RESEARCH CONFERENCE PROCEEDINGS

(Volume 1 of 2)

ISSN 2309-0979

International Group for Lean Construction (IGLC)

IGLC27 – Dublin, Ireland, 3rd – 5th July 2019

Leadership, Culture and Teambuilding

http://iglc2019.com/

Editors

Christine Pasquire & Farook Hamzeh

Conference Chair

Paul Ebbs

Foreword

The 27th Annual Conference of the International Group for Lean Construction is a milestone event because we see Ballard & Howell re-united on a public platform for one last time. It doesn't take a new Lean Construction researcher very long to uncover the enormous contribution Glenn and Greg have made to both the IGLC and to the field of Lean Construction worldwide. The inclusion of authors from 27 countries in the conference proceedings is testament to this along with the numerous Lean Construction groups around the world spawned from their original Lean Construction Institute (LCI) model founded over 20 years ago. This model recognises the importance of integrating Universities with industry to create and share knowledge and practice, advancing the performance of the construction sector as the fundamental provider for human existence. The 'value driven proposition' that is delivered by the principles of lean thinking. The importance of a vision beyond the reductionist view of cutting waste to reduce cost is clearly supported by an increase in the number of papers submitted this year that focus on value, sustainability and human factors.

This year we chose not to call for abstracts proceeding straight to the submission of completed papers and received 157. Following a double, blind review 127 papers were accepted for publication, 26 were rejected and 4 didn't resubmit. The accepted papers represent 27 countries and 5 continents. The 27 countries include (in alphabetical order): Australia, Brazil, Canada, Chile, China, Colombia, Denmark, Finland, France, Germany, India, Ireland, Israel, Italy, Lebanon, Malaysia, Mexico, Netherlands, New Zealand, Norway, Peru, Slovenia, South Africa, Switzerland, Taiwan, UK, and USA. Table 1 shows a summary of the accepted papers sorted by country and number of published papers.

Table 1: Papers accepted to IGLC2019 by country of first author's institution

Country	Papers published	Country	Papers Published
Norway	20	Israel	2
USA	17	Italy	2
Brazil	12	New Zealand	2
UK	12	Peru	2
Germany	10	China	1
Finland	9	France	1
Lebanon	9	Malaysia	1
India	4	Mexico	1
Australia	3	Netherlands	1
Chile	3	Slovenia	1
Colombia	3	South Africa	1
Denmark	3	Switzerland	1
Ireland	3	Taiwan	1
Canada	2		
		Total	***127***

The conference chairs would like to acknowledge the efforts of the international experts for committing time to reviewing these papers. We thank them for their efforts to ensure that the papers accepted for this conference were of a high standard. We would also like to thank the authors for addressing the reviewers' comments and improving the quality of their submissions. We made some subtle changes to the process firstly by providing more guidance on the review form and secondly by refusing to accept inferior papers because they were from "industry" or as posters. All accepted papers are worthy of publication in the proceedings showing that industry people can (of course) write good quality research papers! The improved submission quality has enabled us to choose 15 plenary papers worthy of presentation to the entire IGLC forum. These papers are also identified within the proceedings as plenary papers and all have been offered the opportunity to be included in a Special IGLC Edition of the “Frontiers of Engineering Management” – a leading Chinese Journal signifying the awakening of this country to the opportunities of Lean Construction and the importance of the IGLC as the leading body of knowledge.

Additionally, we extended the list of themes in order to better reflect the growing facets of the field allowing extended reference lists to reflect a growing trend for systematic literature review. The breakdown of papers received is shown in Table 2:

Table 2: Papers submitted by theme

Theme	**Number of Papers**	**Theme**	**Number of Papers**
Contract and Cost Management	9	People, Culture and Change	22
Enabling Lean with IT	6	Product Development & Design Man	13
Language Action Perspective	2	Production Planning and Control	18
Last Planner System	7	Production System Design	6
Lean and BIM	11	Safety, Quality and Health	6
Lean and Sustainability	5	Supply Chain Management & OSM	4
Learning & Teaching Lean	9	Theory	9

A significant move towards the softer issues of lean construction can clearly be seen with People, Culture & Change now forming the largest theme. Production Planning and Control is the next largest and although the Last Planner System holds a significant chunk on its own it can be argued that this concerns social-technical issues and so spans both of the first two themes. Information Technology is the third major theme with Enabling Lean with IT and Lean and BIM combined equalling Production Planning and Control. We didn’t use these themes to organise the conference programme choosing to organise papers around the ideas and subjects that the authors have themselves chosen. We intended to select papers that best represented applied research with direct industry relevance for the Wednesday, middle distance research showing work still needing to be developed and tested for the Thursday and more blue skies or theoretical work for the Friday. Whilst this worked to a degree, the applied nature of the field means the distinction between these types of research are blurred and a little horizon scanning is included in both the Wednesday and Thursday sessions.

We look forward to an exciting conference tinged with sadness because Glenn Ballard and Greg Howell are finally retiring, filled with gratitude for their contribution and looking forward to their legacy fulfilled by the work of the next generation.

Welcome to IGLC2019 in Dublin, Ireland!

Christine Pasquire & Farook Hamzeh

Your IGLC2019 Technical Chairs and Proceedings Editors

Acknowledgements

IGLC2019 Organising Committee

Conference Chair: Paul Ebbs

Technical Chairs: Christine Pasquire & Farook Hamzeh

Summer School Deans: Emmanuel Daniel & Ritu Ahuja

Research Conference Programme Development

Nottingham Trent University, UK

American University of Beirut, Lebanon

Editorial Assistant

Sa'id Ahmed Namadi

Research Conference Sponsorship

Best Paper Prizes sponsored by Frontiers of Engineering Management Journal, China

Special IGLC Journal Edition sponsored by Frontiers of Engineering Management Journal, China

Conference Management, Marketing & Media Services provided by Box Media, Ireland

TABLE OF CONTENTS

VOLUME 1:

FOREWORD AND ACKNOWLEDGEMENTS

VOLUME 2

PLENARY PAPERS (1)

Power, W. and Taylor, D. (2019). "Last Planner® System and Planned Percent Complete: An Examination of Individual Trade Performances." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 1–12. DOI: https://doi.org/10.24928/2019/0164 . Available at: <www.IGLC.net>.

LAST PLANNER® SYSTEM AND PLANNED PERCENT COMPLETE: AN EXAMINATION OF INDIVIDUAL TRADE PERFORMANCES

William Power[1] and Darrin Taylor[2].

ABSTRACT

There is a dearth of research on Lean in the Irish construction sector and on the application of Lean thinking and practices on live capital projects. Lean Construction (LC) is recommended as an antidote to productivity issues encountered on capital project delivery. Last Planner® System (LPS) is a key tool of LC, and high Planned Percent Complete (PPC) achievement is positively correlated to increased productivity. This study examines individual trades' differing PPC performances on two overlapping capital projects; it considers explanations for those differences; and it identifies areas for improvement to enhance PPC on future capital projects. LC-driven contractor selection, early trades engagement in the design process, implementation of all functions of LPS, Lean education and training, increased modularisation and prefabrication, and embracing technological advances are posited as areas for focused improvements.

KEYWORDS

Lean Construction, LPS, Collaboration, Workflow, PPC, Mindset, Ireland.

INTRODUCTION

Upon completion of a part-time executive master's programme in Lean, the lead author has applied Lean thinking and practices within his employer organisation, as well as on its capital projects, and collected data and other information at the gemba as part of ongoing research development in collaboration with his academic partner. This study emanates from the latter applied research on Lean Construction (LC) and Last Planner® System (LPS) on two overlapping EPCMV (Engineering, Procurement, Construction Management, Validation) Projects ("Project A" and "Project B").

BACKGROUND AND CONTEXT

Construction is a dynamic and critical economic sector globally, however, it struggles to add value to its clients, it remains fundamentally inefficient, and it faces a "productivity imperative" (McKinsey 2017). Other economic sectors have transformed their efficiency

1 Productivity & Performance Manager, DPS Group, 4 Eastgate Avenue, Eastgate Business Park, Little Island, Co. Cork, Ireland, +353 21 7305000, willie.power@dpsgroupglobal.com

2 Principal Lead, Academy of Lean Enterprise Excellence, RIKON Centre, School of Business, Waterford Institute of Technology, Waterford, Ireland, +353 51 834129, dtaylor@wit.ie

using Lean (Hines *et al.* 2018). However, construction productivity has remained stagnant or regressed, and thus the sector has looked to LC as an antidote to the ills of the sector (Koskela 1999) and as a means of delivering the requisite value that clients have been long-demanding (Koskela 1992; Ballard 2000; Hamzeh *et al.* 2009).

A key concept in LC is the provision of reliable workflow to the teams to reduce uncertainty in the delivery process (Ballard 2000). LPS is a key waste elimination and variability reduction technique that addresses that uncertainty (Hamzeh *et al.* 2009).

Whilst much has been written on LPS over the past 25 or more years, there appears to be a dearth of research that investigates the performance of individual trade contractors and their respective and collective contributions to the weekly plus overall project PPC. This study explores PPC across two Projects; it examines commonalities and differences between relevant trades' PPC; and it identifies areas of improvement for implementation on future projects.

LITERATURE REVIEW

LEAN CONSTRUCTION

Koskela (1992 p.64) challenged the construction sector to apply extant Lean production thinking and practices, positing that Lean '… contains a promise of tremendous possibilities for improvement and of a solution of the chronic problems of construction'. Ballard was at the same time developing what became known as the "Last Planner System of Production Control" (Ballard 2000). Koskela's development of the theory and more holistic approach, alongside Ballard and Howell's tools, extended Lean into construction (Ballard *et al.* 2007).

Early LC researchers recognised that Traditional Construction Project Management (TCPM) was unable to cope with the increasingly more complex and dynamic projects clients were demanding to be delivered. Construction needed to adopt a productivity mindset, and Koskela's Transformation-Flow-Value (TFV) theory integrated the successful qualities of Craft, Mass, and Lean Production concepts (Abdelhamid and Salem 2005), thus creating a comprehensive theory of production management for construction.

TFV focuses on reducing lead times and minimising variability whilst simplifying on-site and off-site processes (Koskela 1992). TFV also promotes pull concepts and continuous improvement of the delivery process (Koskela 1999). The value view of TFV theory considers voice of customer (VOC) by emphasising delivery of what is considered valuable from the customer's, and crucially the next-customer's, viewpoint (Koskela 2000; Ballard *et al.* 2007).

Accordingly, specific tools were developed for LC, namely Target Value Design (TVD), the Lean Project Delivery System (LPDS), and LPS (Howell and Koskela 2000).

LAST PLANNER® SYSTEM

LPS is central to the implementation of LC and requires continuous and collaborative effort from all stakeholders in a production planning and control system to reduce variability whilst enhancing reliability and predictability in construction workflows (Hamzeh and Bergstrom 2010; Howell *et al.* 2010). This differs to the TCPM approach of directing and adjusting after the occurrence (Koskela and Howell 2002) and the assumption that variability in workflow lies outside the control of management.

LPS was developed from research into productivity improvement, with Ballard and Tommelein (2016 p.59) positing that ‘the inspiration for LPS was the discovery of chronically low *workflow reliability* in construction projects’. Ballard *et al.* (2009) summarise the ‘principles’ underlying LPS as follows:

i. Plan in greater detail as you get closer to doing the work.
ii. Produce plans collaboratively with those who will do the work.
iii. Reveal and remove constraints on planned tasks as a team.
iv. Make and secure reliable promises.
v. Learn from breakdowns.

There is a dearth of research on LPS vis-à-vis how each trade contributes towards the overall PPC which measures the percentage of tasks completed relative to those planned. However, Ballard and Tommelein (2016 p.60) assert that ‘…from the perspective of continuous improvement, LPS’s job is to stabilise operations so they can be further improved, both individually and in the processes which they comprise, but it also improves productivity. Many, perhaps most, people are satisfied with that and don’t exploit the opportunity for more fundamental improvement in performance’.

PPC is a key metric of LPS and measures workflow reliability – a high PPC indicates a well-planned production process with tasks screened in advance, ensuring high workflow reliability between teams (Ballard 2000). However, Ballard and Tommelein (2016 p.59) warn against placing too much focus on PPC figures, stating ‘…PPC could be 100%, productivity excellent, and a project still be falling behind schedule’. This emphasises the importance of using all functions of LPS to ensure PPC and productivity are linked to the overall milestone schedule (Hamzeh *et al.* 2009). As PPC is positively linked to productivity (Liu *et al.* 2010), it is critical for LPS users to ensure that the trades teams executing the work are afforded the greatest opportunity of achieving high PPC.

Howell and Ballard (1994) advise reducing workflow variation by stabilising all functions through which work flows, from concept to completion. Whilst Hamzeh *et al.* (2009) posit formalising the planning and production operations process on the construction project. Ensuring consideration of the eight prerequisite flows (Koskela 2000; Pasquire and Court 2013) to make the right tasks sound is an essential element of LPS: ‘Progress rises and falls with PPC to the extent that tasks are made ready in the right sequence and rate’ (Ballard and Tommelein 2016 p.60).

Understanding the Reasons for Non-Completion (RNC) of tasks will enable future improvement of the planning process (Liu *et al.* 2010) as it provides teams with trends which can be used to develop strategies to prevent re-occurrence of the same failures in the future (Ballard and Tommelein 2016).

METHODOLOGY

Mixed-methods were adopted encompassing a critical literature review, site documentation data-analysis, focus groups, and semi-structured purposeful interviews (Creswell 2013). The first author acted as lead researcher in his capacity as LPS Facilitator on both Projects. The mixed-methods approach helped to minimise bias as both the quantitative and qualitative models have individual weaknesses which can be compensated by the comparative strengths of the other methods (Steckler *et al.* 1992) and such triangulation enhances the depth, quality, and validity of the research findings (Bogdan and Biklen 2006).

A sequential explanatory approach (Creswell 2009) was utilised, with the quantitative data being collected weekly as the Projects proceeded and the qualitative data being gathered after Projects were completed. As per Creswell *et al.* (2003), priority was given to the quantitative data as this was analysed and then connected to the next stage by selection of methods and participants best-suited for the follow-up qualitative data collection phase (Creswell 2009). The analysis of the data informed the secondary data collection process (Creswell 2009) which is useful when unexpected results arise from a quantitative study (Morse 2003).

Table 1 provides an overview of the three focus groups which comprised site construction management team (CMT), trades' Last Planners, and senior operations management; as well as the purposeful sample of seven interviewees representing senior management of the key trades contractors.

Table 1: Qualitative Research Sources

Source	Project & Participants
Focus Group 1	Project A (n6) – CMT (2); Trades Last Planners (3); Director Steel/Roofing/Cladding
Focus Group 2	Project B (n7) – CMT (4); Trades Last Planners (3)
Interviewee A	Project A – Mechanical (M) & Electrical (E) Project Manager
Interviewee B	Project A – Civil, Structural & Architectural Project Manager
Interviewee C	Project A – Cleanroom Project Manager
Interviewee D	Project B – Mechanical Project Manager
Interviewee E	Project B – Electrical Project Manager
Interviewee F	Project B – Civil, Structural, & Architectural Director
Interviewee G	Project B – Cleanroom Project Manager
Focus Group 3	Projects A & B (n7) – Senior Operations Management

Unique sources were sought to increase validity and to provide a wider perspective. Focus group sessions were conducted on both Projects to gather the opinions of the trades' Last Planners on the challenges and opportunities for improvement in LPS implementation. The qualitative findings were transcribed, then analysed using a thematic analysis approach and organised into different themes (Braun and Clarke 2006). Inferences drawn from the emerging themes were checked by triangulation against the literature review findings to check their reliability and integrity (Steckler *et al.* 1992). In accordance with Creswell (2009), the research is presented as two distinct findings sets, with the quantitative findings directing the qualitative research.

The following research questions were posed:

1. *What differences exist between individual trades' PPC?*
2. *How can these differences be explained?*
3. *What areas of improvement can be implemented on future projects to enhance PPC?*

FINDINGS

In summary, data in the form of PPC and RNC was collected weekly on both Projects, accumulating to 69 weeks of data for Project A and 58 weeks of data for Project B.

QUESTION 1: WHAT DIFFERENCES EXIST BETWEEN INDIVIDUAL TRADES' PPC?

To address question 1, we examined the quantitative PPC data that was retained on both Projects for the duration of each trade's presence, and their average PPC is presented in Table 2.

On Project A, there was a noticeable gap in the average PPC between the CSA, Steel/Roofing/Cladding, and Cleanroom trades on one end, and the M&E and Sprinkler trades on the other end. CSA were on site for almost twice the duration of other trades and they committed 43% of the work tasks to the weekly work plan (WWP). Steel/Roofing/Cladding, despite completing only 15% of the work tasks, achieved 80% PPC. M&E and Sprinkler, achieved 91-92% PPC each on a combined 40% of the work tasks. It is noteworthy that the M&E company and Sprinkler company on Project A were knowledgeable and practiced in LC.

Similar gaps were evident on Project B. The CSA were longest on site, completing 29% of tasks and achieving 80% PPC. Mechanical (90%) and Electrical (89%) were the highest PPC achievers with 23% and 22%, respectively, of total tasks committed to the work plan. The M&E companies on Project B (different to that on Project A) were also knowledgeable and practiced in LC. However, the Sprinkler company on Project B – a locally-based incumbent contractor – had a poorer PPC performance, and it is noteworthy that it was neither knowledgeable nor practiced in LC.

Table 2: Individual Trades' Duration on Projects and Average PPC

Trades	Project A			Project B		
	Weeks on Project	Average PPC	Per Cent of Total Project Tasks	Weeks on Project	Average PPC	Per Cent of Total Project Tasks
CSA	69	84%	43%	58	80%	29%
Cleanroom	27	86%	2%	54	84%	22%
Steel/Roofing/Cladding	54	80%	15%	45	72%	2%
Mechanical	34	92%	15%	54	90%	23%
Electrical	34	92%	21%	50	89%	22%
Sprinkler	40	91%	4%	46	79%	2%

In accordance with the sequential explanatory design strategy (Creswell, 2009) the key findings arising from the quantitative research are presented in Table 3.

Table 3: Summary of Key Quantitative Findings

Themes	**Findings**

Trade Contractor PPC	• M&E (different contractors on both Projects) achieved the higher PPC on both Projects A and B. • Sprinkler (different contractors on both Projects) achieved a high PPC on Project A and a lower PPC on Project B. • CSA (different contractors on both Projects) achieved a lower PPC than M&E on each Project. • Cleanroom (different contractors on both Projects) achieved a lower PPC than M&E on each Project. • Steel/Roofing/Cladding (different contractors on both Projects) achieved the lowest PPC on each Project.
PPC ranges	• M&E ranged between 92% and 89%. • CSA ranged from 84% to 80%. • Cleanroom ranged from 86% to 84%. • Steel/Roofing/Cladding ranged more widely from 80% to 72%. • Sprinkler had the greatest range from 91% to 79%.
RNC	On both Projects, “schedule/coordination”, “resource availability”, and “prerequisite work by others” were the top three RNC.

An analysis of the findings from the quantitative element of the study generated key points to take forward to the focus groups and semi-structured purposeful interviews.

QUESTION 2: HOW CAN THESE DIFFERENCES BE EXPLAINED?

As the quantitative research analysis determined a gap existed between individual trades’ PPC, we proceeded to conduct focus groups and interviews as we sought to address this question. Two focus group sessions were conducted with the trades’ Last Planners and members of the CMT from both Project A and Project B, and the key findings from those focus groups are presented in Table 4. We next combined the findings from those focus group sessions with the quantitative data findings and our analysis of pertinent literature, and this provided the basis for a deeper and more nuanced assessment to bring forward into the interviews (Table 5).

The M&E trades clearly performed the best on both Projects – with various companies providing the Mechanical and the Electrical services on each Project, and these companies being early adopters and practitioners of LC. Interestingly, the Electrical company on Project B also provided the Sprinkler services on Project A, which performed substantially better than the Sprinkler company on Project B which is not a practitioner of LC.

It is therefore our assessment that embedded LC knowledge and proven LPDS and LPS practice is *the* primary explanation for the differences in PPC experienced on both Projects studied.

Table 4: Key Focus Group Findings

Themes	Findings
Time required for, and	Lack of adequate trade management time to adequately plan WWP. No dedicated and trained Last Planner management resource.

commitment to, LPS	
Late receipt of WWP from trades	Much greater coordination is needed where trades overlap and late receipt of WWPs left little time for CMT supervision to proof and coordinate the plan.
Specialist resource availability	The local region is currently experiencing a construction boom in the Pharma sector, and availability of specialist resources was a major challenge for clients and management teams.
Not using all functions of LPS	Inconsistency of implementation of all functions of LPS. Project A successfully implemented all functions of LPS, while Project B experienced implementation issues due to its size and complexity.
Design-related issues	Incomplete design led to delays in resolving design-related constraints. Delayed appointment of trades meant a lack of trade involvement in early planning, scheduling, and design coordination decisions.

The key interview findings are presented in Table 5.

Table 5: Key Interview Findings

Interviewees	Findings
A B C E F G	M&E adopt a productivity-based and metrics-focused approach and mindset to construction delivery. CSA approach is more reactionary, with an acceptance of the peculiarities and traditional problems associated with construction work execution.
A C E G	The LC-practiced M&E contractors have developed management systems and structures enabling them to set their own agenda on a project, and they lead out their own design, schedule, and workflows. CSA appear to be under-resourced at site management level with immediate problem-solving prioritised over short- to medium-term planning.
A B C D E F G	Late and incomplete design, as well as contractors commencing on site in advance of design being sufficiently developed, had an impact on the smooth flow of work tasks. Early engagement of the M&E contractors in the design development process was considered a key advantage in maintaining reliable flow and contributing to higher PPC.
A B C G	Engagement with, and preparation for the LPS process, as well as using all functions of the system, is critical for successful project delivery. Poor lookaheads lead to inadequate preparation of workplans, resulting in missed tasks being categorised as ‘schedule/coordination’ and ‘prerequisite work by others’, impacting on other trades’ PPC.
A B D E G	Prefabrication and Modularisation offers distinct advantages by reducing onsite activities and the associated coordination issues.
A C D E G	The embracing of ICT advancements in construction software, allied to the utilisation of handheld applications and devices, enables more efficient solutions to data storage and acquisition.

Question 3: What areas of improvement can be implemented on future projects to enhance PPC?

A final focus group session involving EPCMV senior operations management was held to discuss and validate the research findings, and to identify areas for improvement that could be implemented on future projects to enhance individual trades’ PPC as well as the overall project PPC. Table 6 presents those identified areas for improvement.

Table 6: Areas of Improvement for Implementation on Future Projects

Areas	Findings
Procurement	Feature LC in prequalifications, tenders, and actual contracts. Contractor selection needs to be restricted to proven LC companies. Ongoing assessment systems should incentivise process excellence and continuous improvement.
Trades' Differences	Provide greater attention and involvement at design stage for CSA, Steel/Roofing/Cladding, and Cleanroom. Review contracting strategy to accommodate early appointment and involvement of these trades as early as possible, and engage them across the design process. No contractor should be permitted to commence on site without a clearly defined and agreed design in place. Develop a trust-driven, transparent, collaborative relationship amongst parties at design stage.
LC Training & Education	Deliver LC training and education to the client, the EPCMV team, and contractors to ensure a productivity-based and metrics-focused mindset is embedded amongst the construction delivery partners.
LPS Training & Education	Schedule more detailed LPS training and refresher courses into the project duration and have these supported by the client. Focus to be placed on enabling flow with the Tasks Made Ready (TMR) metric and the creation of sound, constraint-free tasks ahead of committing them to the WWPs.
Off-Site	Demand more off-site fabrication and assembly processes. Contractors should propose a greater variety of options, and clients should ensure modularisation is respected to avoid requirement for bespoke solutions.
ICT	Adopt site-wide technological solutions across all contractors to improve visualisation (BIM), process improvement (RFIs, punch-lists, submittals), planning and coordination (LPS software), and the efficient accessibility of project documentation (cloud-based platforms).

