for help. Just having the numbers exposed is not enough: daily management encourages (and, really, calls for) teamwork and cooperation. The team should always engage in open discussions to understand the situation, do some analysis on the spot, and decide what actions are needed in the event of a gap between current and expected performance.
- Help chain: Essentially, the help chain turns the traditional organizational pyramid upside down, which allows the organization to move away from a command-and-control attitude and towards a culture in which all necessary support is given to the processes of value creation and problem solving
- Leadership: Just having the standup meetings is not sufficient. Leadership should be involved every step of the way. They must be capable of keeping the meetings focused and all team members involved. The meeting routines generate great opportunities to develop the employees' capabilities and change they way people tackle problems and work in teams.

The Last Planner System added the daily huddle in an update made by Ballard (2003), but has not been universally practiced (Ballard et al. 2009; Daniel et al., 2015).

Daily huddle focuses on achieving weekly planning for daily control through quick meetings with team members (Ballard et al. 2009). Daily management focuses on solving problems through a structured help chain with active leadership participation as a way to develop the team (Ferro and Gouveia. 2015).

RESEARCH METHOD

The research strategy adopted was action research, which according to Thiollent (2007) is a type of empirical social research that is conceived and carried out in close association with an action or with the resolution of a collective problem and in which researchers and representatives of the situation or problem are involved in a cooperative or participatory manner.

The research was divided into 3 stages. In the first stage a preparation was carried out to understand the main problems of the project and to align the scope of the research. In the second stage, 3 learning cycles were carried out for three months (1 month per cycle), where one week a month practical workshops were held in the field with significant collaboration between the researchers and the project team.

In cycle 1 the meeting routines (with the supervisors and their teams) and the visual management were created and implemented. During cycle 2 the meeting routines with the engineers and managers were implemented. The last cycle served to improve the routines, and visual management.

In the third stage a final reflection was made aiming at consolidating this practice in the company and expanding to other projects of the construction company (Figure 1).

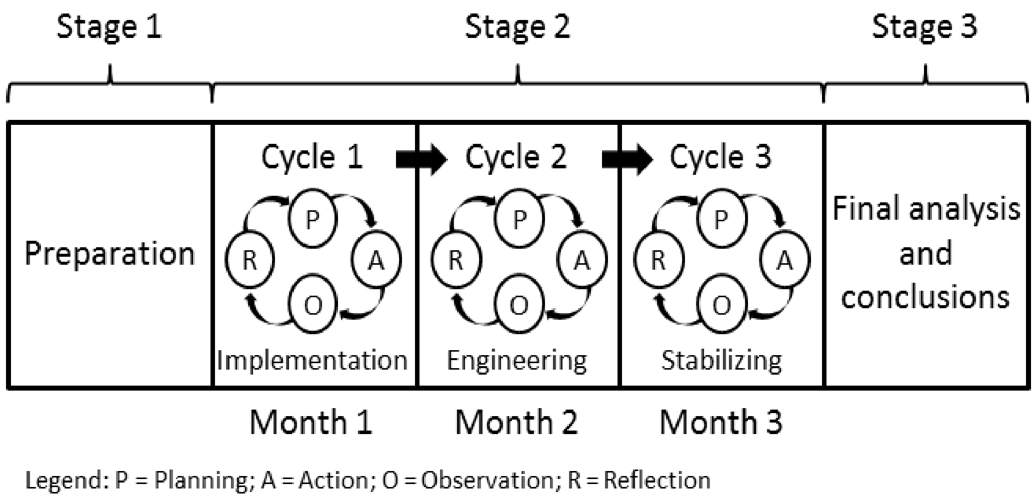

Figure 1: Research Design

The construction company in which this study was developed has almost 60 years of experience in the market and predominantly works with infrastructure projects: paving, dams, drainage, railway, bridges and tunnels.

The pilot project that was chosen by the company was the raising a tailings dam from the 229.60m quota to the 245.00m quota. This project was divided basically on two tasks:

A. Materials Sieving Process: part of the material that was released in the dam was sieved to be later taken to the dam, that is, a task was focused in the sieving process (Thick Shale, Fine Shale and Quartz);

B. Dam: Another task was located at the launch of the processed and unprocessed material (clay and filter).

Figure 2: Dam Construction Site

RESULTS AND DISCUSSION

The discussion and presentation of the results was divided by the elements of daily management, as follows:

VISUAL MANAGEMENT

Site observations were performed in order to identify some waste. These observations helped the project team to identify that the production process of the tasks (Materials Sieving Process and Dam) was very unstable. At the end of the first week a lecture was given on Daily Management with the lean committee (site manager, planning engineer and lean coodinator). Then, a visual management board (first version) was drawn for the Materials Processing task.

Based on what was already usual and also aligned with the field language, it was decided to use the unit to measure production as "trips" and to measure "trips / trucks" productivity. Finally, a meeting was held with those in charge of the Materials Processing task to explain the new practice, to define schedules and participants in the meeting (Figure 3).

Daily meetings were implemented and consolidated in Materials Sieving Process task in 2 weeks (Figure 4). Supervisors showed resistance to change in the beginning. However, once meeting routine was established they perceived its benefits. Then, daily management was also incorporated in Dam task with some adaptations in the board

Figure 3: Presentation meeting of the first version of the Daily Management Board

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Figure 4: Daily meeting in the dam task

Visual management helped to expose the problems and especially the practical understanding of the concept of production and productivity. Before daily management application, only production was controlled, that is, no matter how many trucks, the goal was always to beat the daily goal of trips.

After the visual management board and the routine of meetings were implemented, the team members began to optimize the use of trucks, including a few times a day to stop trucks from queuing in the cycle when there was a change of schedule.

It is important to note that the trucks were rented and paid per hour used, therefore when queuing occurred in a given cycle and they were connected they would have the cost of rent and diesel.

TEAMWORK PROBLEM SOLVING

Team involvement was a key factor in deploying daily management. Many problems were reported with the daily meeting routine implemented. Simple problems were solved with immediate team action and larger problems needed further analysis with the engineering team. During the first month some recurring problems were identified. The most recurring problem for material sieving process was the instabilities in the truck cycles, while for the dam task was the number of trucks above planned.Problems were understood in their root causes with the help of the engineering team. It was identified that the constant change in the location from which the processed material would be withdrawn and transported to the dam caused problems in production in relation to the amount of trucks and machines that would be used to do this task.

Some truck queues could be seen when walking by the field. Every day the client gave information shortly before starting the working day or other times after starting from which stock should be removed the material to be released to the dam. The change was due to the fact that an inventory of benefited material could only be released to be transported once it was fully stocked and the topography team raised its volume.

The team then proposed as a countermeasure the creation of a worksheet that mapped all the possible scenarios and that could absorb the daily changes made by the client. Therefore, all inventories and ATDs (Average Transport Distance) were obtained with revised and timed data in gemba.

This worksheet has been distributed to all team members. Then, they started to have more autonomy in the field and also started to control the correct amount of trucks. A visual board was also created as a way to identify daily from where the materials were being removed (Figure 5).

Figure 5: Visual Control of inventories, trucks and machines

HELP CHAIN

The help chain worked informally, that is, actions were taken on some problems that came from the field, however there was no priority, control or follow-up actions. The contract manager and planning engineer himself missed some of the field information more often.

Then, in the second month when the daily field meetings were already going as planned, the engineering team decided to hold a quick meeting (15-30min) at 11:30 a.m. so that they could align the field information daily, discussing them, generating actions and monitoring them.

Some problems that were staggered from the field meeting to the engineering meeting were already solved by immediate action, while other actions would require visual management for follow-up, so the team deployed a “*Kanban*” board (Figure 4). Therefore, a structured help chain with field and engineering participation was established (Figure 6):

Figure 6: E DOING g da DONE gement utilizing the “*Kanban*” board

Figure 7: Help Chain

LEADERSHIP

The role of leadership was fundamental in implementing daily management. The change of mindset in particular from the engineering team was felt by the project team. The planning engineer and the project manager who did not go often to *gemba* started to go frequently, since a rotation of participation in the meetings involving (project manager, lean manager and planning engineer) was established, therefore, at least 3 times per week they attended the daily meeting in the field, in addition to attending the engineering meeting every day.

As time went by, the team members brought more problems and more actively participated in the meetings. They reported the importance of the presence of the engineers and especially of the actions that were taken at the meetings with their help.

GENERAL RESULTS

The last project had cost overruns of 30% leading the company to implement the aforementioned lean practices to make a turnaround in this scenario. After the end of the project, some data were collected and the cost reduction became evident:

- Materials Processing task - 4% reduction in cost (US$ 71.200,00)
- Dam task - 7% reduction in cost (US$ 535.000,00)

This result came especially from the reduction of the planned quantity of trucks (representing 70% of the project cost) and the best use of the trucks that were available.

Transparency through visual management was also positive for the team. This made the data simple and easy to be controled by the team members.

Furthermore, the project was completed within planned schedule and it was noticed the change of behavior of the managers and engineers who focused not only on production but also on productivity. Such a concept helped to always be aware of the waste and daily problems.

CONCLUSION

Daily management implementation enabled the team to identify deviations daily in production, causing them to take immediate action to correct them.

Visual management helped to clarify the production and productivity goals of the dam and materials processing tasks team. The information on the board served as the meeting's north, including to point out deviations.

Team involvement in problem solving made it easier to identify problems and take action. Team involvement also helped to improve the sizing of the truck cycle.

Help chain alongside with field meetings and engineering team meetings helped to solve more complex problems, as engineering team began to make decisions based on the information that came from the field every day, including monitoring the actions that should be taken.

Leadership has become more present and participatory in gemba. The field team's own perception of the actual presence of engineering team was noted as positive.

Benefits generated by the daily management implementation went beyond the quantitative sphere (cost and time) and were also qualitative (increased transparency and behavior change).

Daily support of these practices helps the company stabilize its processes and also promote improvements. The daily management was considered a fundamental practice for the construction company that will take advantage of the learning of this project to expand this practice to other projects of the company.

Future research might explore daily management system in other company departments (supply, work safety, and quality). A further study could involve the top management level on daily problem solving.

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INTEGRATION OF HISTORIC BUILDING INFORMATION MODELING AND VALUATION APPROACHES FOR MANAGING CULTURAL HERITAGE SITES

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ABSTRACT

In this study, a methodology for quantifying the historical value of the Cathedral of Christ the King, in the municipality of Huejutla de Reyes, Hidalgo, Mexico, was developed through application of historic building information modeling (HBIM) and conventional valuation methods. Despite many studies having been undertaken around the world, there remains a gap in that elucidating and unifying the relationship between HBIM and valuation is still difficult. The methodology developed in this study combined and used information captured via a Leica ScanStation C10 laser scanner, a drone, and a 360° camera. Various software programs were then used to combine the images with the scan data. HBIM facilitated automatic and accurate quantification of the amount of materials used to build the cathedral. A significant finding was that the use of HBIM enables a valuation to be obtained immediately. While the results must be regarded as being exploratory, they provide interesting insights into the synergy between HBIM and historical valuation. Another critical point is that this is, to the best of our knowledge, the first study to link HBIM with a valuation.

KEYWORDS

Cultural heritage, historic building information modelling (HBIM), valuation, collaboration, commitment.

INTRODUCTION

The building information modeling (BIM) methodology, defined as "the use of virtual, multidisciplinary models of design and construction projects, including product models, processes and organizations, to support explicit and public business objectives," is one aspect of virtual design and construction (VDC) (Kunz and Fischer 2009; Mandujano et al. 2017). BIM provides a reliable basis for decision-making and acts as a platform for automated analysis that can assist with planning, design processes, construction management, and operation/maintenance activities (Alarcón et al. 2013). Historic building information modeling (HBIM) is proposed as a new means of modeling historic structures; the HBIM process begins with remote collection of survey data using a terrestrial laser scanner combined with digital cameras. Various software programs are then used to

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combine the image and scan data (Murphy et al. 2009). The HBIM process involves a reverse-engineering solution whereby parametric objects representing architectural elements are mapped onto laser scans or photogrammetric survey data (Dore and Murphy 2012). On the other hand, valuation is a sustainable estimate of the value of a property. As it is only an estimate, the merit of any value judgment depends on the skill, experience, and ability of the person doing it (The International Valuation Standards Committee 2006). Despite many studies having been undertaken around the world (Herrero Prieto and Bedate Centeno 2000; Melstrom 2013; Pérez et al. 1996; Poor and Smith 2004; Riera et al. 1994; Tourkolias et al. 2015), elucidating and unifying the relationship between HBIM and valuation is still difficult. Annually, approximately 200,000 tourists visit the municipality of Huejutla de Reyes, Hidalgo (Departamento de Turismo 2017). These tourists walk its picturesque streets, enjoy the cuisine, and visit the various sites around the region. One of the most well-known sites is Cathedral of Christ the King. Fig. 1 shows an image of the cathedral immediately prior to its completion circa 1545 CE.

Figure 1: Construction of Cathedral of Christ the King, circa 1545 CE. Craftsmen transported materials to the work site in various ways.

The remainder of this paper is organized as follows. Section 2 explains the proposed methodology. Section 3 describes the state of the art and the data collection process. Section 4 presents the analysis of the data. Section 5 outlines the results of the research. Section 6 explains the significance of the results. Section 7 presents concluding remarks.

RESEARCH AIM AND PROPOSED METHODOLOGY

This study developed a methodology for quantifying the historical value of the Cathedral of Christ the King, by historic building information modeling (HBIM) and conventional valuation techniques. To achieve this, the following specific objectives were set:

- Develop a methodology using HBIM and conventional valuation approaches.

- Identify the relative importance and relationship existing between HBIM and conventional valuation approaches.
- Whether or not the work enabled you to draw conclusions about the hypotheses, or further work is needed?

Fig. 2 depicts the proposed methodology.