DISCUSSION

LEAN CONSTRUCTION COMPANIES ARE TOP PERFORMERS

The better performing trades contractors – the highest PPC achievers – are knowledgeable and practiced early adopters of LC. To assure high performance, the prequalification and selection processes should focus on a contractor's LPDS ability as opposed to lowest cost criteria which can promote loss of value (Sarhan *et al.* 2017). Client alignment on this point is critical. In this study, the approach of M&E contractors was productivity-based, and founded on systems and processes that ensured resources and materials were matched with sound, constraint-free tasks prior to commitment to a WWP. That "productivity mindset" understands that creation of even and reliable workflow is critical to improving construction productivity (Ballard *et al.* 2007; Liu *et al.* 2010). Efficiency Ratio metrics are a key driver of forward planning, and a measurement of output and productivity at both task and project level within these M&E companies. However, Howell *et al.* (2010) assert that such traditional metrics reduce the reliability of workflow by creating a focus on local productivity and executing work out of sequence. It is therefore important that a contract that encourages the dissolution of traditional silos and promotes a more collaborative organisational structure be considered.

MANAGEMENT RESOURCING

The findings indicate sufficiently-resourced site management teams and more clearly defined roles amongst the M&E companies. CSA appear to underestimate the level of management required to support both CMT and client reporting and supervisory requirements. With increasingly tighter margins due to more competitive tendering processes, CSA management and supervision staffing levels are minimised, thus contributing towards a cycle of insufficient planning and coordination and missed tasks (Howell *et al.* 2010). M&E primarily have their own direct labour and very few subcontractors, whereas CSA differed in having minimal direct labour and many subcontractors, contributing to greater fragmentation and difficulty of communication on the Projects. The study contends that clients and EPCMV should recognise that CSA requires more attention at both the E and the CM stages.

EARLY CONTRACTOR ENGAGEMENT

M&E were engaged early and involved in the design coordination and completion of the BIM model on each Project. However, the other trades were pressured to commence on site whilst the design was incomplete, which proved to be a constant constraint throughout the delivery phase of both Projects. Early engagement of key contractors is a critical enabler of LPDS (Ballard *et al.* 2007) and this study suggests early engagement of all trades in the design process would contribute towards raising their respective PPC whilst lessening any negative impact on other trades and the project overall.

LEAN EDUCATION & TRAINING

This study earlier referred to the productivity-based mindset of M&E, and we suggest investment in Lean education and training would contribute towards developing a value and next-customer awareness amongst the entire project team. M&E have supervision or charge-hands assigned to specific measurable tasks and are metrics-driven in their planning and setting of outputs and targets. By comparison, CSA appear to thrive on fire-fighting, reactionary problem-solving, and using their creativity to work around constant impending issues, like the improvisation referred to by Hamzeh *et al.* (2016). The introduction of standard work for trades' management, as well as incorporating the LPS weekly cycle into their working week, is considered a key step towards regularising how trades should approach their work planning and coordination.

LPS ALIGNMENT

M&E put more preparation into their weekly planning, and they arrived at the LPS coordination meetings fully prepared and familiar with their scope, whereas CSA were reluctant participants with the LPS process on both Projects. We suggest a more complete implementation of LPS is called for as there is evidence of each trade seeking to maximise their own weekly PPC figures with an absence of consideration for the whole project's gain. CSA's observed constant firefighting left inadequate time for organising and coordinating the flow of work tasks, and that mindset allows little room for effective planning or improvement (Ballard 2000).

PREFABRICATION & MODULARISATION

Because of early engagement, much of the mechanical work scope was prefabricated off-site, with site work primarily just an assembly process. Electrical switch-rooms and panels were also fabricated off-site, resulting in installation and connection tasks for the on-site crews. Cleanrooms work on a modular system and, to create the required efficiency, modularisation must be respected and not turned into a bespoke-modular system. CSA work was exclusively site-based transformation of inputs. The amount of variability encountered from resource constraints, poor coordination, late materials ordering, and inadequately screened design, all gave little respite from resolving crises and issues – common problems accruing from inadequate lookahead planning (Hamzeh *et al.* 2012).

TECHNOLOGY OPTIMISATION

M&E embraced technological advances, and this contrasted with the CSA contractors on both Projects. M&E utilised iPads to view the BIM model and isometric drawings in the field, thus increasing visualisation and understanding for the craft workers undertaking the installation. M&E also utilised cloud-based applications for punch-list identification, monitoring, and closeout. Cleanroom used similar technological aids; however, they highlighted issues relating to incomplete design as well as departures from modularisation impacting on the benefits. CSA only minimally-adopted available construction-based technological assistance. McKinsey (2017 p. 10) suggest the '…biggest barriers to innovation by construction companies are underinvestment in IT and technology more broadly, and a lack of R&D processes'.

CONCLUSION & RECOMMENDATIONS

LC contractors deliver better PPC performances than non-LC contractors. Clients and EPCMV companies should select LC contractors and should use alternative contracting strategies like IPD and relational forms of contract like Integrated Form of Agreement (IFOA) to encourage more widespread use of collaborative working practices. This would help eliminate the siloed approach amongst project parties towards LPS implementation, and embed a "project-first" mindset that aligns project team shared goals with the outcomes valued by the client. Such strategies would also contribute towards resolving many of the issues raised in this study, in particular early appointment and engagement of all parties in the design process. Introducing LPDS requires cultural change (Ballard 2008) and the ensuing LC and LPS education and training would assist in embedding the "Lean mindset" across project participants (Pasquire *et al.* 2015), allowing for more complete implementation of LC tools like LPS and TVD. Clients and EPCMV companies should encourage the use of prefabrication and modularisation while respecting the prerequisites required to achieve the efficiencies offered. A more holistic adoption of advanced ICT-based applications and platforms should be utilised. Finally, future research is recommended to investigate the obstacles and barriers restricting a more complete adoption of LPS on projects, as well as the wider utilisation of collaborative forms of contracting.

REFERENCES

Abdelhamid, T. and Salem, S. (2005) "Lean Construction: A New Paradigm for Managing Construction Projects", *International Workshop on Innovations in Materials and Design of Civil Infrastructure*, Cairo, Egypt, pp.1-25.

Ballard, G. (2000) *The Last Planner System of Production Control*, Doctoral Dissertation, The University of Birmingham.

Ballard, G., Kim, Y., Liu, M. and Jang, J. (2007) *Roadmap for Lean Implementation at the Project Level*, The Construction Industry Institute.

Ballard, G., Hammond, J. and Nickerson, R. (2009) "Production Control Principles", In *Proceedings of the 17th annual conference of the International Group for Lean Construction*, pp.489-500.

Ballard, G. and Tommelein, I. (2016) "Current Process Benchmark for the Last Planner® System" *Lean Construction Journal*, pp.57-89.

Bogdan, R.C. and Biklen, S.K. (2006). *Qualitative Research in Education: An Introduction to Theory and Methods*, Boston: Allyn and Bacon.

Braun, V. and Clarke, V. (2006) "Using thematic analysis in psychology", *Qualitative Research in Psychology,* 3(2), pp.77-101.

Creswell, J. (2009) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. London: SAGE Publications.

Creswell, J. (2013) "Steps in Conducting a Scholarly Mixed Methods Study", *DBER Speaker Series, Paper 48.*

Creswell, J., Plano Clark, V., Gutmann, M. and Hanson, W. (2003) "Advanced Mixed Methods Research Designs", *Handbook of Mixed Methods in Social and Behavioral Research,* pp.209-240.

Hamzeh, F., Ballard, G., and Tommelein, I.D. (2009) "Is the Last Planner System applicable to design? A case study", In *Proceedings of the 17th International Group for Lean Construction Conference*, pp.167-176.

Hamzeh, F. and Bergstrom, E. (2010) "The Lean Transformation: A Framework for Successful Implementation of the Last Planner System in Construction", In *International Proceedings of the 46th Annual Conference. Associated Schools of Construction.*

Hamzeh, F., Ballard, G. and Tommelein, I.D. (2012) "Rethinking Lookahead Planning to Optimize Construction Workflow", *Lean Construction Journal,* pp.15-34.

Hamzeh, F., Kallassy, J., Lahoud, M., and Azar, R. (2016). "The First Extensive Implementation of Lean and LPS in Lebanon: Results and Reflections." In *Proceedings of the 24th International Group for Lean Construction Conference,* pp.33–42.

Hines. P., Taylor, D., and Walsh, A. (2018) "The Lean journey: have we got it wrong?", *Total Quality Management & Business Excellence*, DOI: 10.1080/14783363.2018.1429258

Howell, G. and Ballard, G. (1994) "Implementing Lean Construction: Reducing Inflow Variation", In *Proceedings of the 2nd International Group for Lean Construction Conference,* pp.1-8.

Howell, G.A. and Koskela, L.J. (2000) "Reforming Project Management: The Role of Lean Construction", In *Proceedings of the 8th International Group for Lean Construction Conference,* pp.1-10.

Howell, G.A., Ballard, G., and Tommelein, I. (2010) "Construction Engineering—Reinvigorating the Discipline", *Journal of Construction Engineering and Management,* 137(10), pp.740-744.

Koskela, L. (1992) *Application of the New Production Philosophy to Construction*, (No. 72), Stanford, CA: Stanford University.

Koskela, L.J. (1999) "Management of production in construction: A theoretical view". In *Proceedings of the 7th International Group for Lean Construction Conference*, pp.241-252.

Koskela, L. (2000) *An Exploration Towards a Production Theory and Its Application to Construction.* VTT Technical Research Centre of Finland.

Koskela, L. and Howell, G.A. (2002) "The Underlying Theory of Project Management is Obsolete", In *Proceedings of the PMI Research Conference*, pp.293-302.

Liu, M., Ballard, G. and Ibbs, W. (2010) "Work Flow Variation and Labor Productivity: Case Study", *Journal of Management in Engineering*, 27(4), pp.236-242.

McKinsey and Company (2017) *Reinventing Construction: A Route to Higher Productivity*, McKinsey Global Institute, [Online] Available at www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution (Accessed 31 January 2019).

Morse, J. (2003) "Principles of Mixed Methods and Multimethod Research Design", *Handbook of Mixed Methods in Social and Behavioral Research*, 1, pp.189-208.

Pasquire, C. and Court, P. (2013) "An Exploration of Knowledge and Understanding – The Eighth Flow", In *Proceedings of the 21st International Group for Lean Construction Conference*, pp.1-10.

Pasquire, C., Daniel, E., and Dickens, G. (2015) *'Scoping Study to define a major research project investigating the implementation of Last Planner System, Collaborative Planning and Collaborative Working in the UK Road Transport Sector including identifying funding sources'*, Final Report, Centre for Lean Projects, Nottingham Trent University, UK. [Online] Available at http://assets.highways.gov.uk/specialist-information/knowledge-compendium/2014-2015/Snapshot+Final+Report.pdf (Accessed 02 February 2019).

Steckler, A, McLeroy, K, Goodman, R, Bird, S, and McCormick, L. (1992) "Towards Integrating Qualitative and Quantitative Methods: An Introduction", *Health Education Quarterly*, 19(1), pp.1-8.

Gomez, S., Huynh, R., Arroyo, P., Ballard, G., Tommelein, I.D. and Tillmann, P., (2019). "Changing Behaviors Upstream to Achieve Expected Outcomes." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 13–24. DOI: https://doi.org/10.24928/2019/0216. Available at: <www.iglc.net>.

CHANGING BEHAVIORS UPSTREAM TO ACHIEVE EXPECTED OUTCOMES

Sulyn Gomez[1], Raymond Huynh[2], Paz Arroyo[3], Glenn Ballard[4], Iris Tommelein[5], and Patricia Tillmann[6]

ABSTRACT

A behavior-based approach to quality has been proposed to highlight the impact that upstream behaviors have on the overall outcomes of construction projects. The focus of this pioneering approach is first to understand that certain behaviors lead to conversations in which expectations are clearly identified and understood by the different project participants, and then to set measurable acceptance criteria so that the final result can be compared with what was agreed. Previous research has described the approach and provided positive results in satisfying client's expectations, but the process to achieve such outcomes has not been captured. This paper captures the implementation of this behavior-based quality (BBQ) approach to quality management, that has as its main goal to have no surprises, zero rework, and to improve delivery of value to all the project participants engaged at any point of a construction project. Construction projects are to be planned first for quality to fully understand expectations of what the team should build, then for safety to identify any potential risks associated with the processes to build the agreed work and define how tasks will be built in a safe manner, and then for production to secure flow and an adequate use of resources.

KEYWORDS

Quality, behavior-based quality (BBQ), behavior, distinguishing features of work (DFOW), measurable acceptance criteria (MAC).

INTRODUCTION

Many definitions have been suggested for quality; for example, Crosby's (1979 p. 7) wrote "the first erroneous assumption is that quality means goodness, or luxury, or shininess, or weight." Deming (1982) also defined it as "a predictable degree of uniformity and dependability at low cost and suited to the market", whereas the American Society for Quality (ASQ 2018) defined it as "a subjective term for which

[1] PhD Student, Civil and Environmental Engineering Department, University of California, Berkeley, CA 94720-1712, USA, +1 765 775-6583, sulyn@berkeley.edu

[2] Senior Project Engineer, Quality Champion, DPR Construction, San Francisco, CA 94111, USA, +1 415 528-1045, rhuynh28@gmail.com

[3] Quality Leader, Quality Corporate Team, DPR Construction, San Francisco, CA 94111, USA, +1 510 520-6238, paza@dpr.com

[4] Research Director, Civil and Envir. Engrg. Dept., Project Production Systems Lab., Univ. of California, Berkeley, CA 94720-1712, USA, +1 415 710-5531, gballard@berkeley.edu

[5] Professor, Civil and Envir. Engrg. Dept., Director of the Project Production Systems Lab., Univ. of California, Berkeley, CA 94720-1712, USA, +1 510 643-8678, tommelein@berkeley.edu

[6] Senior Lean Manager, University of California, San Francisco, CA 94103, USA, +1 415 279-9102, patricia.andretillmann@ucsf.edu

each person or sector has its own definition." Quality has been also understood as meeting the requirements of a well-defined scope of work (Ferguson and Clayton 1988), or meeting the legal, aesthetic, and functional requirements of a project (Arditi and Gunaydin 1997). Researchers have suggested that quality is a major concern worldwide in the construction industry and it needs improvement (Rumane 2011; Arditi and Gunaydin 1997). Winch et al. (1998) highlighted that "A surprised client is a dissatisfied client" and particularly in the construction industry as a service industry, the entire team is responsible for delivering a quality product. For instance, failing in doing so might result in waste and may cause delays and increase the project cost. The Navigant Construction Forum reported that the average rework on projects can cost between 7.25% and 10.89% of the total construction cost while potentially impacting the project with a delay of 9.8% from the original schedule (Dougherty et al. 2012). Different approaches to quality converged with the goal to have a predictable result, which translates in zero rework or no surprises on site (Spencley et al. 2018; Arditi and Gunaydin 1997; Winch et al. 1998; Deming 1982); however, traditional approaches focused on quality control only have been proven to be too reactive as they work once errors are detected (P2SL, 2018), moreover, efforts to assure quality in construction are fragmented and quality is often seen as a concern to field activities only.

Flynn (2001) introduced the concept of behavior-based quality (BBQ) for organizations whose quality has reached a plateau and aim to keep improving by managing upstream behaviors rather than downstream defects. Flynn suggested that behaviors are reinforced by consequences; therefore, in an industry such as construction where quality is a concern, project teams are motivated to behave differently by the desire to obtain different results, by the desire to please their clients, by the desire to achieve some goals or to act in accordance with certain principles. Such understanding was strengthened by Spencley et al. (2018) who introduced the BBQ concept to shift the traditional quality management in construction to increase the likelihood of meeting project participants' expectations with a team that is motivated to think and behave differently. This concept to quality management is also well aligned with Deming's quality principles of eliminating fear from the workplace and fostering a leadership that motivate and encourage workers to participate from processes design (Deming, 1986).

Howell et al. (2017) draw a connection between the lean principle of Respect for People and psychological safety, a term coined by Amy Edmondson (1999). Respect for people requires that each person be helped to develop their capabilities, and this principle supports the organizational objective of continuous learning and improvement. Edmondson establishes a link between feeling safe to speak up, various learning behaviors, and individual and team performance. Another connection to lean construction thinking is between these learning behaviors and reliable promising, and with it the perspective that a project is a network of commitments. Reliable promising can be understood as the basic process underlying BBQ, and the underlying behaviors can be understood as those enabled by psychological safety; namely, to speak truth to power, to feel free to ask questions and make suggestions and ask for help, and to be confident that mistakes you make will be met not with punishment but with help. While reliable promising has been recognized as a critical element in planning and coordination, its application is much broader, and includes situations in which one or more people are responsible for providing something to someone else. Clarification and alignment of customer and provider is the first step in reliable promising, and commitment is only made if there is thoughtful consideration of capability to deliver on that commitment. In the context of behavior-based quality, that involves identifying so-called Distinguishing Features of Work (DFOW) (Answering to the question, what do you really want?), developing methods for delivering those features, and having agreement on how to measure whether the features have indeed been delivered.

Construction projects tend to move fast, and information constantly changes. Achieving quality is not a one-time conversation but rather a series of conversations between members to make sure all stakeholders involved in a specific scope of work are aligned around the same expectations, and processes are set in place accordingly to steer towards successfully meeting such expectations. Quality plans are documents that "specify quality standards, practices, resources, specifications, and the sequence of activities relevant to a particular product, service, project, or contract" (ASQ 2018). Such documents contain dense and valuable information about processes and expectations, which might not be easily understood by the trades building the work or it might limit their understanding. Moreover, Willar (2016) included a clear example in which quality plans are prepared solely to satisfy tendering processes. When quality plans are not created for a project-specific case, a misunderstanding of expectations can inevitably create misalignment at early stages. Therefore, finding a way to deliver quality expectations and ensure its compliance on a specific project is required. This paper documents and offers a description of the adoption and implementation process of BBQ in construction practice and the approach followed to foster desired behaviors.

RESEARCH DESIGN

Lewin (1946) and Somekh (2005) suggested that action research help to test and refine a concept or a process through the application of a set of improvements. This paper describes the first phase of an extensive research effort that applies an action research methodology. The authors seek to understand why and how the BBQ approach works in construction projects and what adjustments in the implementation process are needed for a successful implementation. The cycles of action research used in the study are presented in a step by step process (Fig. 1). In practice this process is not linear. Instead it involves a series of iterations of behaviors, constant interaction, and conversations in which the authors set the different steps to implement the BBQ concept.

Figure 1: Research Design to Capture BBQ Implementation Process

At the time the paper was written, the authors completed the first iteration of the action research which took about 8 months. Every cycle includes an initial assessment of the current state, plan to identify major points of release, implementation process which included training and practice of the BBQ approach to increase awareness and foster self-perpetuation.

PROJECT DESCRIPTION

The project studied is a 6-story building which program includes three levels of patient treatment clinics, two levels of wet and dry research space and a vivarium. This building will be the centerpiece of the University of California, San Francisco - Mission Bay Campus. The project is being delivered on a fast-tracked schedule by an integrated team with SmithGroup and MCA as architects, DPR as the general contractor, and a donor's representative who acts as a liaison for the project team and the donor. At the time the study was documented, the design was still in development. This made it possible for the project team engaged in early phases and use BBQ implementation to define the project details included in drawings and specifications for construction.

KEY CONCEPTS

The authors offer their understanding of a set of concepts that facilitate comprehension of the entire implementation framework described in this paper:

Quality

A work or product is said to meet quality requirements when it meets the expectations agreed by the stakeholders. Expectations, if well defined, can be aligned.

Points of Release

A point when the work is released (Christian, 2012) or when the next hand off happens. e.g., material purchase, prefabrication, construction, commissioning, turnover, etc.

Distinguishing Features of Work (DFOW)

DFOWs are the cornerstone of the behavior-based approach to quality. DFOW are the outcomes that each project participant values the most and those areas that the team agrees require increased attention to achieve the intended results. Identifying DFOWs help the project team to pay attention to areas where problems arose in the past, areas that are unique, or there is not shared understanding of what success looks like.

Measurable Acceptance Criteria (MAC)

MAC is an objective way to evaluate a deliverable. By agreeing on MAC, the team increase the likelihood that the job will be done correctly the first time. Defining the MAC allows the team to evaluate the work before releasing it to the next phase.

Prescriptive criteria: Consist on testing and inspecting to verify that the product meets the requirements included in drawings and specifications.

Descriptive criteria: Objective criteria that describe and measure the finish/craftsmanship elements of a product.

RESEARCH FINDINGS

AWARENESS OF THE NEW APPROACH

The initial assessment of the project was done when the superstructure construction started on site. In this phase, the project team awareness of the BBQ approach that drives project participants consensus on what quality means upstream was identified as a potential area for improvement. Different trades were asked about their involvement in the new approach to achieve quality, what the role of the quality champion was and what their own role was on achieving a quality product. When project participants from different companies were asked who was responsible for quality on the project, most answers put most or all the responsibility of quality on the quality champion. However, the concept of the BBQ approach sees the quality champion as a facilitator who guides the implementation of the approach in workgroups.

The corporate quality team along with the project leaders worked on increasing awareness and educating the project team on a BBQ approach in which the facilitators communicated the purpose for shifting to a different approach. During the first training sessions, expectations for each member of the project team were set clearly. The first phase of the research included increasing awareness from the GC's side. Participants attending the training were expected to take the lead and promote the BBQ approach and engage other trades in the process. Additionally, cause mapping sessions were used on site with GC's team to get their engagement as they identified that some causes for failure were linked to misalignment of project participants' expectations. Habits and behaviors developed in the implementation process are described later in this paper.

How BBQ is different from a traditional approach

In a traditional project setting, plans and specifications are often issued to contractors with the assumption that they clearly indicate stakeholder expectations for project outcomes. This misalignment of expectations creates challenges for the contractors during construction because they often build based on a limited understanding of the client's expectations. A consequence is to find defective work once elements of the project are built, which results in a long punch list process for the contractor. Table 1 summarizes the authors' understanding of key differences between traditional quality approaches and the BBQ approach implemented on the project.

Table 1: Traditional Quality Approach Versus Behavior-Based Quality Approach

Traditional Quality Approach	Behavior Based-Approach (BBQ)
Build it – Check it	Seek stakeholders understanding
Stakeholders are not confident to speak up or raise concerns	Foster psychological safety so people can speak up and expectations are uncovered
Culture of knowing / assuming	Culture of learning & asking questions / seek alignment amongst project participants
Quality is responsibility of one person	Quality is my responsibility (every person is responsible to deliver a quality product)
Blame others when mistakes happen	Encourage people to speak up & use cause mapping
Unclear/missing communication details	Quality needs clear language and transparent/documented agreements
Workers are not involved in process design	Workers feel free and are encourage to actively participate in processes design

Fragmentation and miscommunication between design and construction	Foster communication and alignment between points of release

IMPLEMENTATION PROCESS

At the onset of the project, the client engaged all key project participants (design leads, general contractor, donor, and users) to define the project's goals. The contractor, understanding the challenges of constructing such a complex building engaged them in a series of meetings to break down specific distinguishing features of the project.