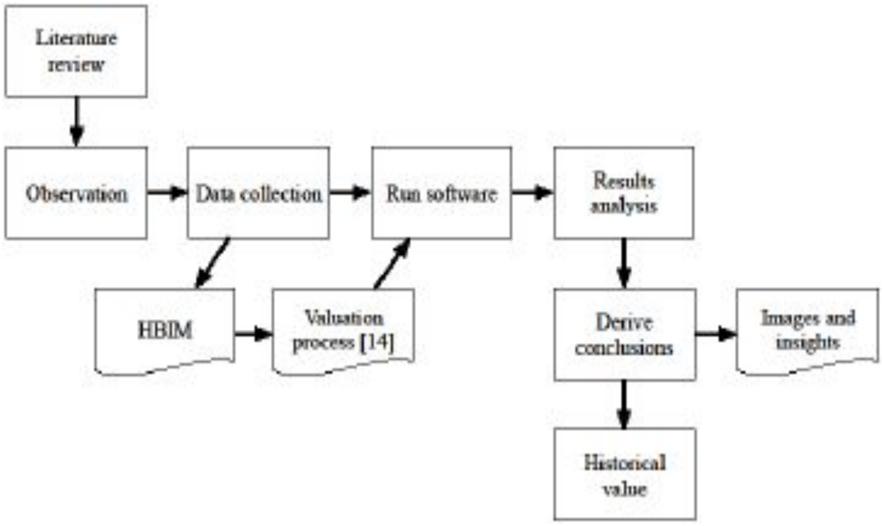

Figure 2: Proposed methodology. The present study set out to realize each step of the proposed methodology.

Different sectors such as municipalities, and the state and federal governments, will have their own methodologies that will give them more confidence in their decision-making. Decision-making is based on hard data acquired through an information, knowledge, experience, analysis, and judgment-based process. Nevertheless, organizations such as the National Council for Culture and Arts (CONACULTA), National Institute of Anthropology and History (INAH), National Institute of Fine Arts (INBA), United Nations Educational, Scientific and Cultural Organization (UNESCO), and Ministry of Tourism (SECTUR), may revalue the Cathedral of Christ the King, assigning resources to its restoration or proposing a project to promote tourism in the region.

STATE OF THE ART

The complexity and difficulty associated with valuation of historical assets is rooted in the concepts of culture and cultural heritage. Culture is difficult to define and even harder to quantify (McLoughlin et al. 2007; Noonan 2003; Papandrea 1999; Throsby 1995). Since its inception in 1972, UNESCO has defined monuments as being groups of buildings and places that are of interest and which have relevance to civilization and culture, and which can, therefore, be classified as being part of the cultural heritage. Klamer and Zuidhof (1999), classified cultural heritage as both tangible and intangible. From an economic perspective, the assumption that cultural heritage is a public good and generates indirect effects has been agreed upon by several authors (Frey and Meier 2006; Johnson and

Thomas 1998). Many studies have been carried out with the goal of determining the value of different historical and cultural patrimonies around the world (Bedate et al. 2004; Cameron 1992; Caulkins et al. 1986; Dilnessa 2014; Herrero Prieto and Bedate Centeno 2000; McLoughlin et al. 2007; Melstrom 2013; Nijkamp 2012; Noonan 2003; Nypan 2006; Parumog et al. 2003; Poor and Smith 2004; Tourkolias et al. 2015). Although only a few studies have addressed the value of BIM to the management and documentation of cultural monuments (Fai et al. 2011), BIM has exhibited considerable growth over the last decade in the cultural heritage field (Achille et al. 2016; Del Giudice and Osello 2013; Dore and Murphy 2012; Garagnani and Manferdini 2013). Architects, archaeologists, conservationists, and engineers regard BIM as a disruptive force that changes the way in which professionals document and manage a historical monument (Brusaporci 2015; Choi et al. 2010; Logothetis et al. 2015; Saygi et al. 2013). Arayici (2008), attempted the first application of BIM to "existing" buildings. The study focused on implementation of automated data acquisition and recognition of patterns, using data in a point cloud to represent volumetric (3D) data in the generation of a construction envelope. Other researchers further developed HBIM to integrate BIM with cultural heritage (Brumana et al. 2013; Khodeir et al. 2016; Oreni et al. 2013), in which a library of prototypes of parametric objects constructed from historical data, and a system for mapping parametric objects in a cloud of points and image survey data are provided (Murphy and Dore 2012; Murphy et al. 2009; Murphy et al. 2013). Most researchers have adopted a particular methodology for developing HBIM for application to historical environments and structures (Hichri et al. 2013; Huesca Tortosa et al. 2017; Murphy et al. 2013; Redmond et al. 2012; Tang et al. 2010; Wang et al. 2015). Brumana et al. (2013), conducted a case study of the church of St. Maria in Scaria d'Intelvi, Italy. Using laser scanning and photogrammetric surveys, they performed an in situ stratigraphic analysis while searching for all available historical documents, in an attempt to study the reconstruction and main transformations and chronological phases, from the Romanesque interventions, through the Baroque, to the most recent. Balderstone (2012), concluded that BIM has great potential as a means of strengthening multidisciplinary approaches to the valuation of historical assets. This study is important in that it is the first to use HBIM to determine the historical value of a monument in the country. Although technologies for digitizing monuments have previously been implemented, to the best of our knowledge, no study has combined HBIM and conventional valuation approaches.

CASE STUDY: CATHEDRAL OF CHRIST THE KING

Cathedral of Christ the King was valuated in accordance with the PT-IH Technical Procedure for valuation works that is applied to the assessment of the value of a historical property (Diario Oficial de la Federación 2009). The procedure began with inspection of the site. The land area was 13,177.23 m2, comprising a terrain with an irregular polygonal shape and an ascending and descending topography (Azcue et al. 1932). Land market exploration was then conducted. As there were no comparable activities, either in terms of location and area, we applied a second authorized alternative: the residual method (Diario

Oficial de la Federación 2009). A topographic survey of Cathedral of Christ the King was conducted. First, the Global Positioning System (GPS) was set up and it and the subsequently obtained point cloud (details below) were linked with the National Coordinate System. This greatly facilitated the georeferencing of the survey. Next, the areas and facades of the Cathedral were scanned using high-definition surveying (HDS) with a Leica C10scanner (Leica ScanStation C10 2018). The Leica C10 scanner was used to first capture images of the scene and then laser-scan everything in its field of vision. The information produced by this scanning, called a "point cloud," consists of millions of individual 3D points. The result of the scan is a visualization of the scene in the BIM, from which any measurement can be obtained. More than 50,000 points per second were captured with millimeter precision, such that the quantification of the cathedral fabric was as precise as the technology would allow. Third, a Sokkia total station (TS) (Addison and Gaiani 2000) helped with the topographic survey. We identified the number of trees as well as their exact location and the area they occupied. Fourth, the point cloud for the upper parts, as well as the inaccessible areas, were measured using a drone with a 360° camera. Then, the polygons of the cathedral were drawn in Autodesk Civil 3D, after which the images acquired by the drone were attached to further enhance the representation. A final "point cloud" was then obtained and used to complement the BIM modeling. The point cloud covered different areas with the goal of attaining a better appreciation and presentation, thus helping the visualization and the valuation of the project. Fig. 3 shows the results of the topographic survey of the cathedral.

Figure 3: Topographic survey of the cathedral.

Once all the field work was complete, the collected data were uploaded to the central office for post-processing. The team performing the field work did not leave the cathedral until the central office confirmed that the uploaded data was free of errors or inconsistencies. The "point cloud" obtained in the field complemented the BIM model such that it was easier to manipulate, while realizing the possibility of creating cross-sections. The BIM model and "point cloud" facilitated quantification of the amount of material used in the construction of the cathedral. Thus, we were able to complete our valuation in an automated, reliable, and accurate manner.

Fig. 4 shows the cathedral modeled in Revit, based on the "point cloud."

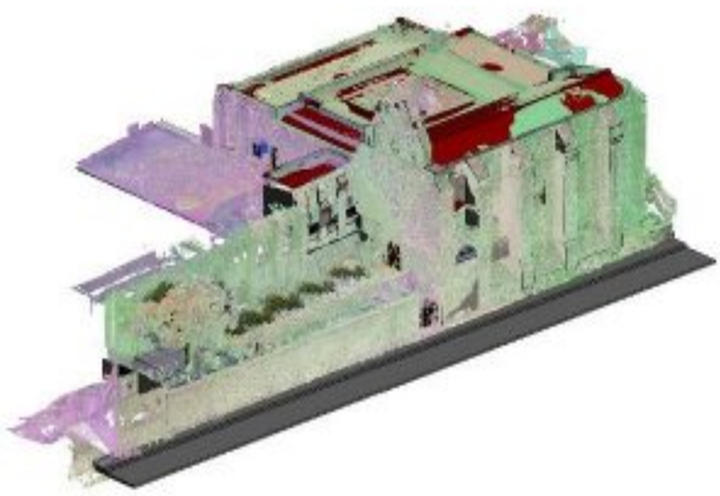

Figure 4: Image of the cathedral modeled in Revit, based on the point cloud generated with the Leica C10. More than 50,000 points per second were captured with millimeter precision.

One of the characteristics of the BIM methodology is that it is based on a technological tool (Mandujano et al. 2015). The models are parametric, so the modeling and their characteristics are intrinsically linked. Whenever the model is modified, changes are automatically generated for every aspect (Mandujano 2016). The application of BIM to the valuation proved to be extremely valuable because it is capable of detecting about 40 types of walls. The combination of the equipment used in the study allowed us to obtain information that even INAH does not possess for the cathedral, such as the thickness of the walls, and the width and shape of the mezzanines. This contribution became clear during the course of the investigation. Within the BIM model, material quantification tables were generated. These were obtained automatically and with pinpoint accuracy.

RESULTS

The land on which the cathedral stands is valued at US$8,396,814.96 (Mandujano 2018). From the classifications of the construction of the cathedral, the volumes were quantified, to determine the corresponding unit prices. In this manner, we obtained a new replacement value (VRN). Considering the state of conservation of the property, as well as the age and functional and/or economic obsolescence, depending on the case, a demerit factor was applied to the VRN, thus giving the net replacement value of the buildings of the cathedral. The BIM model of the Cathedral of Christ the King, made in Revit, plays a crucial role in that it automatically provides the quantities of materials used in the construction. In this way, the VRN was obtained automatically. This saved a considerable amount of time and effort, as the BIM eliminated the need to manually tabulate all of the components of the cathedral. The total value of the construction and the complementary work was found to be US$ 9,506,160.30. Adding the total value of the land, the construction, and the complementary work gives a total of US$17,902,975.26. To this value must be added the historical value. A historical value analysis is proposed whereby a value can be awarded to a historical property that is in a perfect state of conservation and which has a historical, social, cultural, or religious background that is of importance to the country. To determine a heritage value factor, various data were taken as reference for the application of values such as antiquity and historical values (Diario Oficial de la Federación 2009). For the antiquity value, the property is classified according to its age, starting from a minimum of 50 years, up to greater than 400 years. The Cathedral of Christ the King was built in 1545 and is therefore more than 400 years old. When we add a percentage for the historical value and a percentage for the antiquity value, the cathedral attains a value of between 80% and 100%, that is, a value of 1.76–2.00. Because the cathedral has not suffered any significant structural damage, the total value, that is, the value of the land, that of the structure, and that of the complementary works, totaling US$17,902,975.26, is multiplied by 2.00 and the result is added to the above value. Thus, the value of Cathedral of Christ the King is US$53,708,925.79 (Diario Oficial de la Federación 2009).

DISCUSSION

In this study, a methodology for attributing a value to the Cathedral of Christ the King was developed. The work provides a precedent for the valuation of other historical monuments through the application of both historic building information modeling (HBIM) and conventional valuation approaches. We showed that the implementation of HBIM is key to the valuation of historical monuments. The importance of HBIM and the relationship that it has with the valuation begins with the time savings that it realizes in the topographic survey, the precision with which it can be carried out, and the speed of the volumetric design. From this starting point, knowing the volume of the Cathedral of Christ the King enabled determination of the amount and type of materials with which it was built. The degree of precision of HBIM, starting with laser scanning and the creation of a “point cloud,” allowed us to identify the factors that contribute to and/or detract from the value of the cathedral. This includes inherent factors of the monument itself and its location, and external factors such as street vendors, flora, fauna, noise, air, international conflicts, population growth, and economic trends. This work lays the foundations for considerable future research, in that the approval factors can be expanded within the Institute of Administration and Appraisals of National Assets (INDAABIN). By determining the external and internal factors that affect a historical monument, INDAABIN can generate new factors to generate valuations that are more precise.

CONCLUSION

This paper described an investigation conducted in the city of Huejutla de Reyes, Hidalgo, Mexico. Mexico must be aware of the value of its assets, and be able to fully catalog every national asset, given that a country's cultural assets contribute to the identity of every citizen of that country. Cultural identity can be viewed as being both tangible and intangible. It comprises a set of values, traditions, symbols, beliefs, and modes of behavior that function as elements within a social group. Cultural identity is the sense of belonging and is a criterion contributing to differentiation. Thus, an individual can identify with some of the cultural content of a social group. Future avenues for research include the following:

- Propose Huejutla de Reyes, Hidalgo as a Pueblo Mágico (Magical Town) to the Ministry of Tourism. A Pueblo Mágico is a locality that has unique, symbolic attributes, authentic stories, transcendent facts, daily life, which means a great opportunity for tourist use, taking into account the motivations and needs of travelers (Secretaría de Turismo 2017).
- Design a control for the inventory of national assets that are held in the country as a first step in the development of a reliable plan for monuments and thus carry out interventions in the assets that most require it.
- Incorporate the travel cost method into the investigation. Using valuation techniques, economists have discovered that the economic benefits of preserving cultural resources can be substantial.
- Design new factors that will enrich the assessment proposed by INDAABIN.
- Adapt and execute the model based on the P-P-T (Mandujano et al. 2017) in order to ascertain the impact on historical assets exercised by the new factors found: internal, external, and as far as possible, find and formulate new factors.