Mapping out Points of Release

Architectural concrete is a major feature for the project since most shear walls were designed to be exposed concrete. Whereas regular structural concrete is largely specified by ACI standards (ACI, 2019), architectural concrete is specified differently in only one section out of over one hundred listed under topics in concrete by ACI. Due to unfamiliarity, the team realized the scope of work of architectural concrete required DFOW development in detail. In practice, the team used construction milestones from the project schedule to determine the last responsible moment for developing DFOWs and reaching agreement around acceptance criteria. Because of the lack of industry guidelines and a limited understanding of the team in the topic of concrete construction in architectural applications, the team agreed that a mock-up would be the best method for establishing the acceptance criteria. The procurement of the form finish panels was identified as the major point of release and the procurement of the formwork was the driver for completing the mockup and agreeing upon acceptance criteria.

Understanding Expectations

The list of DFOW grow the closer the project gets to construction. The goal is to better understand design intent and how to realize that intent. The team was challenged to build the architectural shear walls and meet high expectations with a set of specifications that needed further development to be clearly defined. The initial specifications of architectural concrete stated as a requirement to have concrete finishes that were "Interior surface: smooth, mirror-like concrete." Since the scope of work required clarity, the quality champion facilitated a series of conversations with the project participants involved in this scope and guided the team by asking a series of questions to better understand expectations for the surface finish, color, location of form joints, and construction tolerances for the architecturally exposed concrete. The responses to these questions were identified as DFOWs and were put on a list that was reviewed by all the project participants involved. As conversations took place, the design team provided tours and examples of concrete with smooth, matte finishes, making their expectations clearer.

In the case of architectural shear walls, the team started by asking themselves what was distinguishing about that scope of work; was it the forms and how they are placed together? Whether the finishes end up clean and neat after removing forms without an extra pass to clean them? If the wall was plumb? are the joints clean so that it won't affect the final finish of the surface of the concrete? The quality champion facilitated the process through the course of 4 months with the structural engineer, concrete superintendent, the architect, the owner, and the donor's representative. The concrete subcontractor referenced industry standard such as ACI 309R-5 – "Guide for consolidation" and ACI 347.3R-13 – "Guide for Formed Concrete Surfaces" to educate the project participants about materials, means and methods that could be used to meet expectations. This step of the process required the leadership of the team creating the vision and defining a path forward for developing success measures.

For the donor's representative in the project, the fact that the process included all the project participants that had relation with a DFOW added value to all; however, she recommended that the process itself needs to be explained to all new people coming in the project or otherwise the process might be watered down for having people not aware of it or not up to speed. Also, she said "sometimes we do not communicate well our priorities to the people building the projects". Even though the process can potentially work, the team cannot rely on it completely if people have not understood it properly and a proper communication is in placed between all project participants.

From the architect's point of view, even though understanding the BBQ process was a little hard at the beginning, going thought the process and having the appropriate project participants onboard to discuss DFOW details was key for the success of the scope of work. He said, "the process helped the team to express what was the intent in the documents to avoid confusion and prevent rework … we're also using a common vocabulary so that everyone can speak the same language."

Getting Team Alignment

The quality champion engaged the team in several conversations to identify DFOWs and to get agreement on how success was defined. The team achieved great results as they worked together ensuring that construction documents reflect what the real expectations were. The concrete subcontractor felt a great commitment with the plan and they were committed to achieve it. The team held weekly meetings for 4 months to breakdown each DFOW to the level of detail that they needed and verify that every detail they agreed on also satisfy compliance with industry standards guidelines in the ACI. Aligning the team on expectations is a constant action that the team got committed to developing throughout the project duration. To the architect, the clearest illustration of how behaviors were shown in the process was having all team members in the meetings where DFOWs were discussed. From the donor's representative, the behaviors that showed commitment from the team was having the concrete sub trying to understand what the client wanted and bringing alternatives to the table for every DFOW conversation, flashing out any discrepancy that could have come later.

The concrete subcontractor along with the quality champion and the architect also did field trips to other projects in which the architect showed the subcontractor examples of acceptable exposed concrete work. Later conversations helped the team define what in reality the architects wanted, what the GC can provide according to standards, and then as a team defined what is quality for the project. Together, the team worked on defining the color and texture, reveals, form ties, and construction joint details because of the impact on the final product.

Agreeing on Measurable Acceptance Criteria (MAC)

After the list of DFOWs was created in parallel with the research initial assessment, the team scheduled weekly meetings, leading up to the point of release for procuring the form finish panels. Each week, the subcontractor and GC would search industry standard, means, methods and tolerances for mix designs, formwork materials, vibration and review process and provide measurable solutions for each feature. Once all the project participants agreed upon the acceptance criteria, the concrete subcontractor produced a shop drawing clearly depicting each DFOW and acceptance criteria and requested that the design team revise contract documents to match accordingly. Through this process, the team was able to develop and agree upon objective criteria for architectural concrete and increased the likelihood that the scope would be built free of defects and meet expectations. Figure 2 shows a piece of the DFOWs list and measurable acceptance criteria that all the stakeholders agreed for the scope of work of architectural shear walls.

f. No.	Scope-Specific DFOW	Agreed to Acceptance Criteria
1	Walls - Rustication and Reveal Strips	Birch, Select and Btr Grade per NHLA; mill straight to profiles shown. Nail to form where shown. Use finish nails only. Laid out per design drawings ACI 117, 303R-12
2	Walls - Aesthetics of Formwork	Form Finish: Sylvan-Durapour Matte Tight seams at panel joints Rustication strips fully conceal panel joints Silicone used at joints to prevent water-absorption on form panel ACI 117, 303R-12

Figure 2: List of DFOW's Developed for Architectural Shear Walls

Execution and Alignment in The Field

The team achieved to have a set of deliverables that were built as the team agreed on the process. Prior to building the shear walls mock-up and first in place installation, the team developed a detailed plan with means and methods to build architectural shear walls showing all DFOW related to the scope. Other key points from the BBQ that the authors noticed throughout the implementation process are:

Training and Awareness: Training sessions were developed for the GC's staff to increase awareness of the process. Similarly, field workers were involved during mock-up building to ensure they understood the process and expectations. Training for trade partners and field workers is to be developed in the second phase of the study. The donor's representative said, "you won't create positive behaviors if people don't know what they are supposed to do – that goes back to communication and understanding that we're talking about the same thing."

Team Commitment and Engagement: The team agreed on being flexible to modify specifications; for example, different quantities of slag were tested in the mock-ups because it affected the color of the concrete. The structural engineer helped to specify maximum allowable slag content that would still provide the concrete strength required for the project. The concrete superintendent also realized that the form release agent and spray cure would affect the finish color, so for each full-scale mockup they did half and half sections with and without form release agent and spray cure. Given the misalignment in the formwork finish (mirror-like vs matte), the team also agreed to build each of the three mockups with different form-facing materials (gloss, matte, and HDO). The project team had developed detailed DFOW for architectural concrete, terrazzo, stone flooring, etc.

Psychological safety: The architect highlighted that field workers from the concrete crew were also confident and engaged in the process because when problems arise, they pull down the red cord and ask for help stopping the construction process until the they get clarity on any issue that they were concern about. He stated, “I think the conversations we had have created an environment where it feels safe and you can walk through the project anytime without workers feeling pressure.”

Visual Aids: While building on site, visual aids were placed out in the field to be accessible for field workers and help them be ready for execution. After the concrete was in place, the concrete project engineer measured the final product against the MAC agreed. The DFOW’s were also identified on pre-pour checklists so that the foreman signing off each section before a concrete pour could continuously identify whether they were built correctly. Figure 3 shows a piece of the drawing with means and methods diagrams that the teams agreed to move forward with based on the DFOW’s. The plans on site show pour sequences, specific vibration patterns, and specific durations for these processes.

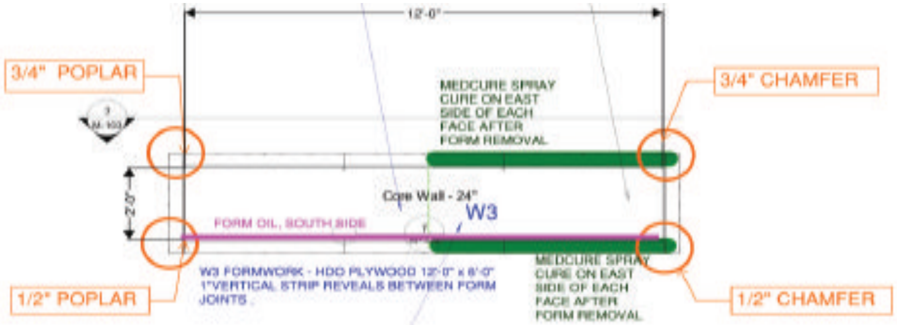


Figure 3: DFOW’s Identified for Architectural Shear Walls for the Field

Transparency and tracking of commitments: Everyone in the job has access to the information about DFOWs developed. The team also made sure that the client understood and approved any potential impact on cost and schedule that might be tied to the process. For example, the higher quality formwork had schedule and cost impacts, so the team discussed the impact with the project participants and allowed the team to make the right decision for the project. The team also created a DFOW log (Fig. 4) to track commitments. As an awareness indicator, the team plan to track whether the team kick off all conversations that they were supposed to. Other meaningful quantifications to measure on the process is how many of the plans in which DFOW were identified were also well-executed.

Upcoming/Scheduled DFOW Meetings

1/18/2019

Scope	Bid Package	DPR Lead	DFOW's Required By	Scheduled DFOW Meeting	Status	Driver	Notes
Lab Casework	N/A	Randy G.	11/30/2018	1/24/2019	DFOW developed	Mock-up	Team to continue DFOW discussion at Equipment Cluster on 1/24
Tile & Stone	26	John S.	12/13/2018	11/28/2018	DFOW issued for buyout	Buyout	DFOW issued 11/29. Pre-bid RFIs issued to SS 12/18

Figure 4: Statusing of DFOW Distributed Weekly to the Project Team

CONCLUSIONS

The outcome of this study is considered significant to practitioners as it provides a detailed description of the implementation of a behavior-based approach to quality in a construction project. The need to set short-term and long-term plans to be achieved throughout the implementation was identified in the initial research assessment. Short-term plans included tying points of release to the master schedule and developing pull plans to identify when conversations need to happen. The authors found the need to also set clear expectations from all team members at the beginning of the process, e.g., project engineers leading a scope of work were expected to lead the DFOWs conversations for such scope. As when implementing any new approach, educating and training plays an important role in the sustainable implementation. Long-term plans included training and learning from the basic initiatives, e.g., building team alignment and cause mapping whenever disruptions occur. Initiatives such as forums or lunch-and-learn sessions are recommended to share knowledge in a project basis. Aiming to build great builders faster, identifying a catalyst to accelerate the dissemination of the BBQ approach is key in the process: a quality champion could facilitate the process and give the ownership of each DFOW conversation to team members that lead the corresponding scope of work.

The behaviors that were identified in this phase of the study are summarized in three principles, acting in accordance with these principles creates the behaviors that support the BBQ approach: (1) *"Ask questions constantly."* Most specifications are generic, and they may not even apply to your project. Therefore, it is important to keep asking questions to better define the scope of work. Only if you ask questions such as what is important for you about this scope will lead to identifying DFOWs. Keep reminding people that if the team does not follow this process, there will be surprises and we will make the same mistakes we did in the past. BBQ has been recognized as a process worth doing, as per the quality champion said: "Some people were asking why we were doing this so early on, and why the architects are not just giving answers... This (process) fundamentally changes the way we build and how we see the end-product. Yes, we will disagree at the beginning, but if we go through this process we increase the likelihood that there will not be any surprises at the end of the day." (2) *"Overcome resistance."* Implementing the process is hard work and you will get resistance, but it is worth doing. Benefits of implementing this approach are: avoiding a massive amount of rework, building trust among project participants, and getting the right quality for the project. The process itself helped build the team. The concrete subcontractor bought the idea and benefits of the process and expressed his thoughts as: "I would highly recommend this (process) for any project that has some ambiguity in their designs and specs. This is the first time I did this on a job, and I would do this for every job." (3) *"Trust and empower your team."* It was important to let the project engineers and superintendent in charge of managing a specific scope to lead kickoff meetings in which they explain the process to subcontractors and lead them throughout the implementation. The team should work together to verify that documents are timely, appropriately complete, and have captured the team's expectations. A very clear procedure communicated in the field is required to achieve expected outcomes.

FUTURE RESEARCH

The authors aim to define a process for behavior-based quality approach to construction projects, capture challenges when it is implemented, and refine the process accordingly.

ACKNOWLEDGMENTS

Development of the ideas presented in this paper was supported in part by gifts made to the Project Production Systems Laboratory (P2SL). All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect those of contributors to P2SL.

REFERENCES

American Concrete Institute (2019). "ACI: Topics in Concrete." https://www.concrete.org/topicsinconcrete.aspx (Feb. 22, 2019).

American Society for Quality (2008). "ASQ Glossary." <https://asq.org/quality-resources/quality-glossary> (Feb. 22, 2019).

Arditi, D., and Gunaydin, H.M. (1997). "Total Quality Management in the Construction Process." *International J. of Project Management*, 15(4), 235-243.

Chandrupatla, T.R. (2009). *Quality and Reliability in Engineering.* Vol. 2., Cambridge University Press (NY), New York.

Christian, D. (2012). "Where Ambitious Owners with Ambitious Projects Need Ambitious GC's to Focus." Unpub. Presentation, DPR Quarterly Mtg., April 25.

Crosby, P.B. (1979). *Quality is Free: The Art of Making Quality Certain*. McGraw-Hill (NY), New York, p. 7.

Deming, W.E. (1982). *Quality, Productivity and Competitive Position*. MIT, Cambridge, MA, UK, pp. 373

Deming, W. E. (1986). *Out of the Crisis*. MIT Press., Cambridge, MA, UK, pp. 524.

Dougherty, J.M., Hughes, N., and Zack, Jr., J.G. (2012). "The Impact of Rework on Construction and Some Practical Remedies." *Navigant Construction Forum*, Navigant, 21.

Edmondson, A. (1999). "Psychological Safety and Learning Behavior in Work Teams." *Administrative Science Quarterly*, 44(2), 350-383.

Ferguson, H. and Clayton, L. (1988). *Quality in the Constructed Project: A Guideline for Owners, Designers and Constructors.* ASCE, Vol 1., New York.

Flynn, K. (2001). "Behavior-Based Quality – Connecting People to the Systems." *Behavioral Science Technology Annual Spring Conf. Proc.*, Chicago, IL.

Howell, G., Ballard, G., and Demirkesen, S. (2017). "Why Lean Projects are Safer." *Proc. 25th Ann. Conf. Int'l. Group for Lean Constr.*, Heraklion, Greece, pp. 4-12.

Lewin, K. (1946). "Action Research and Minority Problems." *J. of Social Issues*, 2(4), 34-46.

Rumane, A.R. (2011). "Quality Management in Construction Projects." ASCE, *Construction Research Congress*, Boca Raton, FL.

Somekh, B. (2005). *Action Research: A Methodology for Change and Development.* McGraw-Hill Education (UK).

Spencley, R., Pfeffer, G., Gordon, E., Hain, F., Reed, D., and Marosszeky, M. (2018). "Behavior-Based Quality Closing the Knowing Doing Gap." *Proc. 26th Ann. Conf. Int'l. Group for Lean Construction (IGLC 26)*, Chennai, India, 1170-1181.

Willar, D. (2016). "Developing Attributes for Evaluating Construction Project-Based Performance." *The Total Quality Management Journal*, 29(2), 369-384.

Winch, G., Usmani, A., and Edkins, A. (1998). "Towards Total Project Quality: A Gap Analysis Approach." *Construction Management and Economics*, 16(2), 193-

Lehtovaara, J., Seppänen, O., and Peltokorpi, A. (2019). "Improving the Learning of Design Management Operations by Exploiting Production's Feedback: Design Science Approach" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 25–36. DOI: https://doi.org/10.24928/2019/0143. Available at: <www.iglc.net>.

IMPROVING THE LEARNING OF DESIGN MANAGEMENT OPERATIONS BY EXPLOITING PRODUCTION'S FEEDBACK: DESIGN SCIENCE APPROACH

Joonas Lehtovaara[1], Olli Seppänen[2], and Antti Peltokorpi[3]

ABSTRACT

This study examines the development and implementation of a learning process in a contractor's design management unit. The purpose is to gain knowledge on how learning can be turned into a standardized process and of methods of accelerating the learning in a design management unit by exploiting the feedback received from the production.

The research took a design science approach, which consisted of a diagnosis of the present situation, testing & development of the formulated process, and analysis & generalization of the results. The diagnosis comprised a literature review, interviews, and active observation, while the testing phase included an intervention where the process was tested and further developed.

The results indicate that while the relevancy of continuous learning is well recognized, construction organizations are incapable of effectively exploiting the best practices of knowledge management. To overcome weaknesses related to the inefficient learning practices, organizations should focus on balancing the operational and strategical viewpoints of learning, emphasize learning from failures and implement project-based communities of practice into an organization's operations.

The study has implications for more standardized and balanced learning processes in contactor operations. It also provides knowledge of ways of taking a design science approach effectively in construction management research.

KEYWORDS

Design management, organizational learning, knowledge management, design science

[1] Doctoral Candidate, Department of Civil Engineering, Aalto University, Finland, joonas.lehtovaara@aalto.fi

[2] Professor of Practice, Department of Civil Engineering, Aalto University, Finland, Olli.seppanen@aalto.fi

[5] Assistant Professor, Department of Civil Engineering, Aalto University, Finland, antti.peltokorpi@aalto.fi

INTRODUCTION

To increase productivity in construction, organizations and especially design management operations should exploit the knowledge created in previous projects, and particularly the knowledge created in the production phase, more effectively. Carrillo & Chinowsky (2006) reason that the most recent knowledge of the design solution's constructability and correctness - in other words, the most recent knowledge regarding the requirements for flow-efficient and value-adding designs - is held by the individuals working in production. They argue that for construction companies to increase their productivity, more efficient learning processes through the coupling of production and design operations are essential.

The importance of effective learning through coupling has been reported in construction management research widely. Several studies consider knowledge management and effective learning among the most important core competencies of construction companies (e.g., Dave & Koskela, 2009, Henderson et al. 2013, Carrillo et al. 2013). In addition, Giridhar et al. (2018) suggest that knowledge management plays a vital role in implementing lean culture effectively into organizations. Even though the identification, collection, analysis, storage and reuse of tacit and explicit knowledge from projects has been recognized as a pertinent part of the learning of design operations, the nature of the project-based industry sets barriers for development. Dave & Koskela (2009) mention that, for example, the fragmentation of the project organizations, constant rush, and reluctance towards radical development hamper effective learning in and between projects. These barriers have led to reinventing the wheel all over again, solving problems reactively and ignoring the deeper root causes, while the lessons from other projects are not transferred into following projects, or to design solutions in the following projects. Henderson et al. (2013, Figure 1) argue that the lack of proactive, double-loop learning from an actor's own mistakes is one of the fundamental reasons for poor productivity development.

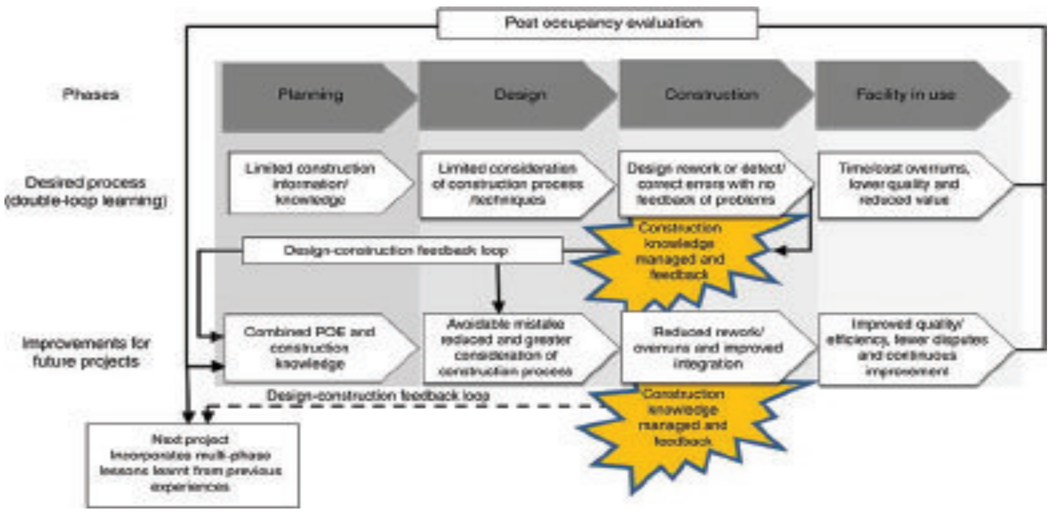


Figure 1: Desired double-loop learning through a design-construction feedback loop (Henderson et al. 2013)

The reactive touch to learning reflects the inefficient implementation of new learning processes, which have been criticized for their inefficiency to drive change. Eriksson (2013) argues that research on project-based organizations has centred only on visible problems at hand and asking ***what*** should be done, instead of focusing on ***how*** to concretely solve the problems. Holmström et al. (2009) suggest that to overcome this inefficiency in management research, researchers should take a more active role in designing the solutions instead of only observing from a distance. In a similar vein, some researchers (e.g. AlSehaimi et al. 2012 and Azhar 2009) have suggested implementing experimental and active research methods, such as design science research, into construction.

Therefore, there is a certain need for designing but also for concretely implementing more effective learning processes into the construction design operations. The goal of this study is to develop a concrete construction design learning process by an experimentative design research approach while answering the following research question: *How can the learning of design management operations in a construction company be accelerated through feedback acquired from production?*

RESEARCH DESIGN

Design science research is an iterative and experimental approach in which the development is conducted in tight, reciprocal collaboration between theory and practice (Wang & Hannafin 2005). This study follows the approach designed by Holmström et al. (2009) and comprises three steps: 1) the diagnosis of the current situation and development of the preliminary learning process from the basis of the diagnosis; 2) testing and development of the process and 3) generalization of the findings and demonstration of a theoretical contribution. The research process is presented in Figure 2.

Figure 2: The structure of the design science research

First, in the diagnosis phase, the authors attempt to find and describe the current state of the observed case. The observations are combined with the literature review, to gain holistic but also specific understanding of the situation. The diagnosis follows an abductive process (Kovacs & Spens 2005), meaning that while the literature review shapes the interviews and observation, the empirical results also direct the literature review reciprocally. Thus, the steps in diagnosis phase are highly intertwined, and presented in symbiosis in the paper. The adequate learning process is developed through the diagnosis. Second, in the testing and development phase, the process is tested and further developed through collaboration with the target company's personnel, including the preparation, testing in workshop, and analysis of the tested process. Third, in the discussion and conclusion phase, authors address whenever the research question was answered properly, and attempt to provide avenues for future research.

The development of the learning process is inspected from the viewpoint of a Finnish general contractor's residential unit. The selection of the case was impacted by theoretical and practical interests. As a relatively typical residential construction unit, the results are generalized in a more straightforward manner, whereas the target company's interest in development offers a concrete premise for the active research design approach.

THE DIAGNOSIS

The diagnosis of the current state consists of a review of current knowledge management and construction operations management literature, nine semi-structured theme interviews of personnel working in company's residential construction unit, and active observation of the company's practices for four months. The adequate learning process for the company's design management operations is developed through the diagnosis, combining the existing literature as well as analysis of the target company's current practices.