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CONSTRUCTION PROGRESS MONITORING USING UNMANNED AERIAL SYSTEM AND 4D BIM

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ABSTRACT

Construction progress monitoring may help for an efficient management process as planned. Studies have proposed the use of visual data technologies; however, little has yet been done for the development and implementation of methods for integrating such technologies into construction management routine. This study aims to implement and evaluate the proposed method for systematic visual progress monitoring integrating into the production planning and control process, supported by 4D BIM, photogrammetric 3D mapping using Unmanned Arial System imagery, and performance indicators. The proposed method was implemented for 20 weeks in a case study on a construction project. The data collection included construction site 3D mapping generation, visual comparison of 4D BIM and 3D mapping status, measurement of performance indicators, and structured interviews. The evaluation focused on the following research constructs: compliance with the planned goals, impact on the construction progress deviations, transparency, and collaboration. The main findings indicate an improved integration of progress analysis and decision-making, improvement of progress deviations' identification, and allowed for better compliance with planned goals and increased transparency and collaboration. The main contribution of this work is a better understanding of the impact and added value of the new information flow provided by using the proposed method.

KEYWORDS

Construction progress monitoring, Visual management, 3D mapping, Unmanned Aerial System (UAS), 4D Building Information Modeling (BIM).

INTRODUCTION

Construction projects are characterized by the great dynamism, complexity, and diversity of activities and processes (Tuttas et al. 2017). This means that the execution of work packages as planned requires monitoring and control of their operations and progress.

Del Pico (2013) defines the process of construction progress monitoring as steps and metrics that aim to evaluate the construction performance and compare it with the planned

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one, identifying deviations and implementing corrective actions. In order to meet the planned goals, such monitoring and control process must be systematically and continuously developed over different hierarchical levels of production planning and control system (Del Pico 2013).

However, according to Teizer (2015) and Yang et al. (2015), the most common practices for construction progress monitoring are based on frequent individual observations, depending on manual data collecting, and rely on textual documentation and subjective interpretations of data. Therefore, they are time-consuming, prone to errors and variability of data quality, and result in distance and delay in the exchange of information between the construction site and the management team (Teizer 2015).

Aiming to improve such aspects, studies propose the use of visual data technologies, such as photographs, videos, 3D and 4D models (Yang et al. 2015; Han and Golparvar-Fard 2017). For Tezel and Aziz (2017), the use of these technologies can contribute to the reduction of non-value adding, error-prone, and time-consuming activities associated with the construction progress monitoring process. Such benefits are related to the optimization of managerial tasks, the decrease of the number of mistakes made in routine tasks associated with the progress monitoring process, and the possibility of integrated visual management between schedule planning and production performance control, making the construction progress monitoring more efficient, transparent and collaborative (Tezel and Aziz 2017; Han et al. 2018; Álvares and Costa 2018).

Among these visual data technologies, recent studies highlight the great potential of: (a) 4D Building Information Modeling (BIM) for visual simulation of the as-planned construction progress, (b) construction site 3D mapping by digital photogrammetry, often as point cloud model, for visual representation of the as-built construction progress, and (c) Unmanned Aerial System (UAS) with an attached camera, as an effective tool to capture site images, since it can provide fast imagery, from different positioning, and with accurate control of the visual records' parameters (Han and Golparvar-Fard 2017; Lin and Golparvar-Fard 2017; Tuttas et al. 2017; Álvares et al. 2018; Han et al. 2018).

Despite the development of studies that address the use of visual data technologies for progress monitoring (Braun et al. 2015; Han and Golparvar-Fard, 2015; Tuttas et al. 2017; Han and Golparvar-Fard 2017; Son et al. 2017), most of them focus on the improvement of the technology itself, in terms of the development of automated computer systems with digital automation of data processes and integration of the visual tools' features.

Based on that, a gap regarding the effective systematic integration of these technologies into construction management systems was identified. Kopsida et al. (2015), Han et al. (2018) and Álvares and Costa (2018) note that there is a growing recognition among researchers that the use of visual data technologies can improve communication and evaluation of the construction progress. However, these authors also acknowledge that little has yet been done about the formalization, development, implementation, and validation of methods based on technologies such as BIM and 3D mapping with UAS, for optimization of the construction progress control.

Therefore, the main motivation for this study is the improvement of the information flow for construction progress monitoring, by using a structured, formalized and effective implementation of visual data technologies. This approach results in an easier understanding and communication of progress information in a quicker way and with greater reliability. The aim of this study is to implement and evaluate the proposed method for systematic visual progress monitoring integrating into the production planning and control, supported by 4D BIM, photogrammetric 3D mappings using UAS, and performance indicators. This work contributes to a better understanding of the impact and added value of the adoption of these technologies for progress monitoring through a practical, structured and in-depth implementation in an empirical study.

This study is part of a research still under development. The scope of this paper focuses on the initial implementation of the proposed method from a case study, and the evaluation of this implementation.

METHODOLOGY

This research uses the Design Science Research (DSR) concepts (Van Aken and Romme 2009) as the research strategy. The proposed artifact of this research is a method for visual construction progress monitoring using 3D mapping by UAS imagery and 4D BIM, named *Integrated 3D-UAS 4D-BIM Visual Progress Method*.

Based on the research strategy adopted and in order to meet the objective of this study, the research methodology was structured according to the following steps: Awareness, Artifact suggestion, Artifact development, Evaluation, and Conclusion. However, this paper focuses only on part of the steps of the artifact (the proposed method) development and evaluation, according to the research design presented in Figure 1.

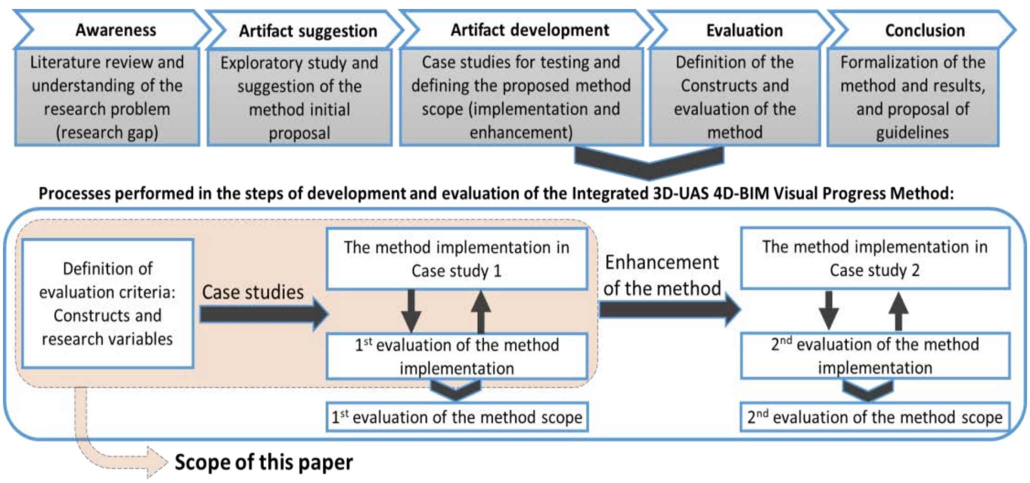

Figure 1: Research design with emphasis on artifact development and evaluation

IMPLEMENTATION OF THE INTEGRATED 3D-UAS 4D-BIM VISUAL PROGRESS METHOD IN CASE STUDY

The case study for the method's implementation was developed on a construction project in Brazil. The main features of this project are presented in Table 1.

Table 1: Features of the case study project

Features Description	Project picture (orthophoto)
- A residential low-income housing project - Land area: 22,800 m² - 20 buildings of five floors each, with a total of 400 units (four units per floor) - Construction time: 18 months (started in July 2017) - Main constructive method: Concrete wall structure	

The case study was developed for almost eight months, from February to September 2018. During the case study period, the following activities were conducted:

- *Adaptations of the proposed method to the management context of the construction project, and BIM models' generation:* conducted from February to March 2018, this activity included the selection of the set of performance indicators to be used, adjustments of protocols for data collection and data sharing, and the development of the 3D BIM model and the initial 4D BIM model of the project (respectively using Revit and Navisworks software).
- *Implementation of the proposed method:* it was conducted from April to August 2018, according to the steps, processes, and products presented in Figure 2 (in the following section). Five cycles associated with the look-ahead planning and control were monthly conducted. A 4D BIM model, using Navisworks software, was updated based on the look-ahead planning data for supporting the monthly visual progress analysis and the preparation of the short-term planning. Twenty cycles associated with short-term planning were weekly also conducted. To support this, automatic UAS flights were performed on a weekly basis, using Pix4D app, following a standard grid path defined to cover the construction area. Protocols for safety flights were adopted based on Álvares et al. (2018). The images collected were processed using PhotoScan software, generating photogrammetric point clouds and orthophotos. For the visual progress monitoring of the outside work packages in the monthly cycles, these point clouds (visual representation of as-built progress) were overlapped with the project 3D BIM model and integrated into the 4D BIM (visual representation of as-planned progress) in the Navisworks platform. The progress deviations for outside work were identified from the visual comparison of the models (point cloud and 4D BIM), and the indoor work packages status were identified from direct field measurements by the project team. The progress deviations of all project work packages were also coded with visual color indicators in the 4D simulation to highlight work behind schedule, ahead of schedule, and on schedule.
- *Structured interviews with the project management team:* For the evaluation of the method implementation, structured interviews were conducted in September 2018. The interviewees were the members of the project management team that were directly involved in the method implementation (Table 2). The interview's protocol includes objective questions, using a three-level impact scale (low, intermediate and high), and complementary open-ended questions.

Table 2: Characteristic of the construction management team interviewed

Function	Years of experience in the construction industry	Management level of the function	Interview results classification code
Construction Coordinator	18 years	Top management	CC
Contract Manager	10 years	Construction general management	CM
Production Analyst	4 years and 10 months		PdA
Planning Analyst	2 years and 3 months		PA
Control Analyst	8 years		CA
Engineering Trainee	1 year and 9 months	Production coordination	ET
Engineering Assistant	6 years		EA

EVALUATION OF THE PROPOSED METHOD AND THE PROCESS OF IMPLEMENTATION

This step aims to evaluate the contribution of the proposed method to the progress monitoring improvement. For this, constructs and research variables (evaluation criteria) were defined, as shown in Table 3. These constructs and variables were mainly defined from the literature review, based on what previous studies highlight as management aspects which were improved through the application of systematic and continuous progress control, and the adoption of visual data technologies for progress monitoring. Those previous studies include, for example, the work from Han and Golparvar-Fard (2017), Tezel and Aziz (2017), Tuttas et al. (2017), Son et al. (2017) and Han et al. (2018).

Table 3: Research evaluation criteria - Constructs, Variables and Sources of evidence

Construct	Variables	Sources of evidence
Compliance with the planned goals	- Compliance with the planned progress - Activities started in the estimated period - Activities finished in the estimated duration - Minimization of progress deviations	- Performance indicators' results - Visual models of progress (4D BIM + point cloud) - Project team feedback
Impact on the construction progress deviations	- Improved analysis of progress deviations - Improved identification of the causes of negative progress deviations - Planning and application of actions to correct negative progress deviations	- Structured interviews - Project team feedback - Visual models of progress (4D BIM + point cloud)
Transparency	- Improved communication and identification of progress status - Simple and fast understanding of progress information - Viewing and obtaining new production information	- Structured interviews - Project team feedback - Visual models of progress (4D BIM + point cloud)
Collaboration	- Improved exchange and sharing of progress information - Improved integration and communication among the management team members - Shared analysis of progress status and joint decision-making	- Structured interviews - Project team feedback

INTEGRATED 3D-UAS 4D-BIM VISUAL PROGRESS METHOD

Figure 2 presents the framework of the *Integrated 3D-UAS 4D-BIM Visual Progress Method*, including its three steps, the flow of processes and products. These steps are based on the long-term, look-ahead and short-term planning and control levels. The proposed method framework includes managerial procedures for collection, processing, and analysis of data, and also decision-making procedures, mainly regarding the work progress status.