KNOWLEDGE MANAGEMENT IN CONSTRUCTION OPERATIONS

Construction can be considered a knowledge-intensive industry, where projects and organizations constantly create a vast amount of information and knowledge. However, the complexity of projects and the previously mentioned barriers to industrial development have created a situation where a vast amount of knowledge is continually lost and an opportunity for learning is missed (Dave & Koskela 2009). Almeida & Soares (2014) argue that this opportunity is lost because a large amount of created knowledge is typically structured to directly benefit only the project at hand. While the approach creates more tangible gains for the current project, information is usually dispersed into different locations and loses its potential for efficient learning and exploitation after the project ends. To effectively prevent knowledge dispersion, Dave & Koskela (2009) note that organizations should focus more on long-term development and process-based knowledge management, instead of investing resources only in projects. To enable effective knowledge sharing and learning through the organization, an organization needs a tangible knowledge management strategy.

An organizational knowledge management strategy can be based on the balance between two different approaches. ***Personalization***, a human-based view, emphasizes the meaning of tacit knowledge and is usually present in small and agile organizations. In contrast, ***codification***, a technology-based view, describes an approach where knowledge is managed through systems and documents and the knowledge is mainly explicit (Hansen et al. 1999). Even though organizations should determine which approach is dominant in which processes, it does not mean that organizations should focus solely on one approach. Lee & Choi (2003) with Mäki (2008) argue that the knowledge management strategy is implemented most effectively when the instruments are determined on the sub-process level, which enables the link between an organization's strategy and tangible operational actions.

Expert interviews yielded observations similar to those in literature. If the learning processes are invisible in the organization, the knowledge management strategy is hard or even impossible to implement in operations. Mäki (2008) states that this is common for organizations, and an unclear link between the strategy and the operational learning processes constitutes one of the major barriers for learning. Also, communication between personnel in production and in design operations should be more efficient and more structured to enable continuous learning. The experts reported that communication is often minimized in the hectic project environment if the communication is not absolutely necessary.

LEARNING PROCESSES IN CONSTRUCTION

In the context of project-based organizations, learning from projects is realized through three concrete steps: 1) collection of information and knowledge created in projects, 2) filtering and analysis of collected information and knowledge, followed by 3) storage of analyzed knowledge (e.g. Carrillo et al. 2013, Dave & Koskela 2009). The usefulness of the definition is based on its tangibility and the ability to present the stages with three knowledge management frameworks: the SECI model (Nonaka & Takeuchi 1995), the 4I model (Crossan et al. 1999), and Blackler's (1995) five types of knowledge. Although it is illustrative to inspect these processes in isolation, it should be kept in mind that these processes are always somewhat connected and intertwined.

Creation and collection of information and knowledge

The creation and collection of knowledge can be examined through the SECI-model (Nonaka & Takeuchi 1995). The SECI model portrays knowledge creation as a continuous cycle, where the project knowledge emerges through the steps of socialization, externalization, combination, and internalization, as the personnel in production experience, share, combine and reuse the knowledge constantly.

To be useful for the organization, the knowledge that is created in the production phase should also be effectively collected. The process should include the collection of both explicit and tacit knowledge, and the process needs to be connected to the broader knowledge management strategy. Also, the process should be connected to daily activities by implementing concrete tools for knowledge creation as well as collection. Hari et al. (2004) argue that in order for data collection to be meaningful and worthwhile, the implemented tools should promote ***accessibility*** and ***objectivity***, and the ***usefulness*** of the collected knowledge should be made visible for individuals.

The diagnosis phase revealed that the target organization focused too much on collecting explicit information, and the entire process of learning was too narrowly centred on codification. Ignorance of the accessibility and usefulness of the collected knowledge demonstrated a sub-optimal process, in which the created knowledge did not systematically lead to further actions. Several studies (e.g., Hari et al. 2004, Kamara et al. 2002) suggest that this barrier is generally present in construction organizations. To develop the process, Hari et al. (2004) argue that the collection of tacit and explicit knowledge should be more effectively balanced.

The analysis of collected information and knowledge

Crossan et al. (1999) find that learning in organizations occurs through a knowledge flow between individuals, groups and the entire organization, which can be expressed through the 4I model of learning. They argue that even though every step of the flow is important for learning, the most effective knowledge creation takes place within the group level, where the knowledge from the projects is analyzed and shared with the organization in a reusable way. For project-based organizations, group-level learning can be enhanced by implementing so-called ***project-based communities of practice*** (Lave & Wenger 1998 with Lin & Lee 2012). In these communities, experts working within the same area of interest (but not necessarily within the same projects), share their knowledge created in the projects, while analyzing the knowledge and simultaneously sharing it with the organization.

In an optimal setting, project-based communities of practice operate freely but at the same time, within a structure that enables continuous filtering and analysis of the created knowledge. When operated effectively, the knowledge flows through the communities and across project boundaries in both codified and personalized form (Lin & Lee 2012). For effective implementation of the communities of practice, the culture of learning from failure was recognized as one of the most contributing factors, in both literature (e.g., Eriksson 2013, Cannon & Edmondson 2005) and in the expert interviews.

The storage of the analyzed knowledge

The knowledge analyzed and shared also needs to be stored. Blackler (1995) states that knowledge can be stored in an organization in five different forms: ***embrained*** (*conceptual and cognitive abilities, ability to form and visualize knowledge*), **embodied** *(know-how, ability to apply knowledge*), ***encultured*** (*collective and shared understanding*), ***embedded*** (*knowledge regarding resources, routines and roles*) or in ***encoded*** (*formal, codified information*) form. Embrained, embodied and encultured knowledge can be stored as personalized knowledge, whereas embedded and encoded knowledge are stored in a codified form.

The balance between personalization and codification should be considered also in the storing phase. Digital tools offer a possibility to store codified and distribute personalized knowledge effectively, once the entity of implemented tools is in balance and their usage is easy and meaningful for the employees (Ruikar et al. 2007, also addressed by several interviewees). The interviewees greatly emphasized that the analyzed knowledge should be structured more systematically. For codified knowledge to be reusable, it should be clear where knowledge is stored and whenever it is updated. Also, the personalization of stored knowledge should be emphasized. The interviewees argued that the know-how and rationalization between different design solutions should be presented, so the following projects could apply the knowledge without questioning its validity. Personalized storage could also increase transparency and trust within an organization.

THE PRELIMINARY LEARNING PROCESS

On the basis of the conducted diagnosis, a learning process for the design management operations was developed. The main objective for the 3-step process was to continuously improve the company's design solutions on the basis of feedback acquired from production, while the knowledge flows through an organization in personalized and in codified form. Also, several key requirements for the learning process were identified, taken into account in the testing phase:

- The vocabulary and process components applied should be clearly determined and presented while connecting the strategic and operations-level actions.
- The balance between personalization and codification should be ensured in every process step.
- The process should be accessible, easy-to-use and lightweight. Also, the collection and storage of information and knowledge should be as automated and standardized as possible.
- The project-based communities of practice should enable a space for effective learning from failures and root causes. The community should be supported by an experienced process owner and facilitator.

TESTING AND DEVELOPMENT

The learning process was iterated and implemented in the unit's operations through an intervention which included preparation, testing, and analysis of the tested process. The preparation of the testing was achieved in collaboration with the unit's key personnel, including the design manager and the unit manager. For testing, one design-specific problem was identified in the feedback acquired from production: *the design process of acoustic and fireproofing connection details in drywalls separating apartments* (Figure 3). Production personnel raised the issue that because these design solutions are rare (most of the dividing walls between apartments are precast concrete in Finland), they are not automated in the design process, which creates a risk for faulty designs and subsequently also for costly rework. The production engineer suggested that the connection detailing process should be automated by the design management operations.

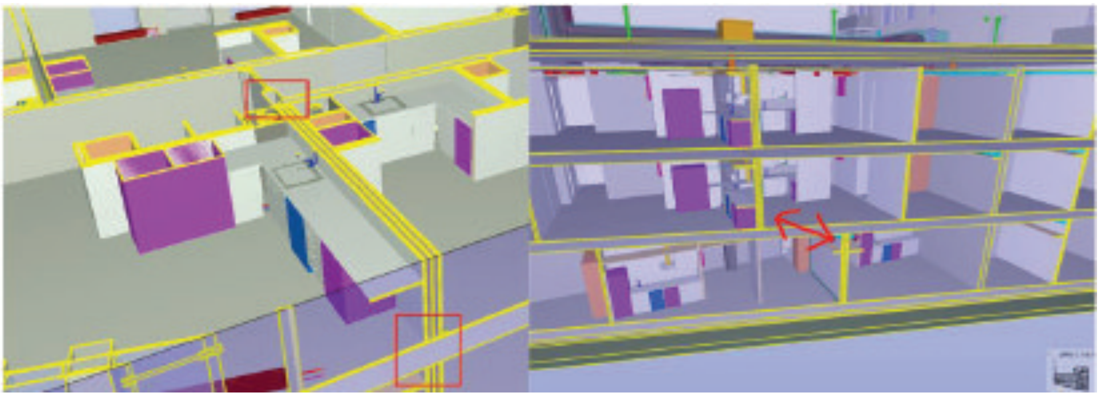


Figure 3: Dividing wall presented in the BIM-model

1) COLLECTION OF THE INFORMATION

The site and project engineers collected more detailed information regarding the received feedback, in both codified and personalized form. They also filtered the information in concise form before assigning it for analysis in the community of practice. The filtered information consisted of basic information regarding the case, feedback from production, as well as preliminary risk and cost analysis. In the collection phase, the goal was to ensure that the community of practice would obtain a tangible problem with sufficient information, but also to ensure that the information was already filtered so that the community could focus on the relevant issues.

2) ANALYSIS: THE COMMUNITY OF PRACTICE

The meeting of the project-based community of practice was implemented as a workshop which consisted of four stages: 1) site visit, 2) introduction and discussion, 3) creation and root cause analysis, and 4) development of further actions and concrete steps for implementation. Westerlund (2007) argues that these steps are vital for creating a mutual understanding of the problem, for collaborative and creative working, as well as for concretely implementing the results in action. The composition of the community was kept concise (seven key persons of the unit who were responsible for designs), including an experienced facilitator who ensured that the workshop followed the structure, but at the same time, provided a safe space for the community to openly share their ideas.

3) STORAGE OF THE ANALYZED KNOWLEDGE

After the workshop, the decided actions were stored in the organization's processes in both codified and personalized form. The design manager ensured that the developed solution, including information for implementation, was added to the unit's design library. He also ensured that the additional actions, such as updating internal risk analysis and cost models were adequately completed. In addition to storing the information in documents, the storage also included making the solution visible in the organization, which aimed to reinforce the culture of learning and transparency. The project engineer informed the organization about the new solution through the organization's intranet and provided brief feedback to the project where the feedback was acquired.

ANALYSIS AND FURTHER DEVELOPMENT OF THE LEARNING PROCESS

After the testing, the process was analyzed with the design and unit managers. The implementation was viewed as a success. The testing also accomplished its initial goal, which was to tackle a specific problem regarding the design by exploiting the feedback from production.

For further development of the process, several actions were proposed. The most important actions concerned process fluency. The process should be as streamlined as possible to minimize the time spent by the participants, and the process steps should be standardized to effectively implement it for another company's internal communities. The constant rush and unclear learning processes were determined as barriers also during the testing phase. The process was further developed to be optimally streamlined and more easily adopted by determining clearer instructions and process steps. Also, a document template for easier implementation and education were created. The document followed partially 'A3 problem solving template' (Shook 2008), which is commonly utilized in lean management. Even though the learning process was developed from the basis of knowledge management literature, the problem-solving process shares certain similarities with principles of lean. The core principles of the updated learning process are presented in Figure 4.

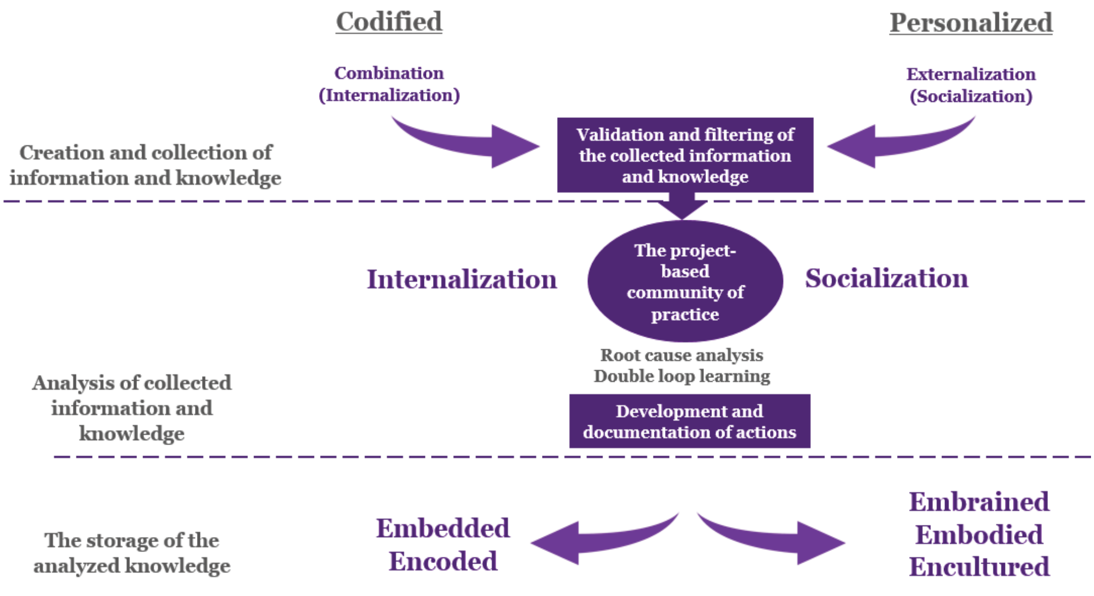


Figure 4: The developed learning process

DISCUSSION

The research question, "*how can the learning of design management operations in a construction company be accelerated through feedback acquired from production?*", was addressed from two perspectives. First, the primary goal of the proposed and developed learning process was to increase the constructability and correctness of the contractor's internal design solutions. During the internal analysis of the process, it was recognized that the learning process was a valuable tool for improving the design solutions in a structured manner. Especially balancing between the personalized and codified sub-processes and implementation of the project-based community of practice (also suggested by Lin & Lee 2012) were seen as major enablers for success.

In addition to the primary goal, the learning process is a potential enabler for tackling wider barriers for productivity development. As missing the common language of knowledge management (Mäki 2008), ignoring the deeper root causes (Dave and Koskela 2009), lack of learning from errors (Cannon & Edmondson 2005), and forgetting to ask "how" (Eriksson et al. 2013) are hampering the development of the entire industry, the proposed learning process attempts to educate the organization to address these barriers in an organized manner. If the process could be implemented widely in the entire organization as a continuous process, it could enable the accelerated and cumulative learning while individuals and implemented communities of practice would internalize the culture of the continuous learning in their daily work.

The concept of continuous learning also connects the developed learning process tightly to lean principles. Giridhar et al. (2018) suggest that an effective knowledge management system can prevent 'waste of knowledge', while acting as an enabler for implementation of lean principles. Thus, it can be argued that knowledge management and lean principles are tightly intertwined when the learning processes are developed in construction organizations. However, further research is needed regarding the wider implementation and the actual, related benefits of the process, and the actual link between the proposed process and its effect on implementation of lean principles.

The design research approach taken enabled an iterative development of the process, but also the initial implementation of the process in the unit's routines, which is the first step in promoting a culture of continuous learning. The proposals of AlSehaimi et al. (2012) and Azhar (2009) were reinforced, as they encouraged to implement design research to enable the concrete development of construction processes. The approach also enabled to bridge the gap between the strategic and the operative level of actions, when the organization's wider goals were connected to the concrete actions by implementing the created process. As stated by Carrillo et al. (2013), bridging the gap is a remarkable enabler for more effective knowledge management processes, which can be seen as one of the main core competencies of construction companies in the future.

CONCLUSIONS

Even though the the relevancy of continuous learning is well recognized in construction research and within the industry, construction organizations are incapable of effectively exploiting the best practices of knowledge management. This primarily stems from the lack of mutual understanding of knowledge management terminology, no link between the knowledge management strategy and the operational processes, as well as poor ability to steer the learning processes in action. Also, construction organizations should increasingly emphasize the learning from failures, which can be enabled by implementing project-based communities of practice into organizations.

These problems were addressed by means of the iteratively developed learning process, which was able to increase the constructability and correctness of the contractor's internal design solution. In addition, the process was also seen as a potential enabler for tackling deeper root causes for ineffective knowledge management, which is an essential core competence for the construction companies. As the present research was limited to a single organization, further research could include the validation of the proposed process in different organizations, as well as in procurement and estimation units, which could also benefit from feedback received from production. Further studies could also include the management of inter-organizational learning, prevention of knowledge dispersion caused by the high mobility of workers, as well as a study on how large amounts of lessons learned information could be managed more effectively.

REFERENCES

Almeida, M. V., & Soares, A. L. (2014). Knowledge sharing in project-based organizations: Overcoming the informational limbo. *International Journal of Information Management*, *34*(6), 770–779.

AlSehaimi, A., Koskela, L., & Tzortzopoulos, P. (2012). Need for alternative research approaches in construction management: Case of delay studies. *Journal of Management in Engineering*, *29*(4), 407–413.

Azhar, S., Ahmad, I., & Sein, M. K. (2009). Action research as a proactive research method for construction engineering and management. *Journal of Construction Engineering and Management*, *136*(1), 87–98.

Blackler, F. (1995). Knowledge, knowledge work and organizations: An overview and interpretation. *Organization Studies*, *16*(6), 1021–1046.

Cannon, M. D., & Edmondson, A. C. (2005). Failing to learn and learning to fail (intelligently): How great organizations put failure to work to innovate and improve. *Long Range Planning*, *38*(3), 299–319.

Carrillo, P., & Chinowsky, P. (2006). Exploiting knowledge management: The engineering and construction perspective. *Journal of Management in Engineering*, *22*(1), 2–10.

Carrillo, P., Ruikar, K., & Fuller, P. (2013). When will we learn? Improving lessons learned practice in construction. *International Journal of Project Management*, *31*(4), 567–578.

Crossan, M. M., Lane, H. W., & White, R. E. (1999). An organizational learning framework: From intuition to institution. *Academy of Management Review*, *24*(3), 522–537.

Dave, B., & Koskela, L. (2009). Collaborative knowledge management—A construction case study. *Automation in Construction*, *18*(7), 894–902.

Eriksson, P. E. (2013). Exploration and exploitation in project-based organizations: Development and diffusion of knowledge at different organizational levels in construction companies. *International Journal of Project Management*, *31*(3), 333–341.

Giridhar, R. , Gaikwad, D. & Lad, J. (2018). Knowledge Management and Its Application in Developing Lean Culture. Proceedings (IGLC 26). Chennai, India.

Hansen, M. T., Nohria, N., & Tierney, T. (1999). What's your strategy for managing knowledge. *The Knowledge Management Yearbook 2000–2001*, 1–10.

Hari, S., Egbu, C. O., & Kumar, B. (2004). Knowledge Capture in Small and Medium Enterprises in the Construction Industry: Challenges and Opportunities. *20th Annual ARCOM Conference*, *2*(September), 847–858.

Henderson, J. R., Ruikar, K. D., & Dainty, A. R. J. (2013). The need to improve double-loop learning and design-construction feedback loops: A survey of industry practice. *Engineering, Construction and Architectural Management*, *20*(3), 290–306.

Holmström, J., Ketokivi, M., & Hameri, A.-P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences*, *40*(1), 65–87.

Kamara, J. M., Anumba, C. J., & Carrillo, P. M. (2002). A CLEVER approach to selecting a knowledge management strategy. *International Journal of Project Management*, *20*(3), 205–211.

Kovács, G., & Spens, K. M. (2005). Abductive reasoning in logistics research. *International Journal of Physical Distribution & Logistics Management*, 35(2), 132–144

Lave, J., & Wenger, E. (1998). Communities of practice. *Retrieved June*, *9*, 2008.

Lee, H., & Choi, B. (2003). Knowledge management enablers, processes, and organizational performance: An integrative view and empirical examination. *Journal of Management Information Systems*, *20*(1), 179–228.

Lin, Y.-C., & Lee, H.-Y. (2012). Developing project communities of practice-based knowledge management system in construction. *Automation in Construction*, *22*, 422–432.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company: How Japanese companies create the dynamics of innovation*. Oxford university press.

Shook, J. (2008). Managing to learn: using the A3 management process to solve problems, gain agreement, mentor and lead. Lean Enterprise Institute.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23.

Westerlund, B. (2007). A workshop method that involves users talking, doing and making. In *Proceedings of international conference on human-machine interaction, Human07, IEEE*.

STREAM 1: VALUE IN DESIGN

Mota, B., Biotto, C., Choudhury, A., Abley, S., Kagioglou, M. (2019). "Lean Design Management in a Major Infrastructure Project in UK." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 37–48. DOI: https://doi.org/10.24928/2019/0251. Available at: <www.iglc.net>.

LEAN DESIGN MANAGEMENT IN A MAJOR INFRASTRUCTURE PROJECT IN UK

Bruno Mota[1], Clarissa Biotto[2], Athar Choudhury[3], Simon Abley[4], Mike Kagioglou[5]

ABSTRACT

Lean Design Management (LDM) is a response from the lean construction community to overcome the chaotic design process in the AEC industry. Many tools, processes and methods were adapted to the context of design with limited success. This paper presents the use and adaptation of different lean design tools and processes in two phases of a major infrastructure project in the UK. The project is the new high-speed railway to be the backbone of the UK transport network, and it is considered Europe's largest infrastructure project. The lean design implementation occurred in a Joint-Venture (JV) that had been awarded the main works civils contracts.

This paper also compares the results of combined use of adapted last planner in phase 1 and adapted design structure matrix in phase 2, and identifies some of the practical challenges and benefits of the implementation of lean design management.

The main contribution of this paper is the contextualisation of different project organisational structures and its influence on the success of the LDM tools implementation. Moreover, a common result for both phases is the enhancement of project communication, collaboration, and transparency of information for planning and control of the project activities.

KEYWORDS

Lean design management, last planner system, design structure matrix.

INTRODUCTION

Lean construction had an initial focus on production aspects; nevertheless, design issues gradually started to receive more attention (Jørgensen and Emmitt 2009). The design management has been left to improvisation: poor communication among stakeholders, incomplete documentation for the subsequent process, unclear input information, poorly levelled resources, unbalanced workloads, lack of coordination between different disciplines and erratic decision making (Freire and Alarcon 2002).

[1] Senior Lean Consultant, Logikal Projects, Birmingham, UK, bmota@logikalprojects.com
[2] Post-Doc Researcher, Federal University of São Carlos, São Carlos, Brazil, clerwice@gmail.com
[3] Graduate Consultant, Logikal Projects, Birmingham, UK, achoudhury@logikalprojects.com
[4] Regional Director, Logikal Projects, Birmingham, UK, sabley@logikalprojects.com
[5] Dean, School of Art, Design and Architecture, University of Huddersfield, Huddersfield, UK, M.Kagioglou@hud.ac.uk

Lean process, tools and methods have been developed for the design management to improve these deficiencies (Ballard and Koskela 1998). Although their relevance to the design process, if the lean processes were used integrated, more improvements could have been achieved (Freire et al. 2002). For instance, the work conducted by Koskela et al. (1997) applied Design Structure Matrix (DSM) with the Last Planner System (LPS) improving the design workflow reliability.

This paper presents a case study of lean design management implementation in a major infrastructure project in the UK, in which a set of lean tools were deployed in two phases of the design stage. In phase 1, Collaborative Planning with LPS, and further, in phase 2, DSM incorporated into the Gives & Gets tool, supported by a control room. The integrated use of the lean tools in both phases enhanced the project communication, collaboration, and transparency of information for planning and control the project activities.

The results obtained in both phases were compared highlighting the context in which the lean tools were deployed. Next, the authors identified some of the main benefits of implementing lean design management into a major infrastructure project, its limitations and room for improvement.

The main contribution of this paper is the contextualisation of two different project organisational structures and its influence on the success of the LDM tools implementation.

LITERATURE REVIEW

DESIGN MANAGEMENT

The design process in the AEC industry is known for being problematic (Emmitt et al. 2004), with high levels of rework, change orders, delays and un-constructible solutions for construction (Macomber et al. 2012). In an AEC project, design management is a challenging effort that must deal with increasing architectural complexity, a high number of interdependencies, uncertainty, and erratic decision-making by authorities and clients (Koskela et al. 1997). Likewise, design management in construction projects is often carried out under time pressure which requires a proper planning and control system, with a focus on information flow among participants (Tzortzopoulos et al. 2001).

LEAN DESIGN MANAGEMENT

Lean Design Management (LDM) is a response from the lean construction community to overcome the chaotic design process. It is rooted in the Transformation, Flow and Value (TFV) Theory (Koskela 2000), i.e., it considers the design as a production process (Ballard 2002; Ballard and Koskela 1998). Namely, the design transformation activities should deliver value for the client, while the information flow activities should be reduced and measured by some metrics (action rate, package size, work-in-progress, batch size, development velocity, bottlenecks and rework) (Tribelsky and Sacks 2011).

A set of tools and methods is recommended to facilitate design management and enhance transparency. For instance, the Design Structure Matrix (DSM) and the Last Planner System (LPS) have been deployed in lean design management with some success (Koskela et al. 1997).

Last Planner System in Design

Last Planner System in design management is not as widely used as it is in construction. However, different sorts of projects have tried the LPS in design, such as office buildings (Koskela et al. 1997), small high-tech facilities (Miles 1998), residential condominiums (Tzortzopoulos et al. 2001), theatres (Ballard 1999), hospitals (Hamzeh et al. 2009), factories (Viana et al. 2015; Wesz et al. 2013), and so on (Bolviken et al. 2010; Hamzeh et al. 2009; Khan and Tzortzopoulos 2015).

With some limitations and peculiarities of design context itself, the LPS in design promotes process transparency, designers' collaboration and communication, and the use of project performance measurement (Biotto 2018). LPS limitations refer to the high amount of change orders or delays in the clients' decisions, plus difficulties in executing the lookahead plan, analysing the root causes of tasks non-compliance, and planning the design activities (Biotto 2018).

Due to these challenges, LPS requires more flexibility (Hamzeh et al. 2009). In the past few years, there have been some adaptations of the LPS to the project and design contexts (Bolviken et al. 2010; Tiwari and Sarathy 2012). In the UK, the partial use of LPS is known as Collaborative Planning (CP). The CP is limited to the implementation of a few elements of the LPS in the construction phase, for instance, the collaborative master planning, weekly planning meetings and PPC (Daniel et al. 2017), and its use in the design is still scarce.

Design Structure Matrix

Design Structure Matrix (DSM) to support the flow view in design management. It was presented as a lean design management tool by Koskela et al. (1997). The DSM is a network modelling tool for visually representing elements of a system and their interactions and supporting the decomposition and integration problems (Browning 2001; Eppinger and Browning 2012).

DSM can be applied in different contexts, for example, "product development, project planning, project management, systems engineering and organisation design", i.e., for the product, or process by aggregating individual interactions among components, people, activities, or parameters (Browning 2001; Eppinger and Browning 2012). To be able to define the relationship among elements, it is necessary to have the participation of experts in each activity to know the outputs of each activity; what activities use these outputs; what inputs are necessary; and, what activities produce these inputs (Browning 2001).

Although the DSM is an effective tool to achieve an optimal work sequence, it lacks production control mechanisms. For this reason, DSM has been combined with other lean methods, such as LPS (Hammond et al. 2000).

The success of lean tools for design management still requires further exploration regarding the organisational context. Managers should be able to recognise the potential results achieved by the different lean tools in order to overcome organisational limitations, such as the number of people involved in the design process, the teams composition, staff time availability for meetings, commitment with planning and control, frequency of client's change orders, and so on.

PROJECT DESCRIPTION

The project, considered Europe's largest infrastructure project, is a new high-speed railway in the UK. It has 555km of new track to bridge the gap between the north-south by connecting city centres of London, Birmingham, Manchester and Leeds. The project began in July 2017 and is expected to be completed in 2033. When fully operational, the railway should carry 100 million passengers a year, with up to 48 trains running per hour and 25 stations served directly, cutting journey times across the country.

The project was divided into different areas, which have different schedules. The section between Birmingham and London was divided into another four subsections to facilitate the management. This paper describes the work developed by the joint-venture assigned to one of these subsections which consist of an 80km section with 17 viaducts, 22km of road diversions, 75 overbridges and 24 million cubic metres of excavation.

JOINT-VENTURE DESCRIPTION

The Joint-Venture (JV) described in this paper had been awarded in July 2017 for the main civil work contract. Two major civil engineering and construction companies form the JV, bringing together different specialist in railway networks.

At the JV office, there were 165 employers divided into 19 functions: Procurement, Finance, Safety, Logistics, Risk, among others. All functions were responsible for receiving the drawings from the design subcontractor (a design joint venture - DJV) based across the street, and then, producing deliverables to the owner, e.g. drawings, reports of cost, accessibility, logistic, environmental, programme, risk, health and safety.

The authors of this paper were lean consultants for the JV, hired from July 2018 until January 2019, in order to facilitate the production of these deliverables through the lean design management in the scheme design phase of the project. The consultancy focused on integrating the production from different functions, planning and control the information flow, reducing the lead-time, rework, and times of gathering information.

LDM IMPLEMENTATION PROCESS

In this case study, lean concepts, tools and techniques, shown in Figure 5, had been implemented over the seven months in which the consultants were part of the project. The tools needed to be adapted to changes in the project organisational structure, characterising two different phases of LDM implementation activities.

Figure 5: Lean implementation timeline.

PHASE 1

In phase 1, all the JV functions were working in 'silos' with independent schedules and asynchronous information flow. Moreover, there was an unbalanced workload and no collaboration among the DJV, JV and the owner.

The sequence of the implementation followed the author's experience from previous infrastructure projects, and further, changes in JV organisation.

In phase 1, the main stakeholders (designers, JV and owner) were working separately, and the teams were organised by function. They followed the traditional project hierarchy, and the lean design management focused on the initial necessity of improving the production planning and control process. Namely, it included the activities of production, review and submission of drawings and other deliverables.

PHASE 2

In phase 2, the stakeholders from the design office, the JV and the owner were co-located and mixed into working groups following the type of deliverable (programme, cost, structure, among others). Then, the lean design management focused on identifying the deliverables collaboratively among these working groups in the scheme design phase. These working groups were called OPT (Optimised Project Teams).

LDM DEVELOPMENT IN PHASE 1

COLLABORATIVE PLANNING (CP) SESSIONS

In order to establish a reliable process throughout the scheme design phase and programme development, the Collaborative Planning Sessions were used to set the design goals of the project, define the main phases, and pull the key activities. The sessions were led by the lean consultant who tried to optimise the workflow sequence.

There were two sessions of CP, which were attended by 32 functions leaders and coordinators from 19 different functions. Each swim-lane on the board was a function, and the participants were invited to mark with post-it's the main milestones from their schedules (developed in PrimaveraP6). These sessions promoted a shared understanding among the participants and enabled the teams to analyse the wastes and criticise the former planned programme together. The teams have also identified the interdependencies between functions, improved the sequence of activities, and created a unified and optimised plan based on the combined knowledge and requirements of the participants. Figure 6 and Figure 3 show one of the CP sessions.

The owner and design team were also invited to participate in the CP sessions, which encouraged the collaboration among all members in the project.

Figure 6 and Figure 7: Collaborative Planning Sessions.

Last Planner (LP) Meetings

The information from the Collaborative Planning Sessions was transferred to an MS Excel spreadsheet to enable the weekly meetings. Rather than gather the whole project participants, these meetings occurred independently in each one of the 19 functions.

The Last Planner was adapted to the design stage of the project, i.e., instead of having two separate meetings for planning the make-ready constraints and the weekly production, the LP for the design management combined both in weekly meetings. It was possible due to the "last planner" being responsible for both planning and removing constraints, as well as for producing the deliverables.

In the LP meetings, the employees of each function gathered together independently to plan their weekly production, set the constraints and control the tasks progression using the adapted spreadsheet (Figure 8).

STAGE 1 COORDINATION				MAKE READY															
Today	24-Feb							August											
Task | Milestone	Start Date	Finish Date	Constraints	Owner	Due Date	Removed Date	Status	09 Th	10 F	13 M	14 Tu	15 W	16 Th	17 F	20 M	21 Tu	22 W	23 Th	24 F
Works information ownership review	10-Aug	31-Aug							Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
			Liaise with Glenn C.	Braiden	10-Aug	10-Aug	Removed On Time												
Close GW3 actions	24-Aug	24-Aug																	B
Close GW3 actions	31-Aug	31-Aug																	
			Agree with HS2 with info still needed	Braiden	31-Aug	31-Aug	Removed On Time												

Figure 8: Production control spreadsheet.

Make-Ready Planning

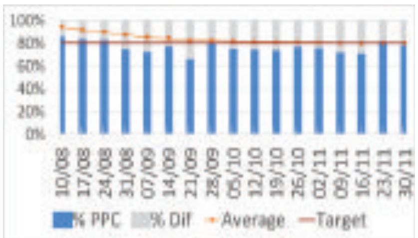
The make-ready planning was a systematic process of identifying and removing constraints to ensure that the tasks forecasted in the Collaborative Planning Sessions were able to be executed. The MS Excel spreadsheet facilitated the visualisation of the constraint's deadlines, its owner, removed date and status. Due to the individual meetings per function, the focus of the constraints was exclusively regarding the function.

The constraints had their status updated weekly: it could indicate removed on-time, removed late or in-progress (open) – see Figure 9. It ensured a smooth production flow and the minimisation of rework and negative iterations.

Figure 9: Constraints removal status.

Commitment Planning

Regarding the commitment planning, it was a process of collaboratively and systematically planning the weekly production, recording progress, looking ahead and adjusting the plan every week. The teams controlled the completion of planned tasks and committed to the next tasks on the following week. They had two metrics: The Percent Planned Complete (PPC)(Figure 10) and Reasons for Tasks Non-completion (Figure 7). The latter was analysed for continuous improvement.



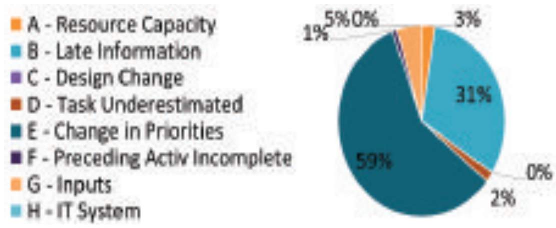


Figure 10: PPC of scheme design. Figure 11: Chart of causes for tasks non-completion.

Even though most of the constraints were removed on time, the PPC shows a decreasing average. Majority of the reasons for non-completion of the tasks were related to 'change in priorities', followed by 'late information', which means that the client used to change requirements and/or number and types of deliverables close to the deadline. This would affect the commitments made during the week and drop the PPC score. This information was taken by the function's leaders to the client every week, during the board meeting, to make the client aware of the effects of late changes.

The Last Planner activities had a duration of over 4 months and stopped after the organisational change into the OPTs.

LDM DEVELOPMENT IN PHASE 2

GIVES & GETS

The Gives & Gets Matrix is an adapted Design Structure Matrix. In the project, it was an effective way of getting teams to work together, recognising the information each other required, transitioning from "over the wall" approach between functions of different companies, to work groups composed by employees from the three companies (design office, JV and the owner) that shared the same deliverable and goal.

It worked similarly as the constraint analysis on the LP: responsibilities, deadlines and status were appointed between parties to keep track of what is required, forming a constructive way to ensure the needs are understood and met. This information was added to cards and posted on a board (Figure 12).

Figure 12: Gives & Gets cards and panel.

This was integrated into the programme to ensure that tasks could be tracked, allowing the teams to see in which manner their collaboration could positively influence activities. Furthermore, a heat map was produced to colour coordinate the more intense areas with greater Gives & Gets, to be focused on enhancing delivery between teams (Figure 13).

Total of Gives/Gets 58	OPT 1 Earthworks/ Drainage	OPT 2 Structures	OPT 3 Environment	OPT 4 Indirects	OPT 5 Stage 2 Delivery Model	OPT 6a EWC/L&P	OPT 6b Mob/Long lead items	IDT VE/ Optimisation	IDT Stage 1 close out	IDT Schedule	IDT Estimate	IDT Risk
Earthworks/Drainage		1	1	0	0	0	0	0	0	0	0	0
Structures	1		2	0	0	0	0	6	3	0	0	0
Environment	2	0		0	0	1	0	0	0	0	0	0
Indirects	2	0	0		1	2	1	0	0	0	2	0
Stage 2 Delivery Model	1	1	1	1		0	0	0	0	1	0	0
EWC/L&P	0	0	0	0	0		0	0	0	0	0	0
Mob/Long lead items	0	0	0	0	0	0		0	0	1	0	0
VE/Optimisation	0	0	0	0	0	0	0		0	0	0	0
Stage 1 close out	0	0	0	0	0	0	0	0		0	0	0
Schedule	1	1	6	2	2	1	2	2	1		2	0
Estimate	0	1	3	0	0	0	0	0	0	1		1
Risk	0	0	0	0	0	0	0	0	0	0	1	

Figure 13: Gives & Gets heatmap.

CONTROL ROOM (*OBEYA*)

Based on the Japanese *Obeya*, the room was critical to develop the visual management. Relevant information was exposed to conducting fact-based decision making. It contained visually engaging charts and graphs depicting the programme, cost, milestones and progress-to-date information (Figure 14).

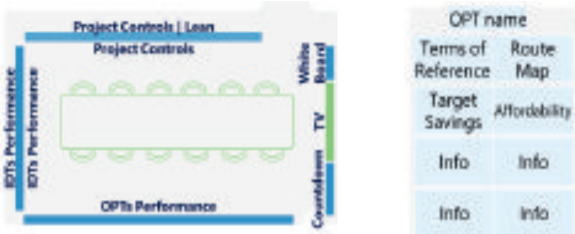


Figure 14: Control room details.

The control room accelerated decision making, encouraged collaboration, built leadership, made the organisation more agile to solve issues, increased the transparency and drove the project management toward a team level.

DISCUSSION: COMPARING PHASE 1 VS. PHASE 2

The lean design implementation bridged the communication gap between stakeholders to significantly increase collaboration, boost project success, and reduce risk. It is important to highlight the following points which have been crucial to its progress:

- Creation of the collaboration culture among teams;
- Stakeholders involvement in the early stages of lean design implementation;
- Understanding and acceptance of project context: changes of requirements and deadlines by the client were constant, and the teams needed to adapt to it.

Comparing the tools and processes of Phases 1 and 2, it was noticed that (see Table 1):

On Phase 1, there was better control over the function's activities, mainly because of the weekly metrics, such as the PPC. The functions were more focused on their weekly activities, commitments and constraints. The CP sessions were the main opportunity for the participants to visualise the relationship and constraints between the functions.

On Phase 2, changing the project organisational structure from "silos" to the OPTs improved the collaboration and the visualisation of constraints between the working groups. The co-location of these people in working groups enhanced problem-solving and made the process more agile. The Gives & Gets had a better result regarding engagement and the number of constraints compared to Phase 1. Despite the fewer control measurements, the teams were collaborating and exchanging more information. The control room was also a fundamental support for the visual management of the design phase.

Table 2: Comparison between LDM in Phases 1 and 2.

	LDM in Phase 1	LDM in Phase 2
Project organisation	Silos: over the wall approach (segregated functions)	Cross-functional teams (OPTs)
LDM method to Master Planning	Collaborative Planning Sessions to integrate different functions schedules	Primavera P6 file
LDM method to Make Ready Planning	Adapted LPS (integrated meetings)	Gives & Gets
LDM method to Weekly Planning		Primavera P6 file
Visual management	CP post-its; Charts of metrics (only electronic report)	Control Room; Gives & Gets cards and panel
Meetings frequency	Weekly	Weekly
Metrics	Constraints status, PPC, Reasons for non-completion	Deliverables status
Number of people involved	165 people	≈ 250 people
Co-located work	No. Only the same function employees.	Yes

LDM RESULTS

It is possible to identify some key benefits of the lean design management in both phases, also some limitations to the applicability of the tools, and some aspects to be improved.

Key Benefits

It was possible to uncover a wide range of factors related to the successful lean design implementation in the project:

- Organisational culture and structure: A key challenge during the early stages of lean implementation was to engage all staff in the process as quickly as possible. Changing the project organisational structure facilitated the planning of constraints and improved staff engagement.
- Effective communication: The high participation in the Collaborative Planning Sessions and the commitment to the weekly meetings showed engagement and a great sharing of knowledge between stakeholders. The Gives & Gets were also an essential contributor to collaboration because it increased transparency regarding the needs between working groups.
- Teamwork: with the creation of the OPTs, the hierarchical boundaries were reduced, and it created a sense of collaborative work between the different stakeholders.

Limitations

Some limitations were found during the lean design implementation, such as: 1. The lack of lean knowledge of the stakeholders; 2. The several change orders from the client; and, 3. The rigidity and long lead-time of working in 'silos' without collaboration between project staff and other stakeholders.

What to Improve

For the continuity of the implementation at the project and the replication in others, some improvements need to be made, such as: Have a better requirements management to understand the client's needs and to improve the change management regarding the deliverables; Deploy lean training for all stakeholders at the beginning of the implementation; Feedback data from the weekly plans to the master plan to allow re-planning and data-driven improvement; Combine the Last Planner with the Gives & Gets and the Control Room; and, Deploy a proper lean maturity assessment to provide better support and direction to the lean implementation.

CONCLUSIONS

The dynamic, rapidly changing, and complex project environment continues to demand excellence in management. Improving efficiency in the delivery of major projects is a common demand of owners. The lean design management showed great potential for continued application in the project, which made impressive advances despite all the challenges of the design context of a major project.

In phase 1, the use of collaborative planning sessions is crucial to integrate different function schedules. However, it is difficult to visualise the constraints across the functions. The LPS was important to formalise the planning and control process, providing more metrics for continuous improvements, such as the PPC and chart for reasons of noncompliance. Both tools were applied in a rigid organisational structure, i.e., the "silos" teams. Collaboration in this context was difficult to achieve.

In phase 2, when the project changed its organisational structure into cross-functional teams, the collaboration increased, despite the increase in the number of people involved. The visualisation of constraints among the teams was facilitated by the DSM matrix incorporated in the Gives & Gets tool. The few metrics in phase 2 was overcome using the control room, which enhanced the visual management of the design process.

The improvements made in a short time frame indicate that the lean efforts are worth continuing moving forward. By tackling the barriers, lean design management is a suitable effort for improving performance and embedding a continuous improvement culture in the project. Thus, the project had effectively adapted lean to the design phase.

ACKNOWLEDGEMENTS

The authors would like to thank the project team for the effort in the lean design management implementation under Logikal's consultant partnership. The second author would like to thank the Coordination for the Improvement of Higher Education Personnel-Brazil (CAPES) for supporting the Post-Doc research and participation in the conference.

REFERENCES

Ballard, G. (1999). "Can pull techniques be used in design management?" *Concurrent Engineering in Construction.* Helsinki, Finland, 149-160.

Ballard, G. (2002). "Managing work flow on design projects: a case study." *Engineering, Construction and Architectural Management*, 9(3), 284-291.

Ballard, G., and Koskela, L. (1998). "On the agenda of design management research."

Biotto, C. (2018). "Integration of overlapped design and construction stages through location-based planning tools." Doctorate, University of Huddersfield, Huddersfield.

Bolviken, T., Gullbrekken, B., and Nyseth, K. (2010). "Collaborative Design Management." *Proc., 18th Annual Conference of the International Group for Lean Construction*, 103-112.

Browning, T. R. (2001). "Applying the design structure matrix to system decomposition and integration problems: a review and new directions." *IEEE Transactions on Engineering Management*, 48(3), 292-306.

Daniel, E. I., Pasquire, C., Dickens, G., and Ballard, H. G. (2017). "The relationship between the last planner® system and collaborative planning practice in UK construction." *Engineering, Construction and Architectural Management*, 24(3), 407-425.

Emmitt, S., Sander, D., and Christoffersen, A. K. (2004). "Implementing Value Through Lean Design Management." *Proc., 12th Annual Conference of the International Group for Lean Construction*.

Eppinger, S. D., and Browning, T. R. (2012). "Introduction to Design Structure Matrix Methods." *Design Structure Matrix Methods and Applications*, MIT Press, 1-15.

Freire, J., and Alarcon, L. F. (2002). "Achieving Lean Design Process: Improvement Methodology." *Journal of Construction Engineering & Management*, 128(3), 248.

Hammond, J., Choo, H. J., Austin, S., Tommelein, I. D., and Ballard, G. (2000). "Integrating Design Planning, Scheduling, and Control With DePlan." *Proc., 8th Annual Conference of the International Group for Lean Construction*.

Hamzeh, F. R., Ballard, G., and Tommelein, I. D. (2009). "Is the Last Planner System applicable to design? A case study." 165-176.

Jørgensen, B., and Emmitt, S. (2009). "Investigating the integration of design and construction from a "lean" perspective." *Construction Innovation*, 9(2), 225-240.

Khan, S., and Tzortzopoulos, P. (2015). "Improving Design Workflow With the Last Planner System:Two Action Research Studies." *Proc., 23rd Annual Conference of the International Group for Lean Construction*, 568-574.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*, VTT Technical Research Centre of Finland.

Koskela, L., Ballard, G., and Tanhuanpää, V.-P. (1997). "Towards lean design management." *5th Annual International Group for Lean Construction*, International Group for Lean Construction, Gold Coast, Australia.

Macomber, H., Howell, G., and Barberio, J. (2012). "Target-value design: Nine foundational practices for delivering surprising client value."

Miles, R. S. (1998). "Alliance Lean Design/Construct on a Small High Tech Project." *Proc., 6th Annual Conference of the International Group for Lean Construction*.

Tiwari, S., and Sarathy, P. (2012). "Pull Planning as a Mechanism to Deliver Constructible Design." *Proc., 20th Annual Conference of the International Group for Lean Construction*.

Tribelsky, E., and Sacks, R. (2011). "An Empirical Study of Information Flows in Multidisciplinary Civil Engineering Design Teams using Lean Measures." *Architectural Engineering and Design Management*, 7(2), 85-101.

Tzortzopoulos, P., Formoso, C. T., and Betts, M. (2001). "Planning the Product Development Process in Construction: An Exploratory Case Study." *Proc., 9th Annual Conference of the International Group for Lean Construction*.

Viana, D., Tillmann, P., Sargent, Z., Tommelein, I., and Formoso, C. (2015). "Analysis of HVAC Subcontractor Mechanisms for JIT Materials Supply to a Construction Site." *Proc., 23rd Annual Conference of the International Group for Lean Construction*, 246-255.

Wesz, J. G. B., Formoso, C. T., and Tzotzopoulos, P. (2013). "Design process planning and control: Last planner system adaptation." 365-374

Giménez, Z., Mourgues, C., Alarcón, L.F., Mesa, H. (2019). "Proposal of a Model for Measuring Value in the Design Process." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 49–62. DOI: https://doi.org/10.24928/2019/0196. Available at: <www.iglc.net>.