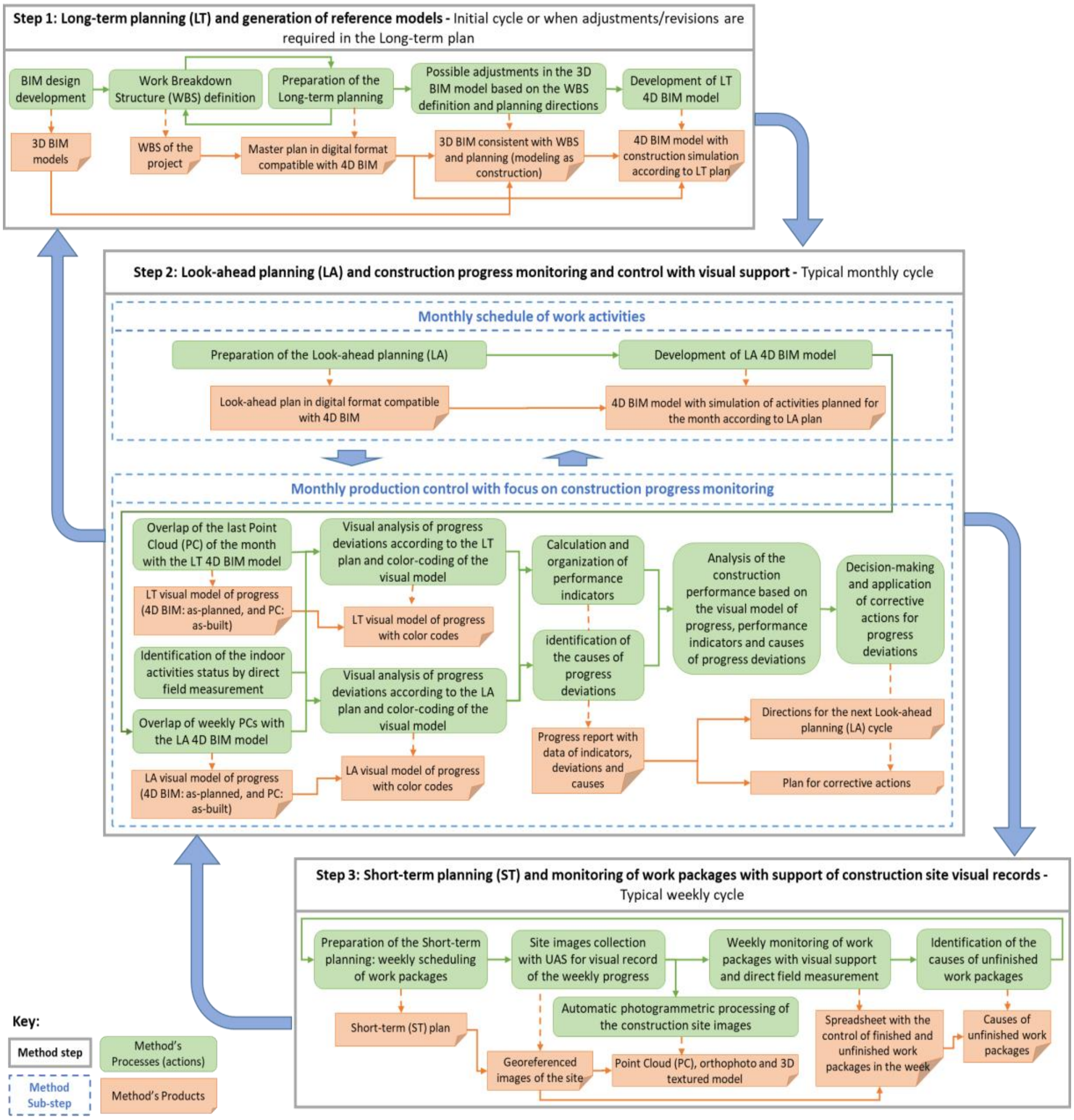

Figure 2: Framework of the **Integrated 3D-UAS 4D-BIM Visual Progress Method**

RESULTS AND DISCUSSIONS

IMPACT ON THE CONSTRUCTION PROJECT DEVELOPMENT

In this section, the data and discussions related to the constructs of "Compliance with the planned goals" and "Impact on the construction progress deviations" are presented.

Table 4 presents performance indicators measured monthly over the implementation period. These data show the construction project improvement in terms of compliance with the planned progress. During the implementation time, the construction eliminated the delays identified in the first three months (negative WPDs) and obtained even higher percentages of work progress than planned over the last two months (positive WPDs).

Table 4: The results of performance indicators over the method's implementation period

Month	Planned Progress (PP)	Work Progress (WP)	Work Progress Deviation (WPD)	% of the Work Progress Visually Measured (WPVM)	% of Activities Started in the Estimated Period (ASEP)	% of Activities Finished in the Estimated Duration (AFED)
April	9.59%	8.75%	**-8.75%**	**66.75%**	69.57%	30.43%
May	10.91%	10.75%	**-1.43%**	**60.18%**	77.27%	31.82%
June	12.70%	9.97%	**-21.50%**	**59.51%**	82.22%	35.56%
July	8.04%	8.51%	**5.81%**	**44.09%**	91.67%	64.58%
August	7.11%	7.66%	**7.72%**	**33.93%**	95.92%	63.27%

Figure 3 shows the results of the visual analyses of progress according to the look-ahead planning on visual models of as-planned and as-built progress (4D BIM + point cloud). In the visual models' view depicted in Figure 3, the 4D simulation paused on the date of the last point cloud of each month is presented with color-coded progress.

Figure 3: Visual models of progress (4D BIM + point cloud) with color codes

Note: Color-code for the work packages: behind schedule in red, ahead of schedule in green, being executed according to the schedule in purple, and already completed in real appearance.

The models in Figure 3 also visually express the improvement of compliance with planned progress. Over the past two months, a decrease in the number of outside work packages behind schedule (in red) can be observed. However, it is important to highlight that the impact of the 3D mapping (point cloud) for visual assessment of as-built progress decreased over the observed months. As long as the proportion of indoor activities grows, such an impact decreased. This can be confirmed by the decrease in "percentage of the work progress visually measured" (Table 4). However, the project team highlighted that the use of the 3D mapping in July and August was still important for the progress monitoring of the activities of facade painting, roof installation, landscaping, and pavement.

Regarding the ASEP and AFED indicators, the values presented in Table 4 also indicate improvements throughout the time in which the method was implemented. The increase of the ASEP represents improvements in compatibility between the activities planned in look-ahead and the monthly activities effectively running at the construction site. The increase of the AFED represents improvements in compatibility between the planned volume of the activities and the total monthly production capacity of the construction site.

The authors believe that the general improvements in terms of compliance with the planned goals and reduction of negative progress deviations could be related to observed changes, including: better structuring in the planning routine at the short-term level; more systematic production control; greater participation of the direct production coordination team in planning and control, providing more realistic production estimates and greater commitment to its compliance; and the positive response of the management team regarding the use of the new information provided by the method implementation.

To further evaluate the impact of the method on the construction progress deviations, three aspects were assessed by the project's team using a three-level impact scale (Table 5) and complemented with questions about the main reasons for the impact levels assigned.

Table 5: Interviewees' evaluation of the "Impact on the construction progress deviations"

Construct	**Evaluated aspect (variable)**	**Evaluation per interviewee of the method's impact**		
		Low	**Intermediate**	**High**
Impact on the construction progress deviations	1) Analysis of progress deviations		CC	CM, PdA, PA, CA, ET, EA
	2) Identification of the causes of negative progress deviations	CC	CA	CM, PdA, PA, ET, EA
	3) Mitigation of negative progress deviations with corrective actions		CC, EA	CM, PdA, PA, CA, ET

Note: The label for the interviewees' classification codes used in this table is presented in Table 2.

The majority of respondents considered the impact of the products and processes of the proposed method high in terms of the "Analysis of progress deviations", "Identification of the causes of negative progress deviations", and "Mitigation of negative progress deviations with corrective actions" (Table 5). According to them, the highest evaluated aspect, "Analysis of progress deviations", was mainly improved by the systematic and integrated use of visual models of progress with color codes and performance indicators.

However, the Construction Coordinator rated as low the impact on "Identification of the causes of negative progress deviations", and as intermediate the impact on the other two evaluated aspects (Table 5). Although he recognized the method's impact on the decision-making about progress negative deviations, he still believes that it is necessary to further incorporate the method's products and processes into the company's management procedures. This would, in his opinion, meaningfully impact all the three evaluated aspects.

The Construction Coordinator is one of the main agents for the implementation's success, so his opinion is essential. In fact, more structural integration of the method into the company's planning and control system is necessary for effective exploring of its potential. Different levels of managerial acting need to be involved in the implementation, adjusting the information and the processes of the method associated with each level.

INCREASED TRANSPARENCY AND COLLABORATION

In this section, the evaluation of the constructs of "Transparency" and "Collaboration" is presented. Table 6 presents the results of the method's impact on the main aspects of these constructs, based on the project team perception using a three-level impact scale.

Table 6: Interviewees' evaluation of the "Transparency" and "Collaboration"

Construct	Evaluated aspect (variable)	Evaluation per interviewee of the method's impact		
		Low	Intermediate	High
Transparency	1) Communication and identification of progress status			CC, CM, PdA, PA, CA, ET, EA
	2) Understanding of progress information			CC, CM, PdA, PA, CA, ET, EA
Collaboration	1) Exchange and sharing of progress information		CC, CM, PdA	PA, CA, ET, EA
	2) Integration and communication of the management team		PdA	CC, CM, PA, CA, ET, EA
	3) Shared analysis of progress status and joint decision-making	CC	CM, PdA, CA	PA, ET, EA

Note: The label for the interviewees' classification codes used in this table is presented in Table 2.

According to the data presented in Table 6, a high impact of the implemented tools and processes for increasing transparency was identified. From the use of the visual data technologies and performance indicators, the management team highlighted that the information flow about the construction progress became more visible and understandable.

The project team also highlighted new information obtained about the production as increased transparency indicative. This new information was associated with the identification, analysis and documentation of progress using the visual models (4D BIM + point cloud); the monitoring of the planning effectiveness and the production performance from the data of performance indicators; and the accurate external view of the construction site status (as-built progress) from the aerial photographs and photogrammetric products.

Regarding "Collaboration", the high impact evaluated on the second aspect presented in Table 6 shows a greater integration and communication of the management team in the progress monitoring, especially between the teams of production coordination and general management in commitment meetings for planning and control.

However, a considerable part of respondents evaluated the impact of the method as intermediate and even low on two of the three aspects evaluated for "Collaboration" (Table 6). Although they consider that a shared analysis of the visual models of progress can contribute to better decision-making; the Construction Coordinator and Production Analyst commented that this will only happen effectively when the management team becomes more familiar and has more autonomy over this new way of progress monitoring.

Such evaluation is indeed relevant since the learning curve is very important when it comes to the adoption of new technologies and new working process. When the user gains more familiarity and autonomy over this new way of progress monitoring, the value perceived and the potential explored of the method's products and process are increased. Because of this, investment in training, development of pilot study for initial experiences, and incorporation of skilled professionals are important aspects that must be considered.

MAIN BENEFITS AND LIMITATIONS OF THE PROPOSED METHOD

To complement the results presented, Table 7 presents a summary of the main benefits and limitations of the proposed method and the implementation process. These benefits and limitations were highlighted by the project management team, based on the interviews.

Table 7: Proposed method benefits and limitations highlighted by the interviewees

Main benefits	Main limitations
• Better visualization and clearer analysis of the construction progress status through the use of the visual models of progress with color codes; • Improvement of compliance with the planned goals; • Better identification of negative deviations of progress and search for solutions; • Increased transparency and collaboration; • Improved short-term planning and control through the systematic information flow and visual data; • A more complete and accurate view of the construction site status from the aerial photographs and photogrammetric products.	• Requires greater incorporation of the proposed method into the company's management procedures; • The short period of the implementation limited the use of the visual models of progress; • The low familiarity of the project team with the used technologies hampered a better use of the visual models of progress; • Lack of visual analysis of the indoor activities.

CONCLUSION

This paper presents the initial implementation and evaluation of the proposed method for systematic visual construction progress monitoring integrating into production planning and control, supported by 4D BIM, 3D mappings using UAS, and performance indicators. The implementation took place in a case study on a Brazilian construction project. The main contribution of this work is a better understanding of the impact and the added value of the information flow provided by the proposed method, in terms of compliance with planned goals, impact on the progress deviations, transparency and collaboration.

The findings show that the adopted visual data technologies and performance indicators have brought about more effective and transparent information flow. It was apparent that the information provided by the method contributed to the improvement of production monitoring and identification of planning failures and progress deviations. This allowed for better compliance with the planned goals over the implementation months. In addition, the project team highlighted the method's impact on the improved analysis of progress and decision-making about planning redirects and corrective actions to negative deviations.

However, limitations were also identified, including the need for a greater integration of the method's processes and products with the company's management procedures; low familiarity and autonomy of the project team with the use of the visual data technologies; and non-visual measurement of the indoor activities' status, still needing of direct field measurements. For the next step in this research, the authors will try to address the identified limitations and a new case study will be developed, including another implementation and evaluation of the proposed method in an enhanced version.

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FACTORS INFLUENCING THE USE OF LAST PLANNER SYSTEM METHODS: AN EMPIRICAL STUDY IN PERU

Danny Murguia[1]

ABSTRACT

The Last Planner System™ (LPS) is a collaborative production and control system that has been implemented by some contractors in Peru in the last two decades. However, the full potential of its implementation has not been totally achieved. The aim of this research is to identify the most prominent factors that dictate the level of use of LPS methods. To achieve this objective, a survey was designed using variables found in previous research and informed by interviews with LPS experts. Ninety-five site engineers responded to the questionnaire. Data was analysed using reliability analysis and multiple linear regression. It was found that 'Trained staff', 'Good Decision-Making', and 'Commitment' are the factors with the highest scores. Nevertheless, 'Integration and Communication,' and 'LPS-knowledge' were found to be important to bring the successful implementation of LPS methods whilst 'Resistance to Change' and the 'firm size' constraint implementation. The findings suggest that 'Integration and Communication', 'LPS-knowledge', and 'Resistance to Change' are not independent factors, thus, the need to explore second-order factors influencing their variability. Such dependency could be found at the firm and institutional levels. Further research can be extended to the development of a prescriptive model for LPS implementation in construction firms.

KEYWORDS

Last planner system, methods, onsite, facilitators, barriers.

NEARLY TWO DECADES OF LPS EXPERIENCE IN PERU

The LPS was first introduced in Peru in the early 2000's with the publication of the seminal book "Productivity in Construction Projects" (Guio 2001). The study showed a staggering 28% of adding-value activities and 36% of waste of labour productivity. Guio (2001) suggested the use of Last Planner as a system to overcome the low levels of productivity in the industry. The approach implemented by the early adopters had a focus on the division of zones per story - to create a stable flow - and on the improvement of labour productivity. As such, early adopters implemented takt-time scheduling (locally known as "the train"), and the work-sampling method. However, the production system design was not entirely

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collaborative. Rather, it relied only on the decisions of the site manager and the site foreman. Moreover, the first LPS methods implemented have been milestone pull planning, look ahead planning, weekly work plans and measurement of PPC (Yoza 2011).

Over the next years, some institutional factors shaped LPS as a normative pressure in the Peruvian construction industry. Such factors include large contractors' decision to standardise LPS as a production management system, the creation of the LCI (Peru) Chapter, and the inclusion of Lean Construction and LPS as modules at undergraduate and master's programmes. As such, LPS focus shifted from takt-time scheduling and the work-sampling method, to efficient flows and processes, and collaborative onsite planning with both in-house foremen and subcontractors (Flores & Ollero 2013; Murguia et al. 2016). LPS implementation, however, has not been without shortfalls. Frequently, weekly meetings omit the analysis of constraints, activities are not revealed at the operational level, and there is a lack of commitment of subcontractors and site engineers. As a result, LPS is partially implemented, the collaborative planning declines, the desired "pull" system becomes a "push" system, and its use decreases in the finishing and fit-out phases (Murguia et al. 2016).

As such, the question remains on what are the factors that constraint the use of LPS to its full potential after nearly two decades of diffusion in the industry. Therefore, the overarching aim of this research is to identify the main factors that dictate the use of LPS methods on site. To achieve this aim, first, a literature review was conducted to find out the most important enablers and barriers discussed in the Lean community. Second, short semi-structure interviews with LPS experts were conducted to inform the catalogue of factors and to identify contextual factors. Third, a questionnaire was designed aimed at site engineers using LPS. The questionnaire was piloted to improve readability and comprehensibility. Fourth, empirical data was collected with ninety-five site engineers currently working on construction projects. Fifth, data was analysed using reliability analysis and multiple regression. Finally, the findings are discussed, and directions for further research are presented.

RESEARCH METHOD

A mixed method approach is selected as the research method. A mixed method combines the flexibility of qualitative research and the structure of quantitative research (Cresswell 2014). As such, a literature review and exploratory interviews with experts on LPS implementation will inform the design of the instrument for data collection. A questionnaire will help to obtain empirical evidence on a larger scale from a variety of projects and respondents. The objective of the data collection instrument is to measure the intensity of the factors under study, rather than to assess participant's perceptions on the importance of such factors. Therefore, relationships between dependent and independent factors can be made.

LITERATURE REVIEW

The LPS is a production planning and control system designed to produce predictable workflow and rapid learning in programming, design, construction, and commissioning of construction projects (Ebbs and Pasquire 2019). LPS has five elements: (1) Master Scheduling (set milestones and phase durations & overlaps), (2) Phase Pull Planning (specify handoffs & conditions of satisfaction between processes within phases), (3) Lookahead Planning (task breakdown from processes into operations, constraint analysis and removal), (4) Commitment Planning (make reliable promises, underloading resources, daily huddles), and (5) Learning (analysis of breakdowns: percentage of plan completed, 5 Whys, frequency of plan failures) (Ballard and Tommelein 2016). It is argued that a systemic implementation with sustainable results must complete the learning process throughout the five stages. A wide range of academic literature have shown exemplar case studies of LPS implementation in the industry (e.g. Alarcon et al. 2005). However, Dave et al. (2015) posited that '*the full potential of LPS is rarely achieved and the root causes for this are not entirely understood*'. Dave et al. (2015) found that firms implementing lean for over 10 years, have only implemented three main tools of the LPS toolset, with a focus on the short-term planning (weekly meetings). Based on literature review and field observations on construction projects in the UK and Finland, the study catalogued several recurrent problems in LPS implementation:

- Lack of ability to deploy collaborative aspects
- Limited deployment of LPS
- Reduced importance of phase and master plans
- Lack of continuous improvement
- Lack of links between detailed and high-level plans

A similar finding was showed by Perez and Ghosh (2018) who examined typical shortfalls of LPS implementation such as an incomplete PPC process, the underutilisation of lookahead plans, lack of a guideline practice for schedule updating, and lack of a structured order for the introduction of LPS on site. Some authors have identified factors that would explain the partial deployment of LPS. For example, Cano et al. (2015) catalogued a set of barriers and critical success factors for Lean Construction implementation. As such, the study identified 'development and selection of the right people' as the most influential success factor and 'cultural problems' was deemed to be the most important barrier. Similarly, Brady et al. (2011) identified the main barriers for LPS implementation, namely, weak communication and transparency, minimum involvement of construction workers and subcontractors, inadequate training of participants, lack of role definition, inadequate use of information, lack of time for implementing improvements, and lack of integration of the supply chain.

Alarcon et al. (2002) conducted a study in twelve construction companies and identified human factors as important barriers that obstruct LPS implementation. Notably, resistance to change is observed as one of the main obstacles, followed by lack of self-criticism, short-term vision and misinterpretation of the PPC indicator. Alarcon et al. (2005) studied 77 Chilean projects and found that lack of time to implement changes, lack of training, inadequate structure at the organisational level, low understanding of LPS concepts, inadequate administration, weak communication and lack of integration were deficiencies found in LPS implementation.

From the literature, it is observed multifaceted factors linked to people, firms and institutions. However, little is known of what are the specific factors that systematically hinder the deployment of LPS. Moreover, there is little knowledge on the impact of the firm size on LPS implementation. The knowledge of this factors would help site engineers and decision-makers to make improved decisions when implementing LPS on site.

EXPLORATORY INTERVIEWS

Three LPS experts were interviewed to gain insights into the challenges of LPS implementation onsite. The experts were selected on the basis to be construction professionals with renowned experience as contractors and consultants. The first expert argued that the main barrier is the human factor due to lack of commitment and insufficient training. The production system is collaboratively designed in the kick-off pull planning meeting, however, efforts decline to sustain the flow during execution and control. The second barrier is the belief that LPS is a reporting system (e.g. PPC or lookahead speaadsheets) for the top management, instead of the tools being facilitators for the learning process. The third problem is the institutionalised problem of lack of anticipation to problems and insufficient responsiveness of the logistics department to remove constraints. Thus, this lack of commitment leads to a focus on looking for the ‘guilty’ instead of identifying root causes and solving problems. To mitigate this, some facilitators are described such as the definition of lead times in logistics, training to staff and subcontractors, and a clear definition of short-term metrics.

The second expert stated that LPS is a learning process to improve planning. The first barrier to achieve good results is a lack of commitment. The expert argued that to solve this, psychological and sociological studies are needed. As such, people need to understand that LPS meetings are meant to achieve collaboration, rather than to accuse others on what they did wrong. The expert comments that LPS is not properly implemented. Several site engineers believe that using a few tools make the site an LPS-enabled project. However, little attention is paid to the thorough LPS cycle.

The third expert posited that LPS helps to reduce the variability in the construction process, thus, helps to improve the schedule compliance. The expert contended that LPS implementation requires a cross-project implementation as top management should assign enough resources and support for effective implementation. In their view, changing people’s mindset is a difficult task and takes time. The expert argues that LPS is not properly implemented, however, foremen and subcontractors have learnt that they must plan in hands with production engineers. Lack of lessons learnt and self-criticism are also pitfalls. Finally, the expert argued that the firm size also matters, as big companies implement LPS due to tangible benefits, however, small and middle enterprises are struggling to implement.

Factor	Sources	Variable
Leadership	Fernandez-Solis et al. (2013), Cano et al. (2015), Ebbs and Pasquire (2019)	Site engineer's leadership Foremen and subcontractor's leadership Top management leadership
Commitment	AlSehaimi et al. (2009), Fernandez-Solis et al. (2013), Interviews with experts	Site engineer's commitment Foremen and subcontractor's commitment Top management commitment Logistics department commitment Central office commitment
Integration and communicati on	Alarcon et al. (2005), AlSehaimi et al. (2009), Brady et al. (2011), Fernandez-Solis et al. (2013), Cano et al. (2015), Ebbs and Pasquire (2019)	Onsite stakeholder's integration Compatible decisions between onsite stakeholders Permanent feedback between last planners and site engineers
Good information and decision-making	Alarcon et al. (2005), Brady et al. (2011), Fernandez-Solis et al. (2013)	Early identification of improvement opportunities Timely information to make decisions A Big-room to facilitate decision-making
Trained Staff	Alarcon et al. (2005), Hamzeh (2011), Brady et al. (2011), Cano et al. (2015), Perez and Gosh (2018)	Trained site engineers Trained foreman and subcontractors
LPS-knowledge	Alarcon et al. (2005), Friblick et al. (2009), Fernandez-Solis et al. (2013),	There is enough LPS knowledge Site engineers know that LPS is more than takt-time scheduling
Lack of time	Alarcon et al. (2005), Brady et al. (2011), Interviews with experts	We focus more on project's timely completion rather than to fully implement LPS We focus more in logistics and contracts rather than to fully implement LPS We focus more in problems with the neighbourhood rather than to fully implement LPS
Firm's LPS-culture	Alarcon et al. (2005), Friblick et al. (2009), Hamzeh (2011), Interviews with experts	LPS requires a pilot project implementation LPS requires a standard procedure across projects LPS requires a knowledge manager across projects
Resistance to change	Alarcon et al. (2002), AlSehaimi et al. (2009), Fernandez-Solis et al. (2013), Cano et al. (2015), Perez and Gosh (2018)	Site engineer's resistance to change Foremen and subcontractor's resistance to change

Table 1: Catalogue of Factors for LPS implementation

QUESTIONNAIRE DESIGN AND DATA COLLECTION

A questionnaire was used as the main method for data collection. The questionnaire was designed using factors found in the literature and the exploratory interviews as shown in Table 1. The target population of respondents was site engineers who have practical experience using LPS in their current or last project. Variables were assessed using a five-point Likert Scale. Respondents were asked to assess from 1-5 to what extent the observed variables were present in their current/last project. For example, the variables "*Foremen and subcontractor's commitment*", or "*Site engineer's leadership*" were assessed as 1 = Very Low, 2 = Low, 3 = Intermediate, 4= High, 5 = Very High. Similarly, the dependent factor – LPS methods – was assessed in a six-point Scale. To capture the implementation of the wide range of methods, participants were asked to assess the level of implementation of each method. For example, the variable "*Constraint analysis and removal*" was assessed as 0 = Null, 1 = Very Low, 2 = Low, 3 = Intermediate, 4 = High, 5 = Very High.

The questionnaire was piloted with five construction professionals with a wealth of experience using LPS. Some suggestions on the wording of variables and the scales were incorporated into the revised questionnaire. Finally, data was collected via three methods: 58 questionnaires were collected face-to-face at construction sites, 16 questionnaires were collected at an LCI (Peru) Chapter diffusion activity in December 2018, and 21 questionnaires were collected via an online post on LinkedIn in January 2019. A grand total of 95 responses were received.

RESULTS

The dataset was screened and four questionnaires were dropped due to lack of commitment in the responses. The criterion for deletion was questionnaires with a standard deviation of less than 0.5. The participants's years of experience were as follows: 13.3% had more than 15 years of experience, 16.7% had 11 to 15 years of experience, 32.2% had 6 to 10 years of experience, and 37.8% had less than 5 years of experience. Additionally, participants' years of experience using LPS were as follows: 8.9% had more than 9 years of LPS experience, 5.6% had 7 to 9 years of experience, 28.9% had 4 to 6 years of LPS experience, and 56.7% had less than 3 years of LPS experience. Participant's demographics show a breadth of professional experience in construction and represents the experience of innovators, early adopters and the early majority (Rogers 2003). From a firm size perspective, 49.5 % of the respondents work in small firms (1-50 employees), 27.5% in medium-sized firms (51-250 employees), and 22.0% in large firms (>250 employees). Similarly, the demographics of projects were as follows: 27.0% of project ≤ 5,000 sqm, 21.3% of projects between 5,001 and 10,000 sqm, 30.3% of projects between 10,001 and 20,000 sqm, and 21.3% projects > 20,000 sqm. Firms' and projects' demographics confirm a sample containing firms and projects covering the range found in the industry. Therefore, the sample is considered to be reliable.

The Cronbach Alpha (α) was calculated for each factor to assess the reliability of observed variables, this is, that the variables in the questionnaires are measuring the unobserved factor (e.g. commitment is measured with five variables as shown in Table 1). Academic literature recommends a threshold of 0.70 as a minimum value to accept the variables measuring the factor. However, in exploratory studies it can be accepted values ≥0.60.

Mean responses of the factors can be considered as indicators of the importance of the factors that contribute to the use of LPS methods. The factors were arranged in descending order of mean values and ranked. Depending on the mean scores and standard deviations, the factors can be divided into two groups: group 1 with mean scores ≥ 3.5 represent the more important factors present in construction projects, and group 2 with mean scores < 3.5 represent factors with significantly less importance. As shown in Table 2, a total of 5 factors are in group 1, and 4 factors are in group 2. 'Trained staff', 'good information and decision-making', 'commitment', and 'leadership' stand out as the most prominent success factors in the LPS.

Table 2: Descriptive statistics of factors influencing the use of LPS methods

Factor	**Mean**	**S.D.**	**Rank**	**Cronbach α**
Trained staff	4.05	0.83	1	0.65
Good information and decision-making	3.93	0.82	2	0.75
Commitment	3.79	0.72	3	0.76
Leadership	3.60	0.79	4	0.77
Integration and communication	3.55	0.73	5	0.67
Firm's LPS-culture	3.44	0.86	6	0.70
LPS-knowledge	3.43	0.85	7	0.68
Resistance to change	3.13	0.92	8	0.64
Lack of time	3.05	1.05	9	0.90

Table 3 shows the mean score, standard deviation and the rank of the dependent variables (LPS methods). It is observed that none of the methods obtain a mean score of ≥4 (High or Very High). On the one hand, Master schedule, pull planning (structure phase), constraints analysis and removal have higher scores. On the other hand, PCC, analysis of breakdowns and reliable promising have the lowest scores (mean ≤3.5).

Multiple regression analysis was also used to establish relationships between dependent (LPS methods) and independent factors (9 factors). A stepwise procedure was applied and four independent factors were selected. Altogether, 49% of the LPS methods' variance was explained by 'Integration and Communication', 'LPS-Knowledge', 'Resistance to Change', and 'the firm size', which were significantly different from zero at a p≤ 0.05. 'Integration and Communication' contribute significantly to the use of LPS methods (R^2= 0.29, p<0.001), whilst 'LPS-knowledge' and 'Resistance to Change' accounted for 13% and 4% of the variance respectively. The firm size accounted for 3% of the variance. Table 4 shows the unstandardized regression coefficients (β), the standard error (S.E.), the t-statistic (t), and the significance level (p-value).