PROPOSAL OF A MODEL FOR MEASURING VALUE IN THE DESIGN PROCESS

Zulay Giménez[1], Claudio Mourgues[2], Luis F. Alarcón[3] and Harrison Mesa[4]

ABSTRACT

Among the current challenges associated with design in the Architecture, Engineering and Construction (AEC) industry is the need for an adequate understanding of the value required by involved customers to avoid decreases in productivity and value losses in the process and product. This paper describes the development of a value analysis model with the conceptual basis of Design Science Research (DSR) and based on Kano's model, which seeks to accomplish the following: (1) identify the desired value of the different clients in the process; (2) understand the value generation process; and (3) conveniently recognize and manage value losses. This paper is based on an existing case study of the Kano´s model found in the literature to evaluate the proposed model. The main contribution is the creation of 3 value indexes—Desired, Potential and Generated—which inform designers of the presence of different degrees of value losses and support the improvement of the capture of requirements and the knowledge of customer satisfaction conditions. The current limitation of the model is the noncorporation of the utilized resources as part of the value equation.

KEYWORDS

Value, value losses, kano model, design science, value index, value analysis

INTRODUCTION

The Architecture, Engineering and Construction (AEC) industry recognizes the design process as a key to the success (or failure) of projects(Knotten et al. 2016). Although design costs are often less than one percent of the life cycle cost of a project(Andi & Minato 2003), they have a major influence on the total cost and performance of the project(Love et al. 2013).

[1] PhD. cadidate, School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile. E-Mail: zmgimenez@ing.puc.cl

[2] Associate Professor of Civil Engineering, School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile. E-Mail: cmourgue@ing.puc.cl

[3] Professor of Civil Engineering, School of Engineering , Pontificia Universidad Católica de Chile, Santiago, Chile. E-Mail: lalarcon@ing.puc.cl

[4] Assistant Professor of Civil Construction, School of Civil Construction, Pontificia Universidad Católica de Chile, Santiago, Chile.

The decrease in productivity of the AEC industry, rework and construction failures are partly attributed to design flaws(Andi & Minato 2003). The most important reasons for project failure include incomplete requirements, unrealistic expectations, multiple changes in requirements and specifications, and lack of user involvement(The Standish Group 2014). In the construction industry, user interaction during the design process has traditionally be considered to be as a nuisance(Arge 2008). The conditions of customer satisfaction are poorly known; an extensive knowledge of "how to do things" (technology and business model) exists with an inadequate understanding of patterns of lifestyles, work and learning(Kumar & Whitney 2007). If customer values are not fully understood in a construction project, the result will probably be low compliance with customer expectations or multiple modifications during the project(Spiten et al. 2016), which represents value losses from the value perspective proposed by Koskela (2000) because part of the value is not provided even though it is potentially possible.

Challenges associated with design include the appropriate formulation of requirements and interactive and multidimensional management to represent the interests of stakeholders(Male et al. 2007). Most design deficiencies are identified at a later stage (during construction), with the possibility that some deficiencies will remain undetected(Love et al. 2013).

This paper describes the development of a value analysis model in real estate design. To address these challenges, it is necessary to understand how the value is generated during the design process. Understanding value as the relationship between the fulfilment of needs and the utilized resources (Association Francaise de Normalisation 2000), this model seeks to accomplish the following: (1) identify the desired value of the different clients in the process via the classification of requirements; (2) understand the process of generating value in the design; and (3) conveniently recognize and manage value losses.

BACKGROUND

CONCEPT OF VALUE

Value is defined as the relationship between the fulfillment of needs and the resources that are implemented for this fulfillment(Association Francaise de Normalisation 2000). Historically, the value of the project was communicated in monetary terms as a relationship between costs and benefits(Rachwan et al. 2016). Currently, we can visualize different concepts of value with a similar approach: value is expressed as a relation between function and total life cycle cost of this function(Orihuela et al. 2015), or as the relation between "what you get/what you give", "balance of benefits and sacrifices involved in a value judgment"(Saxon 2005) and the relation between the value of the product of a process and the value (or cost) of the inputs for this process(Koskela 2000). These definitions are related, as shown in Figure 1.

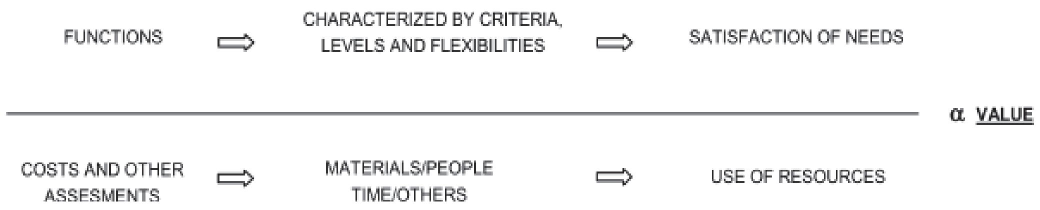


Figure 1. Relationships between the elements that build value(Association Francaise de Normalisation, 2000).

Other research defines value in terms of use, exchange/replacement, performance, and estimated cost(Rachwan et al. 2016). Value is not absolute; value is relative and is perceived in different ways by different parties in different situations(Cuperus & Napolitano 2005), and it is dependent on the theoretical context, subjective perceptions and evaluative judgements(Drevland & Lohne 2015), it means that value for one person is different from value for other people(Koskela 2000).

In the context of Lean Production, value is defined from the perspective of customers(Womack & Jones 1996); it is an assessment that is made in relation to a series of concerns that someone wants to address(Macomber et al. 2007) to obtain a desired product(Bølviken et al. 2014) and to determine what customers need to achieve their goals(Rybkowski et al. 2012).

DESIGN AS PRODUCTION

Design is a systematic process for identifying, exploring and exploiting value opportunities(Lee & Paredis 2014). Although there are differences between material production and the intellectual activity of design (greater iteration and uncertainty in design and greater repetition of activities in production), design is visualized as a productive process from three points of view: transformation, flow and value generation(Koskela 2000).

While the transformation and flow perspective internally focuses on the production process in a manner in which it is efficiently performed and eliminates waste or activities that do not add value, the value perspective focuses on the external result of the process, where the value of the client is created by compliance with its requirements and elimination of value losses (value achieved in relation to the best possible value)(Koskela 2000).

VALUE MANAGEMENT

Value management, which is also known as value analysis, value methodology or value engineering(Rachwan et al. 2016), is a management style that has evolved from previous methods based on the concept of value and a functional approach. In value management, an objective setting considers the psychological needs and desires of the participants, and subsequent analysis considers the deviation between the desired value and that offered by existing macro and micro environments; once this value gap has been identified, participants approve the criteria for seeking the desirable value(Leung & Liu 1998).

KANO MODEL

The Kano model (1984) is an effective tool for the identification and interpretation of the "voice of the client" because it enables a singular classification of the customer's requirements (attributes) toward the product and its subsequent characterization in the design(Arroyave et al. 2007).

Kano et al (1984) categorize attributes as follows (Matzler et al.): (1) Must-be (M): these are the basic elements of a product; if these attributes are not satisfied, extreme customer dissatisfaction will ensue. (2) One-dimensional (O): customer satisfaction is proportional to the level of compliance with these attributes. (3) Attractive (A): these are attributes that are not explicitly expressed or requested by the customer, but they have a substantial influence on the satisfaction of a customer with a particular product. (4) Indifferent (I): the presence or absence of these attributes does not contribute to either increasing or decreasing customer satisfaction. (5) Reverses (R): these product characteristics are not desired by the customer; rather, the opposite characteristics are expected (Matzler et al. 1996). Figure 2 graphically depicts the Kano model.

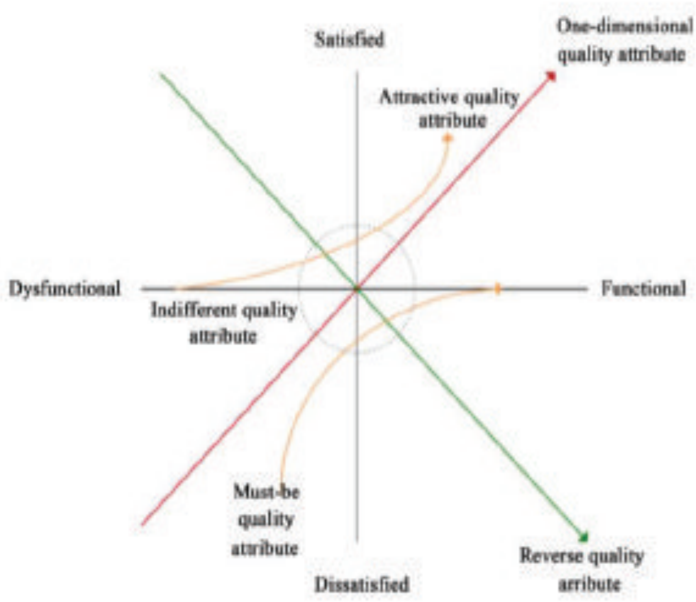


Figure 2. Kano Model(Huang 2017)

KANO QUESTIONNAIRE

To implement the Kano model, a two-dimensional questionnaire is prepared, i.e., two questions for each product/service attribute(Huang 2017). The goal of the first question is to learn how customers feel if the proposed feature is present (functional question), while the goal of the second question is to learn how customers feel if the intended feature is not present (dysfunctional question). Each of the questions has the following answer options: 1. Like, 2. Must-be, 3. Neutral, 4. Live with, and 5. Dislike.

After administering the survey, the results are evaluated with the matrix shown in Table 1 to determine how most clients expressed their needs. Two possible contradictory responses exist; they are expressed as questionable (Q).

Table 1. Kano's evaluation matrix(Huang 2017)

Functional	Dysfunctional				
	Like	Must-be	Neutral	Live-with	Dislike
Like	Q	A	A	A	O
Must-be	R	I	I	I	M
Neutral	R	I	I	I	M
Live-with	R	I	I	I	M
Dislike	R	R	R	R	Q

A = Attractive, I = Indifferent, M = Must-be, O = One-dimensional, Q = Questionable, and R = Reverse.

COEFFICIENT OF SATISFACTION

If the percentage of one of the categories is substantially higher than the other categories, the result is considered to be conclusive. When two Kano categories have the same assessment or very similar assessments of the first score, other considerations should be taken(Berger et al. 1993). Berger et al. (1993) proposed the coefficient of satisfaction to relate other categories to determine both the satisfaction and the dissatisfaction levels(Matzler et al. 1996), which indicates the average impact of the requirements on the satisfaction of all customers(Tontini 2002). This coefficient considers the best value or degree of satisfaction (SI) and the worst value or degree of dissatisfaction (DI) with the following formulas:

$$SI = (A+O)/(A+O+M+I); \quad DI = (M+O)/(A+O+M+I)$$

A: Attractive, O: One-dimensional, M: Must-be, I: Indifferent

After calculating the SI and DI results, the coordinate system shown in Figure 3 is employed, in which the X coordinate represents SI and the Y coordinate represents DI. Each attribute is assigned to one of the quadrants of the coordinate axis, which corresponds to the categories of Kano(Huang 2017). In this way, a more distinct classification is obtained, especially in the previously mentioned cases.

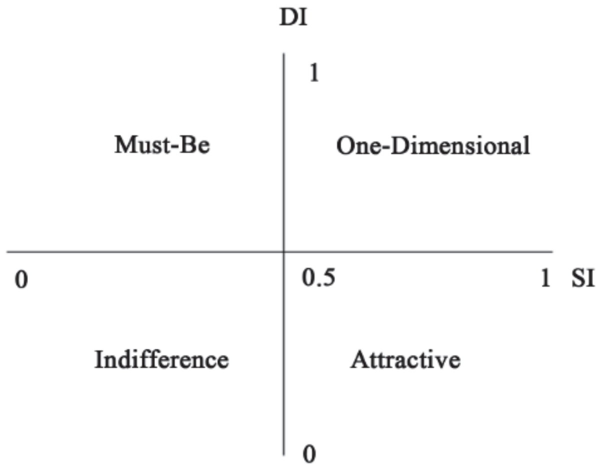


Figure 3. Coordinate system of the Kano type.(Huang, 2017)

RESEARCH PURPOSE

The development of a value analysis model is proposed for application in the design process to understand the process of value generation and value losses via the classification of requirements and the formulation of value indicators.

RESEARCH METHODOLOGY

The analysis model has been developed on the conceptual basis of Design Science Research (DSR). DSR is based on three inherent research cycles(Hevner 2007). The Relevance Cycle connects the contextual environment of the research project with the scientific design activities. The Rigorous Cycle connects the scientific activities of design with the knowledge base of the scientific bases, experience and knowledge that comprise the research project. The central design cycle is inserted between the main construction activities and the evaluation of research design products and processes. The model has not been formally applied in context. Therefore, a case that was investigated by Huang(2017) will be used to settle this limitation.

DEVELOPMENT OF THE MODEL

The value analysis model shown in Figure 4 proposes to analyze the object to be evaluated (design inputs, design process and design product) and relate it to the phase of the project (pre-design, design, pre-construction and construction) and the customer involved (user, owner, specialties, reviewers and builders). Each of these clients in the different stages of the design process has a desired value with respect to the product, sub-product or design process. This information is projected to determine the desired value and the potentially possible value within the considered phase and obtain the Desired Value and Potential Value Indexes. In the design phase, the value is generated; therefore, the Generated Value Index can be obtained. This last index can be compared with previous indexes to determine if a sufficient value has been generated or if losses of value are identified. How the indexes are determined will be subsequently explained.

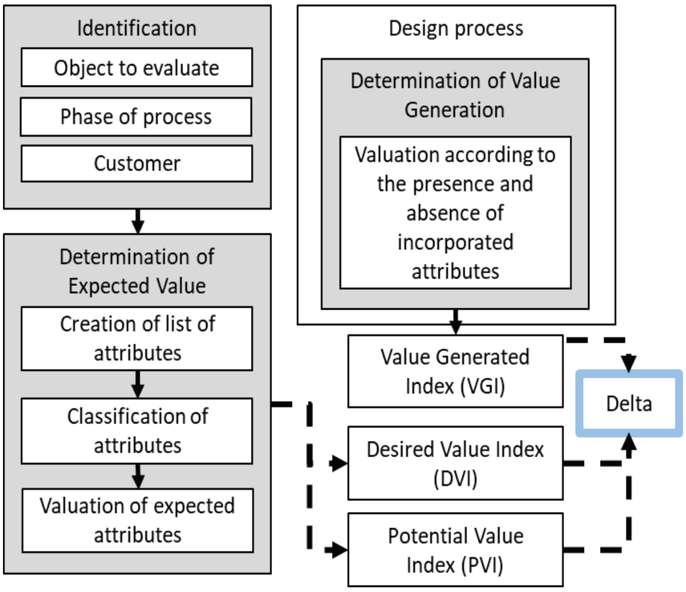


Figure 4. Proposed Value Analysis Model

Determination of Desired Value and Potential Value

Step 1: Elaboration of the list of attributes. In this list of attributes, must be customer needs and requirements must be considered. Delphi's method is proposed to create this list due to the importance of the systematic use of a judgment issued by a group of experts in the area. The list should also be supported by a review of literature, review of regulations and previous experience.

Step 2: Attribute classification. Attributes should be classified because some attributes do not have the same value for the client. For this reason, the use of the Kano model has been considered. Attributes that must be fulfilled by regulations, are considered like “must-be”, are not included in the Kano questionnaire, and the remainder of the attributes are surveyed. If any doubt exists regarding the classification, the satisfaction coefficient proposed by Berger et al.(1993) is applied. In making this coefficient originally, questionable and reverse answers were consciously ignored(Berger et al. 1993). The reason is not questioned and is beyond the scope of this paper. However, in this research, reverse attributes are included within the coefficient because their presence may negatively influence it. For this reason, the reverse attribute will be included in the satisfaction coefficient as follows:

$$SI = (A+O-R)/(A+O+M+I+R); \qquad DI = (M+O+R)/(A+O+M+I+R).$$

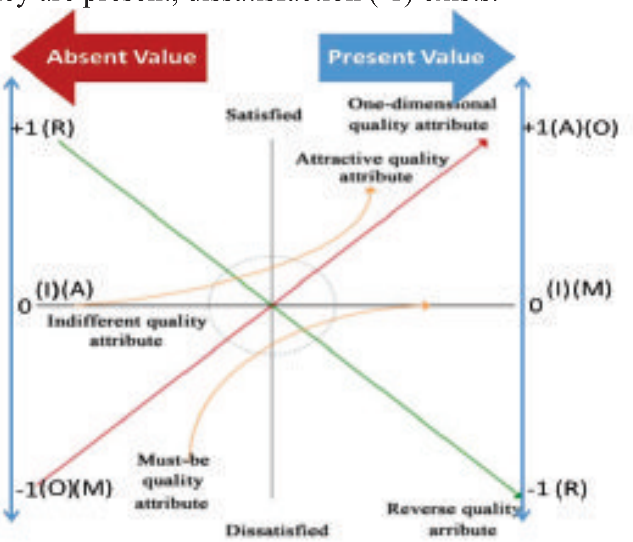
A: Attractive, O: One-dimensional, R: Reverses, M: Must-be, I: Indifferent

As an example, Table 2 shows a hypothetical case of two attributes after being surveyed. R1 shows equal results towards the Reverse and Indifferent classification (R=20, I=20); thus, we should use the coefficient of satisfaction (CS) to decide. Since the opposite attribute is not considered in the calculation, the result would be Indifferent. Using the formula, including the reverse attributes, the SI takes a negative value (SI-R=-0.38), which would not be among the four quadrants proposed in Figure 3 and indicates that their satisfaction would decrease to levels that are substantially lower than desired. Considering that indifferent attributes are neutral for the client and the inclusion of reverses is not desirable, classifying an attribute as reverse rather than assuming it is indifferent is preferable. Likewise, R2 is a reverse requirement based on the majority of the answers. If we wanted to corroborate the information using the CS, the rating would be erroneously changed to indifferent.

Table 2. Examples of Classification of Reverses Attributes

Req	M	O	A	I	R	Q	T	% 1st response	KANO	SI	DI	CS	SI-R	DI-R	CS-R
R1	2	2	1	**20**	**20**	2	47	43%	R-I	0,12	0,16	I	-0,38	0,53	R
R2	3	0	5	12	**27**	0	47	57%	R	0,25	0,15	I	-0,47	0,64	R

<u>Step 3: Attribute Valuation.</u> Based on Kano's model and the behavior of each of the attributes, two rates are established, a rate of absence and a rate of presence of each attribute, as shown in Figure 5. In this way, if the attractive (A) are present, they have a value of 1 or higher; if they are not present, their value is 0. If must-be (M) is present, do not add customer satisfaction (0). If they are absent, they generate high dissatisfaction; thus, the rating is -1 or lower. The Indifferent (I) is the same regardless if they are present or not; in both cases, their value is 0. The reverses (R) are positively valued if they are absent (1); if they are present, dissatisfaction (-1) exists.



	Value	
Req.	Present	Absent
A	≥ 1	0
O	1	-1
M	0	≤ -1
I	0	0
R	-1	1

Figure 5 Attribute Valuation(Huang 2017)Edited version

After these rates have been defined, only the requirements that are expected are considered. One-dimensional and must-be attributes are expected to be present and reverses are expected to be absent. Attractive attributes are not expected, and with respect to the indifferent, the position is neutral, as shown in Table 3.

Table 3. Present and absent values of expected attributes

		Desired Value	
Req.	Expected?	Presence	Absence
Attractive (A)	No	-	-
One-dimensional (O)	Yes, present	1	-

Must-be (M)	Yes, present	0	-
Indifferent (I)	Neutral	-	-
Reverse (R)	Yes, absent	-	1

The classified attributes are multiplied by their values. All ratings are added, and the Desired Value Index is established, which is the sum of the ratings of all attributes with respect to the total number of attributes. The Potential Value Index is the sum of the desired value index and the percentage of attractive attributes.

DETERMINATION OF THE VALUE GENERATED

Value is generated in the design phase for the process and the product. Based on the list of attributes that were previously classified, designers will decide whether to incorporate the attributes that they consider within the design product and/or process. Berger et al.(1993) recommend prioritizing decisions in the following order: M > O > A > I. Our recommendation is M > O > R (absence)> A > I.

Finally, the number of attributes per type incorporated or not incorporated are added; these attributes are estimated to determine the value that was actually generated in the design. All ratings are added, and the Generated Value Index is established, which is the sum of the ratings of all present and absent attributes with respect to the total number of attributes. This index can be compared with the Desired Value Index and the Potential Value Index.

EXAMPLE USING A CASE STUDY

A case studied by (Huang 2017) is analyzed, which he applies Kano's model for the requirements analysis of a project consulting company based in Guangzhou; the main activity of the company is the design and construction of highways. Eighteen attributes were established (their names are not relevant), and 41 professionals were consulted among company managers and staff. For exercise purposes, two attributes that are considered reverses will be included for a total of 20 attributes.

DETERMINATION OF DESIRED AND POTENTIAL VALUE INDEX

Table 4 shows the classification of the attributes, according to Kano, the Coefficient of Satisfaction (CS) and the CS considering the Reverses (CS-R). The classification according to CS-R is the classification that will be conclusive. Therefore, we have 1 attractive attribute (A), 4 One-dimensional (O), 10 Must-be(M), 3 Indifferent (I) and 2 Reverse(R). To calculate the Desired Value Index, only O, M and R are considered; thus, we would have a desired value index of 0.30. The potential value would be the latter added to the percentage of attractive attributes. The results are shown in Table 5.

Table 4. Attribute Classification(Huang 2017) Edited version

Req	Must be M	One-d O	Attract. A	Indiffer. I	Reverse R	Quest Q	Total T	% 1st response	KANO	SI	DI	CS	SI-R **	DI-R **	CS-R **
R1	23	12	4	2	0	0	41	56%	M	0,39	0,85	M	0,39	0,85	M
R2	24	11	4	1	0	1	41	59%	M	0,38	0,88	M	0,38	0,88	M
R3	31	6	3	1	0	0	41	76%	M	0,22	0,90	M	0,22	0,90	M
R4	27	3	5	4	1	1	41	66%	M	0,21	0,77	M	0,18	0,78	M
R5	29	4	7	1	0	0	41	71%	M	0,27	0,80	M	0,27	0,80	M
R6	15	4	1	20	1	0	41	49%	I	0,13	0,48	I	0,10	0,49	I
R7	13	9	14	3	0	2	41	34%	A	0,59	0,56	O	0,59	0,56	O
R8	30	10	1	0	0	0	41	73%	M	0,27	0,98	M	0,27	0,98	M
R9	10	29	2	0	0	0	41	71%	O	0,76	0,95	O	0,76	0,95	O
R10	32	8	1	0	0	0	41	78%	M	0,22	0,98	M	0,22	0,98	M
R11	3	8	6	21	2	1	41	51%	I	0,37	0,29	I	0,30	0,33	I
R12	25	8	2	4	1	1	41	61%	M	0,26	0,85	M	0,23	0,85	M
R13	26	9	3	3	0	0	41	63%	M	0,29	0,85	M	0,29	0,85	M
R14	20	13	4	3	0	1	41	49%	M	0,43	0,83	M	0,43	0,83	M
R15	19	17	4	1	0	0	41	46%	M	0,51	0,88	O	0,51	0,88	O
R16	17	20	2	2	0	0	41	49%	O	0,54	0,90	O	0,54	0,90	O
R17	7	9	19	5	1	0	41	46%	A	0,70	0,40	A	0,66	0,41	A
R18	5	13	3	16	3	1	41	39%	I	0,43	0,49	I	0,33	0,53	I
R19*	2	2	1	20	20	2	47	43%	R-I	0,12	0,16	I	-0,38	0,53	R
R20*	3	0	5	12	25	0	45	56%	R	0,25	0,15	I	-0,44	0,62	R
*requirements included as an example									**coefficient includes reverse requirements						

Table 5. Determination of Desired Value Index and Potential Value

Req	Quantity	%	Value present	Value absent	Desired present	Desired absent	total
A	1	5%	1	0	-	-	0
O	4	20%	1	-1	1	-	4
M	10	50%	0	-1	0	-	0
I	3	15%	0	0	-	-	0
R	2	10%	-1	1	-	1	2
	20	100%					6
					DVI	6/20	0,30
					PVI		0,35
					DVI/PVI		0,86

DETERMINATION OF GENERATED VALUE INDEX

Following the previous example, different hypothetical scenarios are shown. Value 1 has been considered for the presence of an attractive attribute, and -1 has been considered for the absence of a must-be attribute. These values can be modified according to the importance of the impact of the presence/absence of these attributes and can be higher than 1 or lower than -1. Table 6 shows the 3 possible scenarios.