Table 3: Mean scores, standard deviation, and rank of LPS methods

LPS Method	Mean	S.D.	Rank
Master schedule	3.91	0.91	1
Pull Planning (Structures Phase)	3.74	1.00	2
Constraint Analysis and Removal	3.63	1.03	3
Task Breakdown	3.55	0.82	4
Weekly Planning Meetings	3.54	1.06	5
Pull Planning (Finishing Phase)	3.53	0.94	6
PPC Metric	3.46	1.24	7
Analysis of Breakdowns	3.43	1.09	8
Reliable Promising	3.21	1.01	9

Table 4: Results of Stepwise Multiple Linear Regression (R^2 = 0.49)

Variable	β	S.E.	t	p-value
(Constant)	1.761	0.369	4.774	0.000*
Integration and communication	0.393	0.075	5.226	0.000*
LPS-knowledge	0.286	0.064	4.478	0.000*
Resistance to Change	-0.152	0.064	-2.378	0.020
Firm Size (Small Firm)	-0.245	0.106	-2.319	0.023

* p<0.001. Sample size N=91

DISCUSSION

'Integration and Communication' was shown to be the most important factor contributing to the deployment of LPS methods (β=0.39, p<0.000). This factor also represents two key elements pertaining to integration: 'leadership' and 'commitment'. Although 'leadership' and 'commitment' were not significant factors in the stepwise regression analysis, the correlation coefficient between ‘leadership’ and ‘integration and communication’ was 0.59 ($p < 0.000$) and the correlations coefficient between ‘commitment’ and ‘integration and communication’ was 0.52 ($p < 0.000$). This finding suggests a causality relationship between ‘leadership’ and ‘commitment’ to ‘integration and communication’ that can be further explored.

‘LPS-knowledge’ was found to be the second key factor contributing to LPS deployment (β=0.29, p<0.000). This finding is consistent with previous studies (Alarcon et al. 2005; Friblick et al. 2009; Fernandez-Solis et al. 2012). Friblick et al. (2009) found that the knowledge of LPS among construction managers is low in the Swedish construction industry. In order to manage successful implementation, Friblick et al. (2009) stated that LPS knowledge should be clarified to practitioners who execute tasks. However, learning LPS requires standardised and permanent training. Moreover, training can be a direct consequence of institutional factors such as ‘firm’s LPS-culture’ or ‘top management support’. As noted by Dave et al. (2015), the people perspective requires a focus on training and a consistent approach to teaching LPS across universities and consultants.

The question remains whether small firms can tackle the level of training required by LPS. Although some scholars argue that the small firm is a good environment for implementing changes due to their flexibility and dynamism, this study has found that the small firm deploys fewer LPS methods compared to medium and large firms (β=-0.25, p<0.05). Additionally, the results show that there was not a significant difference in LPS implementation between medium and large contractors. This result suggests that small firms have not developed a within-firm LPS culture, thus, a lack of a standardised LPS system for production management and control. By contrast, some medium and large firms did have implemented LPS as the institutional production management system, and engineers are trained to deploy its methods. Nevertheless, ‘resistance to change’ is the human factor that was found to be the second barrier for LPS implementation across small, medium, and large contractors (β=-0.15, p<0.05). Therefore, a meaningful participation of project stakeholders is required. Hamzeh (2011) stated that implementing LPS in a project is more than applying tools. It requires a change on the way *“people think, work, and execute tasks”*. It is argued that resistance to change is overcome when people profoundly understand the benefits of implementation in contrast to the effects of non-implementation.

Fernandez-Solis et al. (2012) emphasised the importance to recognise the challenges for LPS implementation and to tackle these challenges to increase the level of adoption in projects and organisations. The two main factors and the two main barriers found in this study can be managed by site engineers and decision-makers to tackle the deficiencies in LPS implementation. For a current LPS user, the firm discourse on LPS should be consistent with a standardised approach that includes training to enhance the ‘LPS-knowledge’ of site engineers, foreman, and subcontractors; overcome ‘resistance to change’ and foster the levels of ‘integration and communication’. Nonetheless, Hamzeh (2011) posited that successful implementation of LPS requires a deep change at the institutional level. LPS offers a methodological framework for construction planning, however, it will only work if the firm embraces a lean culture.

CONCLUSIONS

Empirical evidence of previous research suggests the partial implementation of LPS worldwide. This research aimed to identify the most prominent factors that influence and constrain the deployment of LPS methods, thus, site engineers and decision-makers are aware of and can handle them. 'Integration and Communication', and 'LPS-knowledge' were found to be the most important facilitators. 'Integration and Communication' requires effective stakeholder's integration, compatible decisions, and permanent feedback between site engineers, subcontractors, and last planners. 'LPS-knowledge' requires standardised training on the concepts involved to implement LPS onsite. Training requires an institutional investigation of the common understanding of LPS in specific contexts. It was also found that small firms struggle to implement LPS. This finding can be further investigated on why the small firm which is deemed to be flexible and adaptable cannot handle the required LPS change. Finally, 'resistance to change' is a human factor present in the diffusion of process and technological innovations. Previous research has found that it can be handled at the firm level.

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LEAN CONSTRUCTION TECHNIQUES AND INDIVIDUAL PERFORMANCE

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ABSTRACT

The adoption of lean construction techniques in construction industry can eliminate waste and increase profit, and this paper is to test the maturity of implementation of lean construction tools in construction project, as well as the impact of lean construction tools on individual performance. In this research, five widely used lean construction techniques were selected (Last Planner system (LPS), visualization tool, six step plan(6S), Just-in-time (JIT) and Total quality management (TQM)), and individual performance was divided into two dimensions: task performance and contextual performance. The data collection methods included interviews and questionnaires, and the data analyzed via SPSS software. The results showed that the highest maturity implementation of lean construction tools in the investigated projects was TQM, had positive impact on individual performance, while LPS was the lowest maturity tool and had least impact on individual performance; for task performance, 6S was the most effective technique, and for contextual performance, the most effective tool was visualization tool. This study provides theoretical support and guidance for construction enterprises to select lean construction techniques to improve individual performance.

KEYWORDS

Lean construction, individual performance, maturity, technique, implementation

INTRODUCTION

As the mainstay industry of Chinese national economy, construction industry brings great wealth to the society. At the same time, a series of problems has exposed with the continuous expansion of the construction market. Research has shown that 25% ~ 30% of the construction process in the traditional construction industry is to rework, which lead to 30%~ 60% waste of labor force, as well as the 10% waste of material, up to 10%~20% of

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the total project cost. Therefore, in order to achieve sustainable development and green development of construction industry, it is necessary to reduce the building energy consumption and minimize the waste of material, time or labor force. Numerous approaches have been developed to reduce waste and improve efficiency of construction processes, and Lean Construction(LC) as a new philosophy based on lean manufacturing concepts (Koskela, 1992), with its focus on the reduction and elimination of the waste, offer the promise to minimize non value-adding work. In addition, research has indicated that the implementation of LC had benefits associated with sustainable construction; the contribution of LC techniques in sustainable construction cannot be over emphasized.

The study of LC beginning in the early 1990s, had made achievement in countries like UK (Mossman, 2009), Singapore (Dulaimi and Tanamas, 2001), Brazil (Silva and Cardoso, 1999), USA (Nahmens and Ikuma, 2009), and so on. At the beginning of 21st century, the Chinese scholars also explore the implementation of lean philosophy in the construction industry. Current research about application of LC mainly focuses on the following two aspects: one is the implementation of LC techniques, including applicability, influencing factors, implementation path, and so on; the other is the performance research of LC implementation. There are still a lot of manual work in the implementation of LC; the overall performance of the project comes from the individual performance set in the production process. The existing research about lean philosophy mainly focused on the research of project performance but ignore the importance of individual performance, hence, this paper research the impact of LC techniques on individual performance, provides theoretical support for company to choose suitable LC techniques in order to improve individual performance and project performance.

THEORETICAL BASIS AND HYPOTHESIS

LEAN CONSTRUCTION

Lean construction was pioneered by Koskela (1992), who developed the transformation flow view (TFV) theory of production in construction, and introduced the idea of understanding construction as production (Ogunbiyi et.al, 2014; Salem et.al, 2005). LC was described as a way to design production systems to minimize waste of materials, time, and workforce, in order to generate the maximum possible amount of value (Koskela, 2002).The Construction Industry Institute (CII) has defined LC as "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". LC visualizes the project as a flow of activities that must generate value to the customer. According to Koskela(1992) and Thomas et al.(2002), the core concepts of LC is just-in-time (JIT) , which use pull-driven scheduling to reduce the variability in process and waste, units should be available only when required. Three methods are associated with JIT: *kanban* system, production level, and decrease the number of setup activities (Chaoiya et al. 2000; Miltenburg, 2002; Salem et al., 2006). The concept of last planner proposed by Ballard is a technique based on lean think to minimize the waste in a system through assignment-level planning or detailed look-ahead scheduling. The “last planner” refers to the last individual, typically the subcontractor superintendent or foreman, who best understand their abilities to complete their respective work with a determined time duration, providing more accurate input on the construction schedule (Fernandez-Solis et al., 2013; Kongguo,2014).

Besides these two tools, other three LC tools are chosed in this paper to evaluate visualization tools, six-step plan (6S), and total quality management (TQM). Visualization lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. Works can remember elements such as workflow, performance targets, and specific required actions through the visualization tools (Moser and Dos santos, 2003; Salem et al., 2005). 6S helps to eliminate wasteful resources to create an organized and facility environment with six steps (Hirano, 1996): Seiri (straighten up), seiton (put things in order), seiso (clean up), seiketsu (personal neatness), shitsuke (discipline) and safety. TMQ is the quality management at every stage of operation, from planning and design through self-insection, to continual process monitoring for improvement opportunities (Radnor, 2000).

In the next parts the maturity of the implementation of these five LC techniques (LPS, JIT, 6S, Visualization tool and TQM) are evaluated, and the relationship between the implementation of LC techniques and individual performance are investigated.

INDIVIDUAL PERFORMANCE

Performance is behavior with an evaluative component, behavior that can be evaluated as positive or negative for individual or organizational effectiveness (Motowidlo et al., 1997). It has proven that individual performance involves not only task performance, but also contextual performance, which was first proposed by Borman and Motowidlo (1993). Task performance behaviors are associated with the use of technical skills and job-specific knowledge that provide indirect support for the organization's core technical processes. When employees use technical skills and knowledge to accomplish a task, they are engaging in task performance. In contrast, contextual performance behaviors are associated with interactions with coworkers, supervisors, or customers, that support the organizational, psychological and social context in which task activities are performed. When employees help others complete a task, cooperate with their supervisors, or suggest ways to improve organizational processes, they are engaging in contextual performance (Scotter et al., 2000; Edwards, et al., 2008; Muhammad, et al. 2016). The two dimensions of individual performance had been widely accepted by researchers, and in this paper the author choose task performance and contextual performance as the measurement of individual performance.

HYPOTHESIS

The research about the implementation of LC techniques mainly focus on the reduction of waste, improvement of efficiency and workflow, project performance and so on. Luis et al. (2008) spend five years to evaluate the LC implementation in more than 100 construction projects in Chile, the result showed that different implementation levels of LPS impact the improvement of project. The LPS was also found can improve the flow of the finishing stage by assigning the tasks in sufficient detail and modeling the production units (Murguía et al., 2016). Concha et al. (2015) proved that lean principles and concepts could positive impact the cost, time, variability and waste reduction in organizations. Beside this, as the important position of LC tools to deal with the issues of wastes in projects, LC implementation has been discussed as the robust approach for project management (Ansah et al., 2016). Zhang and Chen (2016) talked about the knowledge management of LC and the results showed that lean tools have a positive effect on knowledge creation and finally promote lean performance. There are few studies about the implementation of LC techniques and individual performance, while contextual performance makes an important contribution to organizational effectiveness (Borman and Motowidlo, 1993). Therefore, the following hypothesis are proposed:

H1: PLS is positively associated with individual performance;
H2: JIT is positively associated with individual performance;
H3:TQM is positively associated with individual performance;
H4: 6S was positively associated with individual performance;
H5: Visualization is positively associated with individual performance.

METHODOLOGY

DATA COLLECTION

Data were collected through respondents from China construction workers via questionnaires. The contents of the questionnaire include the basic information of projects, the maturity level of implementation of LC techniques, the level of individual performance, and personal information. The questionnaire was rated on 5-point Likert scale with strongly disagree to strongly agree at points 1-5, respectively. The distribution way including e-mail, mailing and on-site distribution. A total of 770 questionnaires were sent out and 710 questionnaires were completed and returned. Invalid questionnaires were removed according to the three criterions: 1) the number of missing items exceeds 10% of the total items; 2) the answers of all items in the questionnaire are regular, such as the same answer for all items or repeated answers regularly; 3) two or more answers in the multiple choice question, 667 valid questionnaires were obtained, and the usable response rate was 86.6%.

Among the valid samples, the investigated projects were distributed in 18 provinces, most located in North China and East China. The main types of projects are civil engineering, accounting for 57.7% of the total, and the main structure type is frame structure, accounting for 53.4% of the total. Among the 667 construction workers investigated, 93.4% were male and 6.6% were female. In terms of age distribution, most of the respondents were under 40 years old, especially those aged 31 to 40, accounting for 43.1% of the total. In terms of educational level, the number of people with less than junior college degree accounts for 66.8 % of the total number, and the proportion of those with college degree or above is 33.2 %. For the distribution of management levels, grass-roots managers and professional and technical personnel are relatively concentrated, accounting for 83.2% of the total personnel, followed by the proportion of middle-level managers of the company is 14.1%, and finally the proportion of senior managers is 2.7%. The result is in line with reality.

RELIABILITY AND VALIDITY ANALYSIS

Firstly, the reliability and validity of the questionnaire were analyzed by SPSS software, the commonly used reliability test index is the Cronbach's Alpha coefficient. The closer the coefficient is to 1, the better the reliability and stability of the questionnaire is. As shown in Table 1, the Cronbach's Alpha values of LC technique and individual performance are 0.875 and 0.803, and the Standardized Cronbach's Alpha values are 0.877 and 0.823, respectively. The results indicate that the scale has high internal consistency and high reliability.

Table 1: Reliability statistics

Constructs	Cronbach's Alpha	Standardized Cronbach's Alpha	items
LC Techniques	.875	.877	26
Individual performance	.803	.823	14

Validity test is a test of the accuracy or validity of the items in the questionnaire. The Kaiser-Meyer-Olkin (KMO) coefficient and the Bartlett sphericity test are generally used as the measurement indexes. As shown in Table 2, the KMO values of LC techniques and individual performance were 0.894 and 0.862, respectively, and the sig.=0.000 < 0.005, indicated that the validity of the scale was better.

Table 2: Test of KMO and Bartlett

Constructs		LC Techniques	Individual performance
KMO		.894	.862
Bartlett	χ^2;	4834.317	2523.844
	χ^2/df;	325	91
	Sig.	.000	.000

HYPOTHESIS TEST AND DISCUSSION

HYPOTHESIS TEST

Firstly, the maturity level of the implementation of LC techniques were evaluated by the average score of each item. The results showed that the highest maturity level is TQM, followed by visualization tools, 6S and JIT, while LPS had the lowest maturity.

Table 3: Maturity level of the implementation of LC techniques

LPS		Visualization		6S		JIT		TQM	
Daily work plan	3.59	PPC charts	4.10	Seiri	3.86	Workflow linked closely	3.73	PDCA techniques	3.56
Weekly work plan	3.94	Project schedule	4.17	Seiton	3.94	Mariterial and equipment arrived on time	3.85	Total staff take part in quality control	4.07
Commitment plan	3.48	Work standard	3.91	Seiso	3.89	Standardization of workflow	3.97	Whole process of quality control	4.24
Look-ahead schedule	3.9			Seiketsu	4.08	Workload is similar in each section	4.02	Cost accounting	4.3
Learn	4.02			Shitsuke	4.01	Component prefabrication	3.67	Eliminate equipment failure	4.09
				Safety	4.13			Maintain well cooperation	4.08
Average	3.80	Average	4.01	Average	3.99	Average	3.85	Average	4.06

The relationship between LC and individual performance was analyzed via the bivariate correlation analysis in SPSS software. The correlation coefficient of Pearson is used to express the relationship between variables. As shown in Table 4, there is a significant positive correlation between LC techniques and task performance (LPS:0.383, visualization: 0.394, 6S: 0.464, JIT:0.438, TQM: 0.452; $p < 0.01$).There was a significant positive correlation between LC techniques and contextual performance (LPS:0.377, visualization: 0.470, 6S: 0.388, JIT: 0.435, TQM: 0.436; $p < 0.\ 01$), which indicated that the H1~H5 were accepted. In terms of task performance, the correlation ranking of LC technique is 6S, TQM, JIT, visualization and LPS; for contextual performance, the ranking is Visualization, TQM, JIT, 6S and LPS.

Table 4: Pearson correlation coefficient between LC techniques and individual performance

	LPS	visualization	6S	JIT	TQM	Task performance	Contextual performance
LPS	1						
Visualization	0.581**	1					
6S	0.480**	0.464**	1				
JIT	0.543**	0.503**	0.530**	1			
TQM	0.511**	0.490**	0.568**	0.571**	1		
Task performance	0.383**	0.394**	0.464**	0.438**	0.452**	1	
Contextual performance	0.377**	0.470**	0.388**	0.435**	0.436**	0.674**	1

**p < .01(two-tailed set)

DISCUSSION

The highest maturity of the implementation of LC technique is TQM (4.06), followed by visualization (4.01), 6S (3.99), JIT (3.85), while LPS (3.80) has the lowest maturity. TQM is a LC technique that related to project cost and quality, it has higher maturity in project indicates that cost control and quality management have become the focus of construction company. The tools of visualization and 6S are the comprehensive LC techniques which complex cost, quality and schedule of the project, have widely used in construction company because of its strongly operability. The tools of JIT and LPS are the LC techniques concerned with the project schedule. Take account of the actual situation of the construction project, the duration of the project is affected by many uncertain factors. Therefore, the implementation of LC techniques related to project schedule has lower maturity level.

The correlation coefficient between LC and individual performance indicates that, LC has a positive impact on individual performance. In terms of task performance, the most effective LC technique is 6S, which means that promoting the implementation of 6S has the most obvious impact on job-related behaviors. For the contextual performance, the most effective LC technique is visualization tools, that means, improving the visualization of project site can promote psychological and social context. Combined with the maturity of implementation of LC techniques, TQM has the highest maturity and has the greatest impact on individual performance, while LPS has the lowest maturity and has the least impact on individual performance. Therefore, it can be concluded that the maturity level of LC techniques has relationship to the individual performance; Different LC technique has different impact on task and contextual performance. The supervisors should choose suitable LC tools to improve individual performance, instead of implementing blind.

CONCLUSION

In this paper, five LC techniques were selected to investigate, including the maturity of implementation, and the relationship between LC techniques and individual performance. The data were obtained by questionnaires and analyzed by SPSS software. The research showed that LC techniques could positively promote the two dimensions of individual performance, and the maturity level of implementation of LC techniques affects the effect degree of LC implementation of individual performance. The results provide theoretical support for the selection of appropriate LC techniques for construction company.

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TARGET VALUE DESIGN IN REAL ESTATE MARKET: A CONCEPTUAL MAP MODEL

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ABSTRACT

The Target Value Design (TVD) approach has been successfully used mainly in healthcare projects, delivering products with higher added value in the users´perspectives, and mainting the projects targets and stakeholders expectations under control. However, the use of this approach in other contexts, such as the real estate market, has been little explored. Therefore, there is an opportunity to deepen the discussion of the adoption of the current TVD benchmark in the real estate market. For these reasons, this work sought to (i) elaborate a conceptual map with the elements of the TVD, offering a graphic and visual insight to ease the integration of concepts and its associations, as well as classifying concepts, tools, catalysts, and ii) insert, in this Conceptual Map, particular externalities of the real estate market context through the methodological approach of Design Science Research. In this way, this work contributes to a discussion of the adoption of the TVD in other contexts, bringing an organization of the practices from its original benchmark.

KEYWORDS

Target value design; conceptual map, real estate

INTRODUCTION

The construction sector coexists with the conception of complex products and has some peculiar characteristics, inherent to their environment (Koskela, 1992). In such a context, there is a number of variables that influence the design process, such as: cost and schedule constraints, stakeholders from different areas of knowledge and a highly fragmented design process. In Brazil, in addition to the characteristics mentioned above, the construction sector counts with adversarial relationships, where private agendas often overlap the interests of the product as whole and where a collaborative environment is unusual and achieving it effectively can be quite challenging (Oliva, 2014; Melo and Granja, 2017; Neto, Costa and Ravazzano, 2018). On the other hand, the Target Value Design (TVD) consists of a proactive approach to cost management, encouraging collaboration among the stakeholders, and positioning costs and the value perspective for the end user as drivers of

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the design process. (Ballard and Reiser, 2004; Macomber, Howell and Barberio, 2007; Ballard, 2011).

Evidences from the literature show that TVD has been successfully adopted in the construction sector, promoting collaboration between the teams involved in the design process (architects, complementary designers, contractors, suppliers, customers), adding value to the product, launching them faster and with the budget under control (Denerolle, 2013; Do, Chen, et al., 2014; Do, Ballard and Tillmann, 2015; Melo, Doahn, et al., 2015). In the USA, where TVD was first conceived, these concepts have been applied efficiently, reducing costs and adding value to products, particularly in the healthcare environment (Ballard and Reiser, 2004; Macomber, Howell and Barberio, 2007; Rybkowski, Munankami, et al., 2011; Zimina, Ballard and Pasquire, 2012; Denerolle, 2013);(Do, Chen et al., 2013), energy efficiency retrofit projects (Lee, 2012), schooling (Ballard and Reiser, 2004) and have been mentioned even in less collaborative environments or with more adverse characteristics (Denerolle, 2013; Melo, Doahn, et al., 2015).

However, successful cases of application in other contexts and situations have been little explored, due to the specificities of development of certain types of products in the sector. Specifically, the potential of the use of TVD in the development of products with units for sale in the real estate sector has been little discussed so far (Oliva, 2014, Oliva and Granja, 2015; Neto, Costa and Thomas, 2016; Oliva et al., 2016) .This context, mainly in Brazil, presents some challenging characteristics for a TVD adoption, since its philosophy presupposes collaborative relationship and setting the cost of the product as a driver for the design process.

In the real estate market, some restrictions are imposed from an environment outside the business case itself, unlike the traditional applications of the TVD, where these restrictions are defined mainly in the internal domain of the project. One of such external imposed restriction is the price of the selling unit, which is defined by the benchmark in the real estate market, influenced by the existing demand for similar products. In addition, this price must be set according to how much a potential buyer is willing and able to pay to obtain certain benefits offered by such a product.

Besides the need for an adaption for real estate market use, the TVD approach according to its current benchmark (Ballard, 2011) proposes 17 elements, which range from tools and techniques to concepts and constructs. Therefore, there is a research opportunity for clarifying and extending the existing current benchmark of TVD for possible adoption in the real estate market, observing its implications. Therefore, the aim of this paper is to propose an extended conceptual map model for TVD adoption in the development of products with units for sale in the real estate market.

CONCEPTUAL MAPS

Considering a qualitative study, the development and use of a new theory may pose some obstacles for common uderstanding. In order to clarify the understanding of a new theory, several tools can be used, such as the Conceptual Maps (CM) (Maxwell, 2012). The CM was developed primarily by Joseph Novak (Maxwell, 2012) in order to understand how students learned and later it became a learning tool.

The CM for a given theory represents a visual structure that explains graphically what is being studied (MAXWELL, 2012). It is a tool that assists in the development and presentation of a conceptual structure in a visual form of a theory, and are formed by two parts: first, concepts, contained in boxes or circles, and second, the relations between these theoretical concepts. In addition, it also presents the so-called connectors, words that link concepts and express relationships between them (Novak and Cañas, 2008).

The CMs can be created for a variety of purposes, such as: (i) Adding and making visible implicit information contained in existing theories or clarifying an existing theory, allowing to observe the implications of such a theory and its limitations and (ii) To develop theory as a way of "putting on paper," assisting in the observation of unexpected connections or to identify gaps or contradictions in a given theory and helping to find solutions for these issues (Maxwell, 2012).

RESEARCH METHOD

This work used the Design Science Research (DSR) as a research strategy. When observing traditional sciences, such as the natural and social sciences, these present results that seek to explain, describe, explore or predict phenomena and their relations (Dresch, Lacerda and Júnior, 2015). However, when the objective of the research is to study a project, the construction or creation of a new artifact, or, in the case of works dedicated to problem solving, the field of traditional sciences presents limitations. In this case, DSR can be more adequate for this type of research (Dresch, Lacerda and Junior, 2015). The researches that best fit the DSR methodology are usually studies that search for: problem solving, innovations, methods, models, product and process improvements (Koskela, 2012). In general, this type of research contains verbs such as design, build, change, improve, develop, enhance, correct, adapt, adapt, extend, introduce (Jarvinen, 2004).

The literature review points out that the TVD approach, has efficiently applied in healthcare context (Ballard e Reiser, 2004); (Macomber, Howell e Barberio, 2007); (Rybkowski, Munankami, et al., 2011); (Zimina, Ballard and Pasquire, 2012); (Denerolle, 2013); (Do et al., 2014). However, some externalities wield influence in the product development process for the real estate market situation, which need to be considered. In addition, the current TVD benchmark does not structure its elements into various levels of abstraction, such as concepts, techniques, tools and catalysts. CM as an artifact can ease the understanding of the different elements of the TVD benchmark according to the various levels of abstraction and their associations as well. This levels of abstraction classification has the main advantage of helping to clarify the understanding of management approach, especially in contexts in which the TVD is not yet applied, where the mindset still deals with tradictional management technicques. Furthermore, adding to the CM the externalities inherent of the context of the real estate market can provide revealing insights for the possible adoption of TVD in this situation.

The CM proposed underwent several evaluation cycles with so-called focus groups. In DSR, focus groups represent one of the tools for evaluating the artifact (Dresch, Lacerda and Junior, 2015). The use of focus groups (FG) allows for a more in-depth and collaborative discussion about the artifacts, and allows the combination with other techniques, as well as presenting low cost and supply of valid and reliable data (Dresch, Lacerda and Júnior, 2015; Trad, 2009). This approach allows the critical analysis of the outcomes of the work and creating possibilities for new and better solutions to the problem. The research FG gathered four academics with great knowledge and research on TVD, as well as related topics such as Lean, Target Costing and Integrated Project Delivery.

TVD CONCEPTUAL MAP

DEFINING THE CONCEPTS, TOOLS AND CATALYSTS

The next stage of CM construction, a classification was proposed, using as reference the TVD Benchmark (Ballard, 2011) and the basis of the three groups proposed by Denerolle (2013) (in this study, the author classifies the TVD benchmark into three categories: organization, defining and steering), with some adaptations to enable the construction of the CM. By analyzing each one of the 17 points of the TVD, three categories were proposed: Definition (in terms of viability), Organization (in terms of behavior and communication) and Organization (related to commitment).

The first group, Definition (viability), brings the elements of TVD related to the feasibility study, which have great importance in the process. It originates cost, scope, schedule and constraints of a new product and the alignment between means, ends and constraints is sought, in addition to the early involvement of stakeholders in the business case, assigning goals to those involved and establishing the constraints of the product.