Table 6. Determination of Generated Value Index. Three possible scenarios.

				Scenario 1			Scenario 2			Scenario 3		
		Value		Attributes			Attributes			Attributes		
	Quantity	present	absent	present	absent	score	present	absent	score	present	absent	score
A	1	1	0	1	0	1	0	1	0	1	0	1
O	4	1	-1	3	1	2	4	0	4	4	0	4
M	10	0	-1	9	1	-1	10	0	0	10	0	0
I	3	0	0	3	0	0	1	2	0	1	2	0
R	2	-1	1	1	1	0	0	2	2	0	2	2
	20			17	3	2	15	5	6	16	4	7
					GVI	0,10		GVI	0,30		GVI	0,35
DVI 0,30		Desired value fulfillment			DVF	33%		DVF	100%		DVF	117%
PVI 0,35		Potential value fulfillment			PVF	29%		PVF	86%		PVF	100%

Scenario 1. Loss of value. Not all expected attributes were satisfied. The desired value was an index of 0.30 (DVI), and 0.10 was obtained (GVI), i.e., 33% of the value expectation was satisfied. With respect to the potentially possible value (PVI), only 29% of the value expectation was achieved (PVF).

Scenario 2. Fulfillment of 100% of the desired value. In this case, all expected attributes were satisfied, i.e., all must-be, and one-dimensional attributes were included, and opposites were excluded. 100% of the desired value was achieved (DVI=GVI). With respect to the potentially possible value (PVI), 86% was satisfied (PVF).

Scenario 3. Fulfillment of potential value. In this case, all expected attributes were satisfied, and due to the incorporation of attractive attributes 100% of the potentially possible value was achieved.

CONCLUSIONS

The model is flexible and adaptable to various study needs. With respect to the attributes to be evaluated, the model can be channeled to a specific area; for example, it is possible to apply this model if you want to evaluate the value generated by sustainability aspects or in another area. In the same way, the value expectations of one target population or how the different design schemes satisfy the conditions of customer satisfaction can be compared.

The application of the developed value analysis model favors the identification of the desired value of the different clients within the design process, the understanding of value generation, and the timely identification of value losses. The use of value indexes supports the design process in improving the capture of requirements and the knowledge of customer satisfaction conditions. The inclusion of 3 indexes that can be used separately or simultaneously is a key factor of this model. The comparison of the value generated with respect to the desired or potential value indexes can be applied to determine the value losses related to noncompliance with the desired value or the potentially possible value. With these Value indexes is possible clearly identify when the desired value is not satisfied, when the desired value is satisfied but the potentially possible value is not satisfied, and when this potential value is satisfied, which may exceed the desired value depending on the attractive value considerations that exist in the study. Evolution of the different indexes can also be investigated, which demonstrates the dynamic change in customer preferences.

The benefits of the model have not been quantified, but it is expected that designers can make informed decisions in the process, avoiding value losses and generating the value required by different customers. Among the challenges associated with the model is the incorporation of the resources that are employed as part of the value equation and the evaluation of the impact that the incorporation of the proposed value indexes may have in the process.

ACKNOWLEDGMENTS

The authors would like to acknowledge the funding and support provided by FONDECYT (1181648) and GEPUC to develop this research and CONICYT-PCHA/National Doctorate/2016-21160571 for funding the postgraduate studies of Zulay Giménez.

REFERENCES

Andi, & Minato, T. (2003). Design documents quality in the Japanese construction industry: Factors influencing and impacts on construction process. *International Journal of Project Management*. https://doi.org/10.1016/S0263-7863(02)00083-2

Arge, K. (2008). *Tverrfaglighet og fagkompetanse i prosjekters tidligfase*. Oslo, Norway, Norway.

Arroyave, C., Maya, A., & Orozco, C. (2007). *Aplicación de la metodología qfd en el proceso de ingeniería de requisitos*. Universidad EAFIT, Medellín, Colombia.

Association Francaise de Normalisation. (2000). *French standard NF EN 12973*. France.

Berger, C., Blauth, R., Boger, D., Buss, D., Dambolena, I., Graham, A., … Wood, R. (1993). *Kano's Methods for Understanding Customer-defined Quality.* Cambridge, MA. USA.

Bølviken, T., Rooke, J., & Koskela, L. (2014). The Wastes of Production in Construction – A TFV Based Taxonomy. In *22nd Annual Conference of the International Group for Lean Construction* (p. pp 811-822). Oslo, Norway.

Cuperus, Y., & Napolitano, P. (2005). Open building/Lean Construction evaluation of a case in Brazil. In *13th Annual Conference of the International Group for Lean Construction.* (pp. 457–462). Sydney, Australia.

Drevland, F., & Lohne, J. (2015). Nine tenets on the nature of value. In *23rd Annual Conference of the International Group for Lean Construction* (pp. 475–485). Perth, Australia.

Hevner, A. R. (2007). A Three Cycle View of Design Science Research A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92. https://doi.org/http://aisel.aisnet.org/sjis/vol19/iss2/4

Huang, J. (2017). Application of Kano Model in Requirements Analysis of Y Company's Consulting Project. *American Journal of Industrial and Business Management*, *7*, 910–918. https://doi.org/10.4236/ajibm.2017.77064

Knotten, V., Svalestuen, F., Laedre, O., & Hansen, G. (2016). Improving Design Management With Mutual Assessment'. In *24th Conference of the International Group for Lean Construction* (pp. 173–182). Boston, U.S.A.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction.PhD Dissertation*. Helsinki University of Technology, Finland. Retrieved from http://www.inf.vtt.fi/pdf/

Kumar, V., & Whitney, P. (2007). Daily Life, not markets: customer-centered design. *Journal of Business Strategy*, *28*(4), 46–58. https://doi.org/https://doi.org/10.1108/02756660710760944

Lee, B. D., & Paredis, C. J. J. (2014). A conceptual framework for value-driven design and systems engineering. In *Procedia CIRP*. https://doi.org/10.1016/j.procir.2014.06.147

Leung, M.-Y., & Liu, A. M. M. (1998). Developing a value management model by value-goal system approach. In *14th Annual ARCOM Conference* (Vol. 2, pp. 496–505). University of Reading. Association of Researchers in Construction Management, Vol. 2, 496-505. .

Love, P. E. D., Lopez, R., & Edwards, D. J. (2013). Reviewing the past to learn in the future : making sense of design errors and failures in construction. *Structure and Infrastructure Engineering*, *2479*(June), 675–688. https://doi.org/10.1080/15732479.2011.605369

Macomber, H., Howell, G., & Barberio, J. (2007). Target-Value Design: Nine Foundational Practices for Delivering Surprising Client Value. *AIA Practice Management Digest*.

Male, S., Bower, D., & Aritua, B. (2007). Design management: changing roles of the professions. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, *160*(2), 75–82. https://doi.org/10.1680/mpal.2007.160.2.75

Matzler, K., Hinterhuber, H., Franz, B., & Sauerwein, E. (1996). How to delight your customers. *Journal of Product & Brand Management*, *5*(2), 6–18. https://doi.org/https://doi.org/10.1108/10610429610119469

Orihuela, P., Orihuela, J., & Pacheco, S. (2015). Communication Protocol for Implementation of Target Value Design (TVD) in Building Projects. In *Procedia Engineering*. https://doi.org/10.1016/j.proeng.2015.10.048

Rachwan, R., Abotaleb, I., & Elgazouli, M. (2016). The Influence of Value Engineering and Sustainability Considerations on the Project Value. *Procedia Environmental Sciences*, *34*, 431–438. https://doi.org/10.1016/j.proenv.2016.04.038

Rybkowski, Z. K., Shepley, M., & Ballard, G. (2012). Target value design: Applications to newborn intensive care units. *Health Environments Research and Design Journal*, *5*(4), 5–23.

Saxon, R. (2005). *Be Valuable. Report of Value Task Group. Constructing Excellence.* London, UK. Retrieved from www.constructingexcellence.org.uk

Spiten, T. K., Haddadi, A., Støre-Valen, M., & Lohne, J. (2016). Enhancing Value for end users. A Case study of end-user involvement. In *24th Annual Conference of the International Group for Lean Construction* (pp. 153–162). Boston, MA, USA.

The Standish Group. (2014). *Chaos Report. Project Smart*. Retrieved from https://www.projectsmart.co.uk/white-papers/chaos-report.pdf

Tontini, G. (2002). *Deployment of customer needs in the QFD using a modified Kano model Maturity of Organizations Management-dynamic models of maturity in innovation management and its relationship with organizational performance View project*. Retrieved from www.researchgate.net/publication/291783561

Womack, J., & Jones, D. (1996). *Lean Thinking. Banish waste and create wealth in your corporation*. (S. and S. London, Ed.).

Grau, D., Cruz-Rios, F., and Sherman, R. (2019). "Project Validation – A Novel Practice to Improve Value and Project Performance." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 63–72. DOI: https://doi.org/10.24928/2019/0199. Available at: <www.iglc.net>.

PROJECT VALIDATION – A NOVEL PRACTICE TO IMPROVE VALUE AND PROJECT PERFORMANCE

David Grau[1], Fernanda Cruz-Rios[2], and Rachael Sherman[3]

ABSTRACT

The study presented in this article investigates the practice of validation, which is not supported by the current literature. In this study, data was collected from subject matter experts through phone interviews. A multiple case study method was leveraged to characterize validation through the analysis of empirical data from remarkable project validation efforts. Project validation aims at proving or disproving with limited or no design whether the team can deliver a project that satisfies the owner's business case and scope within the owner's allowable constraints of cost and schedule and with an acceptable level of risk. During validation, multi-disciplinary innovation clusters within the team investigate, compare, and propose distinct options for major project components, and enable the team to collaboratively select an option for the conceptual estimate without committing to the design of such option. Exploring solutions with a multi-disciplinary lens without committing to their design enables the team, later on during design, to make decisions on solutions that ensure the cumulative impact of such solutions and further increase value to the owner. Validation culminates in a go/no-go decision, is undertaken following the business case and precedes the contractual agreement, and must have a dedicated budget, schedule, and project team. This article characterizes what validation is, when it is performed, how it should be implemented, and its benefits. Lessons learned are also discussed. When properly implemented, subject matter experts express that validation virtually eliminates cost and schedule deviations.

KEYWORDS

Value, lean construction, collaboration.

[1] David Grau, Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (480) 727-0665; email: david.grau@asu.edu

[2] Fernand Cruz-Rios, Post-Doctoral Researcher, School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (480) 727-0665; email: fernanda.cr.ford@gmail.com

[3] Rachael Sherman, Ph.D. Student, School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (480) 727-0665; email: rpsherm1@asu.edu

INTRODUCTION

Many industry leaders claim the inability of project teams to predict project performance outcomes reliably (Grau and Back 2015). Evaluation of project team performance is often based on the deviations of outcomes at completion based on initial prediction values. Implicit to such team evaluation is the assumption that deviations will occur. Predictability of cost and schedule outcomes has been low since the emergence of the modern construction industry. A "hockey stick" pattern in which the disclosure of accurate outcomes is only made late in project execution when corrective actions are difficult, expensive, or unfeasible has been norm (Grau and Back 2015). Indeed, the existence of major deviations in the delivery of capital investments has been constant since early in the 20th century (Flyvbjerg 2006). Thus, the eradication of cost and schedule deviations would become a major cornerstone for the construction industry.

In reality, the capability to reliably predict time and cost outcomes at completion early, as opposed to late, in the project delivery process is critical for owner and contractor organizations in an industry characterized by recurring cost and schedule deviations (Payne 1995; Flyvbjerg et al. 2002; Isidore and Back 2002; Bordat et al. 2004; McKenna et al. 2006; Liu et al., 2013; Kim and Reinschmidt 2011; Orberlender and Trost 2001; Grau et al. 2014). The weight of such deviations is often "not only by a few percent but by several factors" (Flyvbjerg 2006). An average of almost 30% cost overrun characterized the delivery of infrastructure investments in the United Kingdom between 1927 and 1998 (Flyvbjerg 2006). No pattern of improvement relative to cost deviations existed during the seven decades of analysis. Studies based on recent project performance efforts have emphasized the persistence of such deviations. Thus, the analysis of nearly 1,000 projects completed until 2011 found that nearly 70% of them resulted in cost and schedule deviations above 10% (Mulva and Dai 2012). Only 5% of those projects were completed with cost and schedule deviations below 3%. In another example, the analysis of 135 projects completed between 2008 and 2012 determined median cost and schedule deviations of 6% and 8% respectively. In Norway, substantial increments in cost estimates have been recently publicized during the front end planning of the project or even before the project is authorized (Welde and Odeck 2017). At the same time, though, the same group of researchers alerts of cost underestimation during the same front end planning phase (Andersen et al. 2016). These researchers state "the underestimation of costs at the front-end is grossly neglected in the literature compared with whether costs comply with the budget. While cost overruns are an indication of failure in terms of the project's tactical performance, the contention is that the up-front underestimation of costs might result in an inferior project being selected and thus affect the strategic performance of the project". This industry-wide uncertainty around cost and schedule performance emerges from multiple and likely intertwined causes (Back and Grau 2013a; Back and Grau 2013b). However, human behavior components have been statistically determined to result in a prevalent impact on inaccurate or biased predictions and thus largely influence predictability (Grau et al. 2016; Grau et al. 2017).

The validation of a project before making a commitment to design and construction offers the possibility to increase value to the owner and also becomes a potential solution to alleviate these endemic cost and schedule deviations. However, to date, the literature on project validation is null with only a recent study that tangentially addresses the practice of validation. Within an IPD-centered study, Cheng et al. (2018) documented that validation is about establishing certainty for the owner and the team whether the team can deliver a project that meets the owner constraints. In a concise discussion, the cited IPD Guide briefly discusses the reasons to validate a project, how to plan for such validation effort, and a cyclic design-estimation-constructability process to gain certainty. Building on top of these basic definitions, this study aims at providing an in-depth characterization of project validation. While most of the findings from this study support the core but succinct discussion by Cheng et al. (2018), in this study industry evidence strongly indicates that the value of validation resides in providing an answer to whether or not a project should be designed and built with no design or, at most, minimal schematic design information. Improving certainty by advancing design is not a novel competency. The rest of this article details its objectives and scope, research methodology, and results before reaching the conclusions of this study.

OBJECTIVES AND SCOPE

As a departure from previous efforts, the study presented in this article aimed at characterizing the novel practice of validation. The study focused on exploring: concepts and fundamental aspects of validation; leading-edge case studies; and lessons learned. Questions that this study aimed at explaining include: what is validation, and what it is not?; what are the resources required to perform validation?; what is a typical validation schedule and budget?; what are the necessary team skills?; what are its steps?; what are its deliverables?; what happens during the solicitation for project authorization?; or, what are the potential outcomes from such solicitation?

The scope of the study is reduced to projects that had been validated. As the results indicated, validation is primarily used in projects delivered with an Integrated Project Delivery (IPD) approach due to their same team-sharing and collaborative approach, and thus the study focused on IPD projects.

METHODOLOGY

A multiple case study method (Yin 2014) was leveraged to obtain the results from the collected data. The analysis of multiple sources of empirical evidence enables a holistic understanding of the topic of investigation (Gummesson 2000), which in this study was deemed necessary due to the lack of literature about validation. The multiple case study method also induces the emergence of core characteristics and immanent patterns of such type of novel or undocumented processes (Hartley 1994). Finally, the multiple case study analysis is best suited to document and respond to questions related to how a process, such as validation, occurs (Yin 2014). Initially, this study aimed at maximizing the number of industry experts participating in the study. A cohort of 30 potential participants from distinct organizations was individually screened with the purpose to ascertain whether their professional experiences related to project validation. Such screening was necessary due to the perceived confusion about validation among industry practitioners. As it turned out, all but eight (8) of the corresponding screened processes related to established practices such as business case development, front end planning, stage-gate design, or did not aim at deciding whether or not to proceed with a project.

Thus, in this study data was collected from eight subject matter experts through phone interviews with an open-ended interview protocol. Experts averaged 19 years of design and construction experience and 10.5 years of lean construction experience. Experts were affiliated with owner, designer, and contractor organizations with a record of validation efforts. Phone interviews lasted between 1 and 2 hours and were audio-recorded. During the interviews, each expert was requested to select one remarkable project validation effort as a result, for example, of scale, cost, schedule, complexity, or success. Within the context of such a project, each expert shared validation aspects such as information inputs and outputs, team and culture, validation steps, or approval solicitation. Table 1 illustrates the descriptive statistics of the sample of projects. In addition, experts were requested to shared lessons learned gained through their cumulative validation experience. After each interview, additional questions and information were communicated via email. Interview transcripts and additional information were analyzed. The rest of this article summarizes the results that characterize project validation. A comprehensive discussion of the results from the study presented in this article can be found in Grau and Cruz-Rios (2019).

Table 1. Project Sample – Descriptive Statistics

Investment Source	Private = 8 Public = None
Project Sector	Healthcare = 6 Manufacturing = 1 Biotechnology = 1
Experts' Affiliation	Owner = 5 Design and Construction = 3
Total Installed Costs (TIC)	Average = $183.8 million
Completion Time	Average = 36.3 months
Validation Costs (% of TIC)	Average = 0.54%
Validation Schedule	Average = 16.9 weeks

WHAT IS VALIDATION?

Project validation aims at proving or disproving with limited or no design whether the team can deliver a project that satisfies the owner's business case and scope within the owner's allowable constraints of cost and schedule and with an acceptable level of risk. During validation, multi-disciplinary innovation clusters within the team investigate, compare, and propose distinct options for major project components, and enable the team to collaboratively select an option for the conceptual estimate without committing to the design of such option. Exploring solutions with a multi-disciplinary lens without committing to their design enables the team, later on during design, to make decisions on solutions that ensure the cumulative impact of such solutions and further increase value to the owner. Validation culminates in an informed decision by the owner on whether to authorize (go) or not (no-go) the project and thus ahead of the final resolution to fund, design, and build the project. Validation is executed within a short duration and limited budget.

During the study, it came to our attention the convoluted understanding of validation among industry practitioners. We found instances of practitioners claiming the validation of their project while they were doing what they had always done and "*called it something else*" (quoted from one of the subject matter experts interviewed in this study). Thus, an effort was made to characterize validation. Among other intrinsic characteristics, a validation effort must unequivocally result in a go or no-go decision on behalf of the project. Also, dedicated budget and schedule resources are necessary to support the validation effort. We documented instances of validation attempts that, without such support, were obviated by project players (e.g. contractor, designers, consultants). In reality, validation requires the full-time dedication of the project team. Team members, either individually or in combination, must provide in-depth cost estimating skills (inclusive of conceptual estimating) and at least basic design skills for each discipline within the team. Finally, design is purposely kept at a minimum during validation. Schematic design is obviated or at least minimized in favor of the basis of design. The practice of validation, when properly implemented, results in an accurate cost estimate despite design drawings and specifications are not available.

WHEN TO PERFORM VALIDATION?

Validation follows the owner's business case and precedes the contractual agreement to deliver the project through design and construction. Traditionally, the need to mitigate risks and gain project knowledge before the project is authorized has required the advancement of design and corresponding estimates, which is often referred to as stage-gate design. In contrast, validation aims at an informed authorization decision with limited or no design on whether the team can meet the owner constraints. On the one hand, the owner's business case defines the owner priorities such as scope and program/operational needs that guide validation. On the other hand, validation precedes and informs schematic design, so that design only starts once validation is completed and the project has been authorized. See Figure 1. In specific instances, though, the owner requires the team to advance schematic design during validation. For example, schematic design can be performed in order to reduce completion time when an expectation exists that the project will be authorized. See Figure 2.

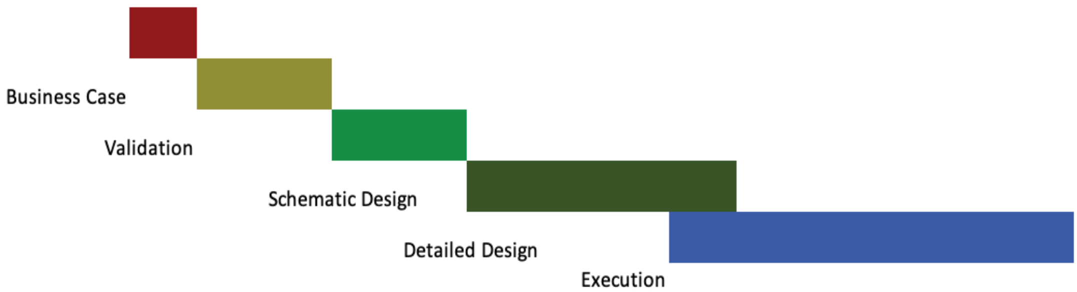


Figure 1. Validation in the Project Delivery

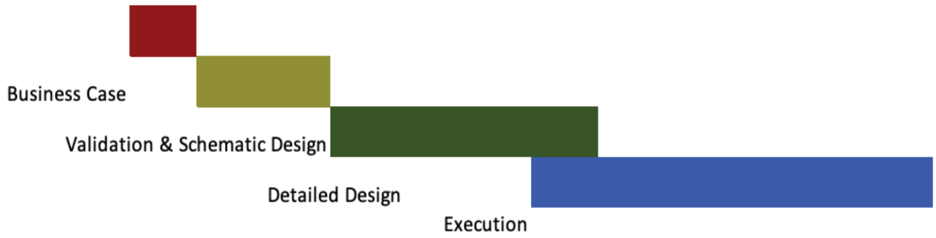


Figure 2. Concurrent Validation and Schematic Design

HOW TO PERFORM VALIDATION?

At the core of validation, a cycle of big room charrettes and cluster work events rapidly builds predictability and generates a basis of design, which, later on, will improve project value. Figure 3 illustrates the validation process, in which the subject matter experts participating in this study consistently agreed on. Big room charrettes precede cluster work and contribute to validation through multiple attributes. For instance, the team builds alignment during the face-to-face big room charrettes. Team members often meet for multiple days during every charrette and review the team objectives, project information, team behavior and conduct rules, or contrast validation progress against the initial validation milestones and thus ascertain corrective actions when necessary. During charrettes, each cluster or discipline provides an update on work status, estimates, and solicits input and feedback from the other disciplines in order to advance the estimate. In the big room, decisions are collaborative and often made in real-time. For example, A3s are created with multi-disciplinary design options for the same project component so that comparisons and decisions can be efficiently made. Recording the decision-making process enables that, later on, designers can come back to such records and make informed design decisions or revise such decisions. During charrettes, the team defines the objectives for the next charrette meeting, so that multi-disciplinary clusters within the team can precisely figure out the work that they must accomplish. Thus, during cluster work, multi-disciplinary teams work remotely, but the team maintains a constant communication. The lapse of time between big room charrettes varies, but teams often decide to alternate charrettes and cluster work weekly, so that charrettes occur every other week and cluster work fills the week in-between charrettes. Such cycles of big room charrettes and cluster work rapidly advance the estimate, increase value, and build confidence.