The second group, Organization (behavior and communication), brings together the elements related to the understanding the product, seeks collaborative work among those involved and the facilitation of the exchange of information between the stakeholders during the product development process. The objective is to align the behavior of those involved in a collaborative way, often through incentive agreements and partnerships, and seek efficient communication among all, to meet the targets set in the definition phase, always looking to achieve the established value expectations.

The last group also refers to the Organization, but in terms of commitment of those involved in the process. This commitment takes place in the sphere of established targets, especially costs and schedule, and the commitment of the teams in the efficiency, decision making in different project solutions, and controlling all the constraints.

A second phase of this construction allowed us to identify the main constructs for insertion into the CM, through the elements: what / how / stakeholders / objectives and their relations. This evaluation was performed for each elements of the TVD. Finally, the catalysts and/or related tools for each element (if any) are pointed out. This organization can be seen in Frame 1 below.

Concepts for Conceptual Map Insertion						
What	How	Stakeholders	Objetive	Element Description (Ballard, 2011)	Main Concepts	Tools and Catalists
DEFINITION (FEASIBILITY)						
Feasibility Study						
Feasibility study is performed prior to the start of product development process				With the help of key service providers, the customer develops and evaluates the project business case and decides whether to fund a feasibility study; in part based on the gap between the project's allowable and market cost	Analisys and realization of feasibility study.	---
	Feasibilit study is developed through parameters, such as: purposes, means and restrictions			The business case is based on a forecast of facility life cycle costs and benefits, preferably derived from an operations model; and includes specification of an allowable cost—what the customer is able and willing to pay to get life cycle benefits. Financing constraints are specified in the business case; limitations on the customer's ability to fund the investment required to obtain life cycle benefits	Cost and post- occupancy value	---
				Feasibility is assessed through aligning ends (what's wanted), means (conceptual design), and constraints (cost, time, location, ...). The project proceeds to funding only if alignment is achieved, or is judged achievable during the course of the project.	Ends, means and constraints alignment	---
		All stakeholders		The feasibility study involves all key members (designers, constructors, and customer stakeholders) of the team that will deliver the project if the study findings are positive.	Early involvement of all stakeholders	---
			Produces a detailed budget and schedule, aligned with scope	The feasibility study produces a detailed budget and schedule aligned with scope and quality requirements	Detailed needs	---

Figure 1: TVD Concept Map Organization

Concepts for Conceptual Map Insertion						
What	How	Stakeholders	Objetive	Element Description (Ballard, 2011)	Main Concepts	Tools and Catalists
ORGANIZATION (BEHAVIOR AND COMMUNICATION)						
Common understanding of scope and value of the product						
Scope evaluation and understanding				All team members understand the business case and stakeholder values	Joint understanding of product's scope and value	—
		Client		The customer is an active and permanent member of the project delivery team.	Client involviment/ Active client	Post Occupancy Evaluation (POV), Value Engineering, Value Hierarchy (tools)
		Stakeholders	Intensify communication and make faster decision making	Co-location is strongly advised, at least when teams are newly formed. Co-location need not be permanent; team meetings can be held weekly or more frequently.	Partial Co-location	Co-Location (catalist), Evaluation (POV), Value Engineering, Value Hierarchy (tools)
			Interests and targets alignment	Some form of relational contract is used to align the interests of project team members with project objectives.	Use of multi-party contracts/establishment of contractual agreements	Multi-party contracts (catalist)
			Schedule and activities accuracy	The Last Planner system is used to coordinate the actions of team members	Short-term control tools	Last Planner (catalist)

Figure 1: TVD Concept Map Organization (cont.)

Concepts for Conceptual Map Insertion						
What	How	Stakeholders	Objetive	Element Description (Ballard, 2011)	Main Concepts	Tools and Catalists
ORGANIZATION (COMMITEMENT)						
Non-extrapolation of targets and deadlines						
Commitment to desired targets				A cardinal rule is agreed upon by project team members – cost and schedule targets cannot be exceeded, and only the customer can change target scope, quality, cost or schedule	Commitment to the contractual requirements "costs and schedule"	—
	Target, scope and cost allocation among different teams			Target scope and cost are allocated to cross-functional TVD teams, typically by facility system; e.g., structural, mechanical, electrical, exterior, interiors, ...	Target and cost allocation among teams	Budget reports (tool) e BIM (catalist)
	Joint evaluation of design alternatives			The cost, schedule and quality implications of design alternatives are discussed by team members (and external stakeholders when appropriate) prior to major investments of design time	Design solution evalutions	CBA, A3, Set basd design (tools)
	Costs allocation and control for each team			The project cost estimate is updated frequently to reflect TVD team updates.	Cost control by services	Budget reports (tools) e BIM (catalist)
	Cost estimating updates			The project cost estimate is updated frequently to reflect TVD team updates. This could be a plus/minus report with consolidated reports at greater intervals. Often project cost estimates are updated and reviewed in weekly meetings of TVD team coordinators and discipline leads, open to all project team members.	Frequent cost update	Budget reports (tools) e BIM (catalist)
		All stakeholders		Cost estimating and budgeting is done continuously through intimate collaboration between members of the project team—'over the shoulder estimating'	Interaction and general cost control	—
			Spur innovation through challeging targets	Targets are set as stretch goals to spur innovation.	Incentives for innovative ideas	—

Figure 1: TVD Concept Map Organization (cont.)

In addition to the organization of the elements of the TVD benchmark, we sought to couple in the Conceptual Map the externalities inherent to the real estate market context. Previous studies (Oliva, 2014; Oliva e Granja, 2015; Melo et al, 2015), have shown that these externalities are mainly related to: (i) fierce competition through the offer of similar products by competitors in this type of context; (ii) launch time for new products in general is very long in these companies, causing loss of competitive advantage; (iii) there is difficulty in capturing and understanding the value perspective of this final customer, considering that its client is external to the process and (iv) in the real estate market, the price of the product is defined externally, due to market pressures. Those researches collected data with several practioners in the real state market context, and they were used as basis for the main externalities proposed in the map, that are often highlighted by those professionals.

After de analisis of Figure 1, the Final Conceptual Map turned into the following configuration, as Figure 3 shows.

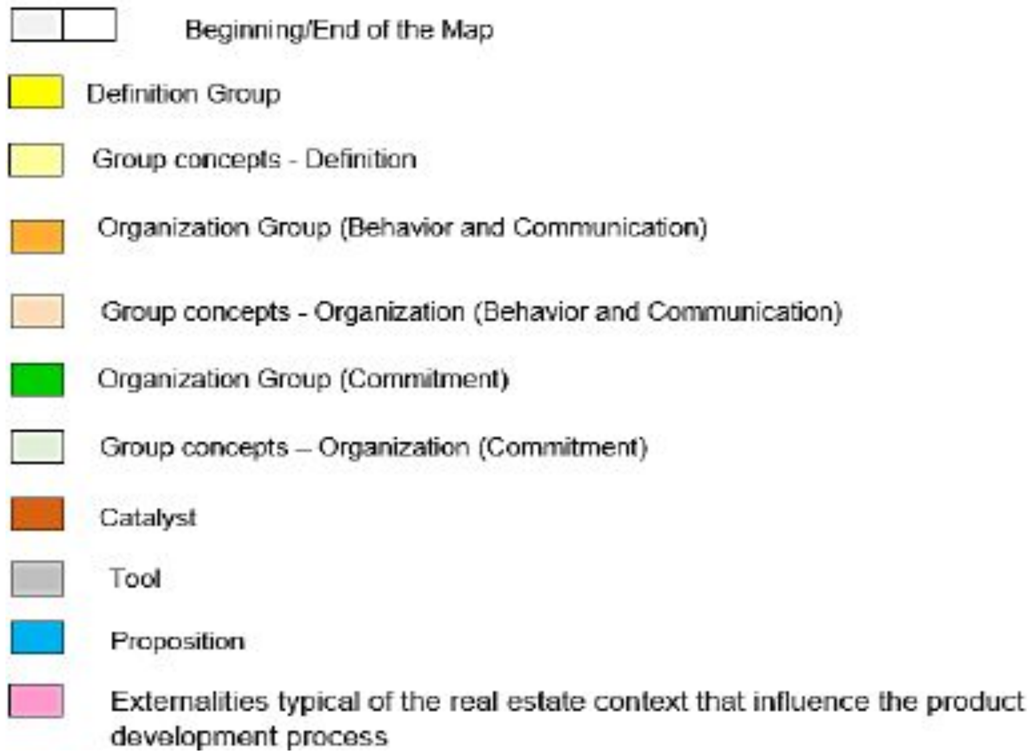

Figure 2: Captions for Conceptual Map

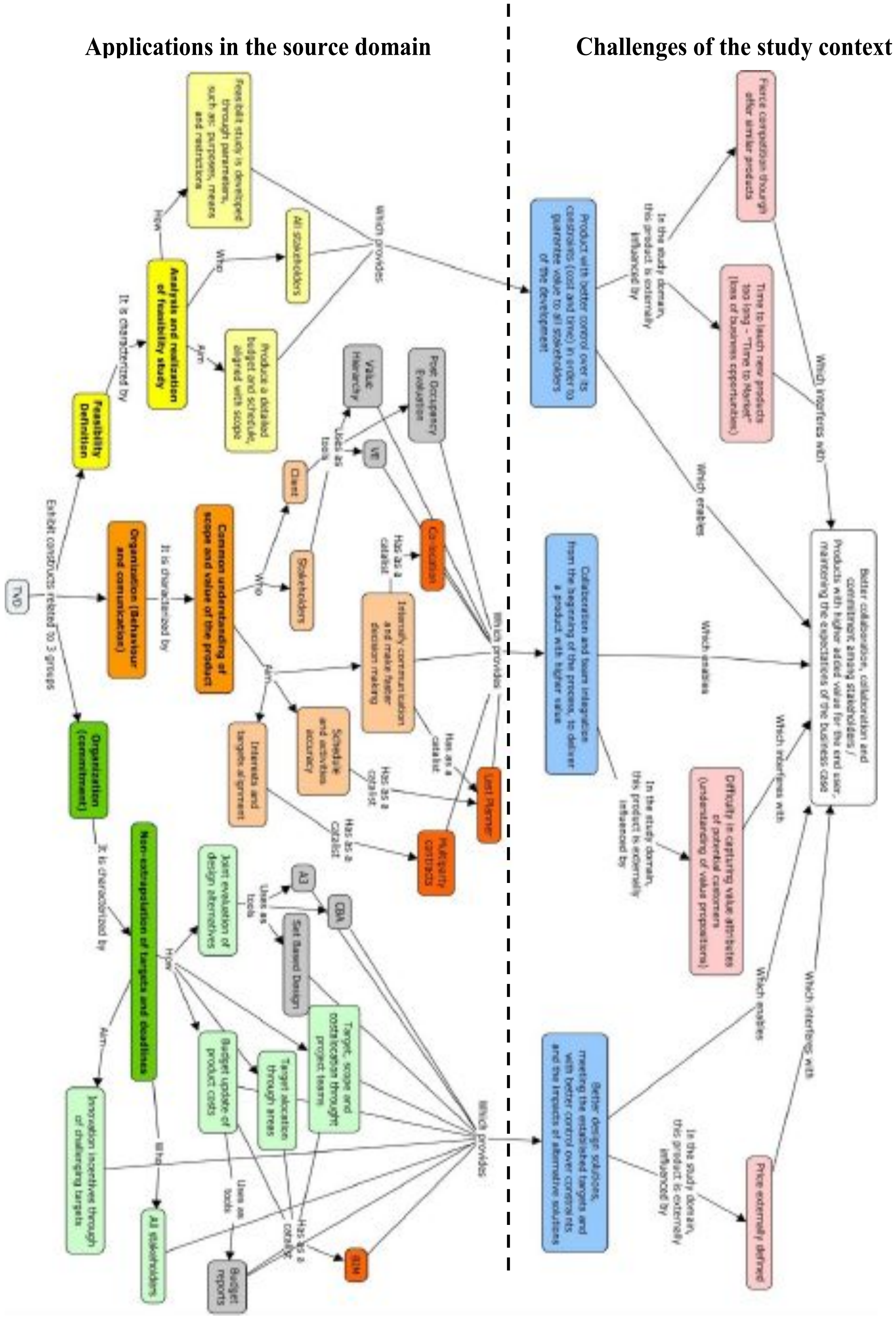

Figure 3: TVD Conceptual Map for the Real Estate Context

CONCLUSIONS

The research has deepened the discussion of the adoption of the current TVD benchmark in the real estate market.The construction of a conceptual map as an artifact has started by identifying the constructs that would be part of the map and has established relationships between them. For this reason, the first step has involved identifying and classifying the constructs present in the current TVD benchmark, establishing relationships to enable the construction of the map, where the interaction with the focus groups was essential to obtain the CM. It was necessary to identify principles, catalysts, tools, objectives, parties involved. This is highlighted as the first result of the theoretical work.

After the organization and classification of the constructs, the elaboration of the conceptual map took place, which has allowed a graphic visualization of the elements of the TVD and the relation between them, as well as the propositions for which they were intended. In addition, the peculiarities inherent to the study context were inserted, especially the externalities which influence the process of developing products with units for sale in the real estate context. In addition, searching the literature, the authors couldn´t find any precursors proposing new collaborative practices through a visual structure such as a conceptual map.

The main contributions of this research were the following: (i) Classification of the TVD benchmark concepts into groups and associations between them ; (ii) Proposal with elements of TVD adapted to the real estate context with inclusion of externalities characteristic of the real estate, which directly influence the product development process and (iii) Results of the organization and relationships between the constructs, which represent the results that each set of constructs can achieve, and how these propositions aim at the final goal of the adoption of the TVD.

The authors acknowledge that the size of the focus groups proposed (with 4 partcipants) can be a limitation for the proposed conceptual map. Nevertheless, the results can be highlited as a first attempt to organize the TVD approach into a more conceptual and graphic structure, considering the particularities of a new context of application.

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