When properly implemented, subject matter experts express that validation virtually eliminates cost and schedule overruns. Experts expressed that validation does not only offer the opportunity to eliminate cost overruns virtually, but also results in a pattern of reduced costs over time among similar type of projects. For example, an owner organization with a record of validation expertise set the end of validation to the attainment of a certain percentage of reduction from the allowable budget. However, the reader should notice that quantitative data to substantiate such repeated experts' claim could not be obtained.

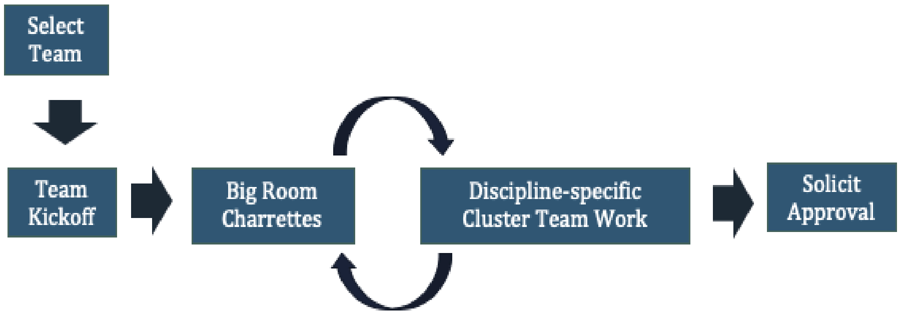


Figure 3. Validation Process

In addition, experts express that validation enhances value to the owner. During validation, the team focuses on project components and systems that can have an impact on the conceptual estimate. The team analyses and documents distinct multi-disciplinary options for each major components (for instance through A3 analyses) and chooses an option in order to build the conceptual estimate without making a commitment to design and build such option. Such multi-disciplinary and explorative focus drives value and innovation. In addition, exploring solutions with a multi-disciplinary lens without committing to their design enables the team to, later on during design, make decisions on solutions that ensure the cumulative impact of such solutions and further increase value to the owner. Also, designers express that information loops during design are substantially reduced since the team has documented major design options.

GO/NO-GO DECISION

The outcome of validation is a report that summarizes the work of the team and becomes the basis of the presentation to the owner during approval solicitation. The validation report unequivocally determines the team commitment towards scope, schedule, and budget and provides information that supports such commitment. If the project is authorized, the validation report continuously guides design and execution.

At approval solicitation, the validation report is presented to the distinct stakeholders within the owner organization with the objective to obtain the project authorization. The owner evaluates the team commitment and the certainty that the team can meet such a commitment. Approval solicitation culminates in two possible outcomes: go or no-go.

On the one hand, that the project is authorized implies that the owner is satisfied with the team's commitment to execute an agreed-upon scope and level of risk. The project is eventually designed, built, commissioned, started, and operated. The team and the owner agree to the target cost value in the contractual agreement based on the results from project validation.

On the other hand, that the project is not authorized implies that owner priorities cannot be met or that uncertainty is too high from the owner's perspective. For example, that the project cannot be delivered to satisfy product-to-market constraints is an example of a failed priority that often leads to the cancelation of the project. However, a no-go decision does not necessarily imply that the project is forgotten -being this one possibility. Other possibilities exist. For instance, the owner may decide to reduce the project scope with the goal to reduce its allowable budget. Alternatively, the owner can maintain the scope and decide to freeze the project with the expectation that the allowable budget can be increased in the future. In other instances validation is extended to reduce uncertainty further before the project can be solicited for approval once more.

LESSONS LEARNED

The study presented in this article collected lessons learned, which, when implemented, enhance the chances of successful validation. Such lessons learned are introduced below.

Conceptual estimating, the ability to estimate project costs with minimal or none design documents, is a core competency in order to eliminate schematic design during validation while still producing a reliable estimate.

The more the maturity and experience with validation, the larger the threshold of uncertainty that the team is willing to accept when committing to the project and thus the shorter the validation process.

An effective validation process does not necessarily add time to the total project delivery schedule since it often results in the minimization of design re-work and information loops.

Validation most often precedes an Integrated Form of Agreement (IFOA) within the Integrated Project Delivery (IPD) approach, even though it can be eventually implemented with other delivery methods.

When a political aspect exists, the owner should make sure to plan for and be able to manage it during validation.

CONCLUSIONS

This article presents the first research effort solely dedicated to documenting the practice of project validation. Validation proves or disproves whether the project team can successfully deliver a project while meeting the owner constraints and with an acceptable level of risk. It results in an informed decision by the owner on whether or not to authorize the project. Validation is executed with little or no design and ahead of the contractual agreement. In essence, the practice of validation generates value to the owner and builds predictability -the team's ability to anticipate project outcomes early in the delivery process. It offers owners what likely is the "biggest bang for the buck" in today's capital delivery landscape. The value of validation resides in making an informed decision (whatever the decision is) on behalf of the owner and team. Organizations with an expert validation capability regard it as a competitive advantage. Future research efforts should further advance the knowledge about validation. An understanding of how validation can be applied in projects with non-IPD delivery approaches should be investigated. Specifically, how non team-driven validation efforts can realistically build certainty and increase predictability should be answered.

ACKNOWLEDGMENTS

We want to acknowledge and thank the Lean Construction Institute (LCI) for the sponsorship and support to all aspects of the study reported in this article. In addition, we also want to thank all the subject matter experts that contributed to this research effort through the data collection, analysis, and validation steps. Finally, we want to thank the members of the Research Committee at LCI.

REFERENCES

Andersen, B., Samset, K., and Welde, M. (2016) "Low estimates – high stakes: underestimation of costs at the front-end of projects." International Journal of Managing Projects in Business, Vol. 9 Issue: 1, pp.171-193.

Back, E., and Grau, D. (2013a). "Improving the Predictability of Project Outcomes." *Construction Industry Institute*, Research Summary 291-1.

Back, E., and Grau, D. (2013b). "Four-Casting for Early Predictability." *Construction Industry Institute*, Implementation Resource 91-2.

Bordat, C., McCullouch, B.G., Sinha, K.C., and Labi, S. (2004). "An analysis of cost overruns and time delays of INDOT projects." Publication FHWA/IN/JTRP-2004/07 Joint Transportation Research Program,West Lafayette, IN: *Indiana Department of Transportation and Purdue University*.

Flyvbjerg, B., Holm M. S., and Buhl, S. (2002). "Underestimating costs in public works projects. Error or lie?" *J. Am. Plann. Assoc.*, 68(3), 279–296.

Flyvbjerg, B. (2006). "From Nobel Prize to Project Management: Getting Risks Right." Project Management Journal, 37 (3), pp. 5-15.

Grau, D., and Back, W.E. (2015). "Predictability Index – A Novel Metric to Assess Cost and Schedule Performance." *ASCE, Journal of Construction Engineering and Management,* 04015043-1 to -8.

Grau, D., and Cruz-Rios, F. (2019). Project Validation – A Guide to Improving Project Value and Team Performance. Version 1.0. School of Sustainable Engineering and the Built Environment, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ, USA.

Grau, D., Back, E., Abbaszadegan, A., and Sirven, R. (2014). "The Predictability Index – A Novel Project Performance Metric to Assess the Early Prediction of Cost and Time Outcomes." *Conference Proceedings, Construction Research Congress 2014*, pp. 2306-2314, Atlanta, GA, May 19 – 21, 2014.

Grau, D., Back, W.E., and Aguilar, G.M. (2017). "Organizational Behavior Influence on Predictability." *ASCE, Journal of Management in Engineering*, 33(5), pp. 04017027-1 to -8.

Grau, D., Back, W.E., and Hossain, N**.** (2016). "Influence of Risk and Change Events on Cost, Schedule, and Predictability Performances." *ASCE, Journal of Professional Issues in Engineering Education and Practice*, 04016006-1 to -9.

Gummesson, E. (2000). Qualitative Methods in Management Research. 2nd ed. Thousand Oaks, Calif: Sage Publications.

Hartley, Jean (1994). Case studies in organizational research. In Catherine Cassell & Gillian Symon (Eds.), Qualitative methods in organizational research, a practical guide (pp.208-229). London: Sage.

Isidore, L.J., and Back, E. (2002). "Multiple simulation analysis for probabilistic cost and schedule integration." *J. Constr. Eng. Manage*., 128(3), 211–219.

Kim, B.C., and Reinschmidt, K.F. (2011). Combination of project cost forecasts in earned value management. *Journal of Construction Engineering and Management, 137*(11), 958-966.

Liu, Y., Hansen, M., Wang, Z., Gupta, G., and Malik, W. (2013). "Predictability in airport surface operation management." *Aviation Technology*, integration, and Operations Conference, Los Angeles, CA

McKenna, M.G., Wilcznski, H, and VanderSchee, D. (2006). "Capital project execution in the oil and gas industry: Increased challenges, increased opportunities." McLean, VA: *Booz Allen Hamilton* <Retrieved from http://www.boozallen.com/media/file/Capital_Project_Execution.pdf> (January 2019)

Mulva, S.P., and Dai, J. (2012). *Performance assessment*. Austin, TX: Construction Industry Institute and The University of Texas at Austin.

Oberlender, G. D., and Trost M. (2001). "Predicting accuracy of early cost estimates based on estimate quality." *J. Constr. Eng. Manage*., 127(3), 173–182.

Payne, J. H. (1995). "Management of multiple simultaneous projects: a state-of-the-art review." *International Journal of Project Management*, 13(3), 163-168.

R. Cheng, M. Allison, H. Ashcraft, S. Klawans, and J. Pease (2018). "Integrated Project Delivery –An Action Guide for Leaders." University of Washington, Seattle, WA, USA.

Welde, M., & Odeck, J. (2017). "Cost escalations in the front-end of projects – empirical evidence from Norwegian road projects." Transport Reviews, 37:5, 612-630.

Yin, R, K. (2014). Case study research: design and methods. Fifth Edition. Thousand Oaks, Calif: Sage Publications.

Zaheraldeen, H., Khoury, H., and Hamzeh, F. (2019). "An AHP Approach for Selecting and Identifying off-site Construction Systems." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 73–82. DOI: https://doi.org/10.24928/2019/0238. Available at: <www.iglc.net>.

AN AHP APPROACH FOR SELECTING AND IDENTIFYING OFF-SITE CONSTRUCTION SYSTEMS

Hayyan Zaheraldeen[1], Hiam Khoury[2], and Farook Hamzeh[3]

ABSTRACT

Many studies have shown the positive impact of applying lean principles in off-site construction. However, limited research have focused on evaluating the attributes associated with those various systems needed to highlight their difference. In fact, off-site systems present different advantages and disadvantages implying a need to evaluate their value maximization in terms of cost, time, quality, etc. when selecting the appropriate off-site system. Although some research studies have attempted to compare off-site against on-site systems, none has performed a comparison among non-volumetric systems (e.g. panelized and natural materials), volumetric systems, and hybrid systems. Therefore, this paper takes the initial steps and presents work targeted towards identifying the optimal off-site systems for a given project by extracting and elaborately analyzing the attributes of the different systems using the Analytical Hierarchy Process technique (AHP). The outcomes of this study will yield standardized policies for properly choosing optimal off-site systems based on lean principles.

KEYWORDS

Lean construction, Off-site construction, Analytical hierarchy process (AHP), Value maximization.

INTRODUCTION

Traditional on-site construction methods have been popular since the end of the 19th century (Mydin et al., 2014; Kamali et al., 2016). These methods are also defined as "site-built" or "conventional" construction and refer to construction being built on site after the design is done and the contractor is awarded the contract. The respective systems had been predominantly built using reinforced concrete frames and are typically divided into two

[1] Graduate Student, Civil and Environmental Engineering Dept., American University of Beirut, Lebanon, hnz04@mail.aub.edu.

[2] Associate Professor, Civil and Environmental Engineering Dept., American University of Beirut, Lebanon, hk50@aub.edu.lb.

[3] Associate Professor, Civil and Environmental Engineering Dept., University of Alberta, Canada, hamzeh@ualberta.ca.

groups. The first group is the structural system including cast in-situ columns, beams, slabs and frames. The second one includes bricks and plaster as the non-structural infill material. However, these methods have been witnessing a high level of waste in production, low productivity rates, high costs, poor safety records, poor quality control, and long project durations (Deffense et al., 2011). As a result, off-site construction emerged as an alternative modern method aimed at enhancing the overall traditional process (Vernikos et al., 2013; Howell,1999; Bekdik et al., 2016). Off-site construction is one of the construction strategies that applies the principles of industrialization in the construction projects; in other words it couples construction with manufacturing. It refers to the planning, design, fabrication and assembly of elements of a construction project at off-site factories typically situated at a different location from the jobsite.

After World War II, this technology became one of the major construction methods in many developed countries as it was tested and applied to provide soldier accommodation during the war (Arditi et al., 2000; Ghazilla et al., 2015). However, it didn't get the full attention of both academia and industry in these developed regions (e.g. United States, Australia, parts of Europe) up until late (Kamali et al., 2016) where engineers have increasingly turned to using the off-site method due to its ability to reap the benefits of automotive manufacturing principles and achieve the lean construction goals of adding value while reducing process and material waste (Howell,1999; Vernikos et al., 2013; Antillón et al., 2014, Bekdik et al., 2016). More specifically, off-site systems allow projects to be delivered with higher value to the users, shorter construction times, lower on-site labor cost, higher safety level through eliminating the on-site risks, higher on-site productivity rates, lower waste production and tighter control of quality (Polat et al., 2005).

Furthermore, many studies tackled the division of the off-site construction into several classifications to assist in understanding the differences among off-site systems. In a study conducted by Švajlenka et al. (2017), the off-site systems were divided into several categories. In short, off-site systems can be classified into different levels according to the product's manufacturing process (Gibb and Goodier, 2007; Li et al., 2014). As shown in Table 1, the first level, sub-assembly and component manufacturing, involves small-scale elements assembled in the factory environment (e.g. windows). The second level is the non-volumetric manufacturing which defines pre-assembled units that do not enclose a usable space (e.g. the timber panels). On the contrary, the volumetric manufacturing involves pre-assembled units that enclose a usable space. The units are processed inside the factory and do not form a part of the building structure. Finally, the complete manufacturing, also known as the modular construction, involves pre-assembled volumetric units that form the actual structure and fabric of the building. (Gibb, 1999; Goodier and Gibb, 2007).

Table 1: Off-site construction categories

Off-Site Construction	Systems	Example

	Sub-Assembly Systems	Windows
	Non-Volumetric Systems	Timber Panels
	Volumetric Systems	Bath Rooms
	Modular Systems	Hotel Rooms

On the other hand, in developing countries like Lebanon and Syria, four off-site categories were identified based on thorough investigation in the regional and local manufacturing market, namely Non-Volumetric Panelized Systems: Non- Volumetric Natural Materials Systems, Volumetric Systems and Hybrid (Panelized-Volumetric) Systems. However, despite the aforementioned advantages, the off-site method is still not widely adopted in these regions, which explains the lack of literature, and does not even follow lean principles whenever employed.

As such, resorting to off-site systems is very important to continually improve current construction methods. However, none of the previous works have selected the optimal off-site construction systems for a given project while considering value maximization and waste minimization. The greatest challenge facing construction practitioners is that of achieving the balance between: (1) the effort expended to predict related benefits and (2) the value provided by the adopted evaluation system (Pasquire et al., 2004) as lean construction principles suggest. Therefore, the objective of this research study is to design a new decision support tool targeted at identifying and selecting the best off-site system for a project at hand while maximizing the value and meeting customer requirements through continuous improvement and waste elimination. This lean decision tool can, in turn, incite practitioners to use off-site systems and better assess them, especially in the Lebanese and Syrian construction sector.

METHODOLOGY

In order to achieve the aforementioned objective, a conceptual three-stage decision model was initially developed using the combined key findings gathered from the literature review and regional data. Figure 1 depicts the proposed model.

Figure 1: The proposed decision model

The first stage consists of establishing the purpose or goal behind a certain decision; in this case evaluating the importance and comparatively assessing off-site alternatives. The second stage consists of defining the main decision criteria. A wide range of criteria was identified from the literature review in relation to the adoption of off-site construction methods (Pan et al., 2012a). After conducting semi-structured interviews with construction practitioners in Lebanon and Syria, six specific criteria were singled out, namely:

1. Cost: the cost of design, implementation and maintenance.
2. Time: the time of design and implementation.
3. Quality: high quality achieved in erecting the facility and high customers' satisfaction.
4. Health and safety: risk minimization during the construction process.
5. Sustainability: high building energy efficiency and waste minimization.
6. Process: project site access, logistics, and installation planning strategies

The final stage entails delineating the alternative options for each criterion; in this case the four off-site categories adopted in Lebanon and Syria:

1. Non-Volumetric Panelized Systems: These units are produced in the plant then transported to the project site to fit within the assembly into existing structural systems. Examples include wall, floor or roof panels that can be load or non-load-bearing and can be made of light gauge steel, timber, structurally insulated panels (SIPs) or concrete.
2. Non- Volumetric Natural Materials Systems: These units are similar to the panelized systems with one difference: the source of materials. This difference leads to the consideration of natural materials systems that are more environmentally friendly and sustainable than other systems.
3. Volumetric Systems: These units are produced with high quality control then transported to the project site to be assembled through bolting. The structural skeleton of these modules are usually fabricated with concrete, light gauge steel, timber frame, or composite with different external and internal finishes materials.
4. Hybrid Systems: These units (called semi-volumetric units) combine panelized and volumetric technology in the same constructed facility or building. The highly serviced areas of a building (e.g. kitchen, bathroom units, etc.) are constructed as volumetric units while others are built as panelized units.

Therefore, at the heart of this model lie various off-site building categories for which weights are to be allocated with respect to various decision criteria using the Analytic Hierarchy Process (AHP) method. AHP, developed in 1980 by Thomas Saaty, is an advanced, powerful, and flexible tool that provides the ability to calculate the degree of importance for each alternative following pairwise evaluations of the criteria introduced by decision makers (Saaty, 1980). In fact, most researchers recommend the AHP method as a suitable prioritization technique due to its flexibility and simplicity, which leads to enhanced data collection and improvement in the quality of comparisons among the results (Pan et al., 2012b). Moreover, decision makers can easily fill out the survey without having previous knowledge on AHP. It is worth noting that the choosing by advantages (CBA) theory is employed at a later future stage to evaluate the attributes of the chosen off-site methods or systems and is thereby not within the scope of this paper.

As such, the next step involves designing the AHP survey. The survey is divided into three sections: (1) A cover letter to the participant including the invitation, (2) A brief summary of the research topic including the goal of the survey, and chosen criteria and alternatives, and (3) Questions about the type of systems adopted in the interviewed companies, the scale system (Table 2) as introduced by Saaty (1980) and a small example on how two criteria can be evaluated and ranked, and the actual pairwise comparison with respect to the cost, time, quality, health and safety, sustainability and process criteria.

Table 2: The AHP pairwise comparison scale (Saaty, 1980)

Intensity of weight	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objectives
3	Weak/moderate importance of one over another	Experience and judgment slightly favored one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation

The survey was then conducted with a selection of senior construction managers from top off-site builders in the Middle East. More specifically, a total of 20 managers working in 20 different Lebanese and Syrian off-site construction companies responded out of 35 surveys sent, whereby most of them have more than 5 years of experience in this field. The data gathered from the construction managers was basically pairwise comparisons for multiple criteria.

RESULTS AND DISCUSSION

The first part of the third section in the AHP survey has investigated about the decision making process and type of the off-site systems that are used in each company. It was found that off-site companies have chosen the systems according to personal evidence without using any rigorous data. Additionally, it was established that the construction participants have agreed that adopting a decision support tool to choose the optimal off-site systems can potentially shrink the construction waste while expanding the value of this method.

The last part of the survey asked the participants to fill the pairwise comparison with respect to the group of criteria (cost, time, quality, health and safety, sustainability and process). Accordingly, an analysis was conducted to combine the individual comparison judgements from the 20 participants so that a single comparison matrix is produced. This was achieved by computing a geometric average for each response and checking for its consistency. Proper mathematical procedures were then implemented to compute the importance of each criterion relative to the goal and calculate a weight for each off-site option/alternative. Table 3 and Figure 2 present the results of a pairwise comparison of one criterion with respect to the other criteria.

Table 3: The pairwise comparison of one criterion with respect to the other criteria

Criteria	Cost	Time	Quality	Health and Safety	Sustainability	Process
Cost	1	1.530	0.467	0.223	0.346	0.813
Time	0.656	1	0.253	0.172	0.275	0.357
Quality	2.0765	3.739	1	0.625	1.251	1.654
Health and Safety	4.338	5.639	1.426	1	1.795	2.596
Sustainability	2.799	3.641	0.695	0.557	1	1.588
Process	1.229	2.799	0.498	0.385	0.629	1

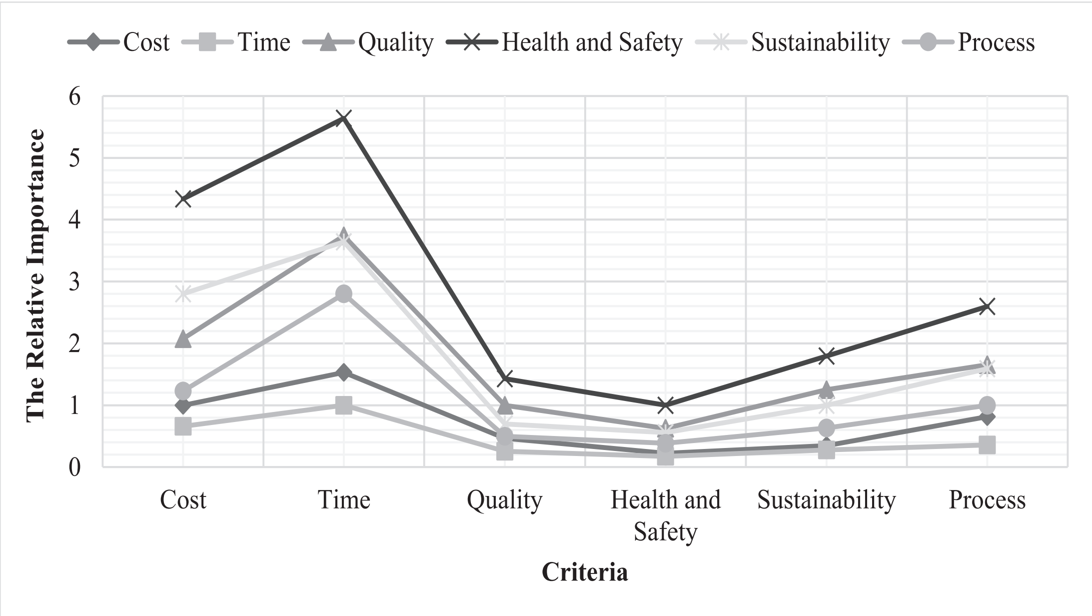


Figure 2: The pairwise comparison of one criterion with respect to the other criteria

Results reveal that the health and safety, quality, sustainability and process criteria ranked high when compared to the cost one. These results reveal the importance of other criteria in the decision making process, besides cost and time, that are often underrepresented.

Table 4 and Figure 3 depict comparison results considering the cost criterion. It can be noticed that the participants prefer the panelized system over others when the decision is based on cost. On the other hand, the natural materials system was the least preferred.

Table 4: The pairwise comparison matrix with respect to the cost criterion

Alternatives	Panelized System	Natural Materials System	Volumetric System	Hybrid System
Panelized System	1	2.747	1.329	1.845
Natural materials System	0.364	1	0.757	0.993
Volumetric System	0.752	1.369	1	2.132
Hybrid System	0.542	0.970	0.469	1

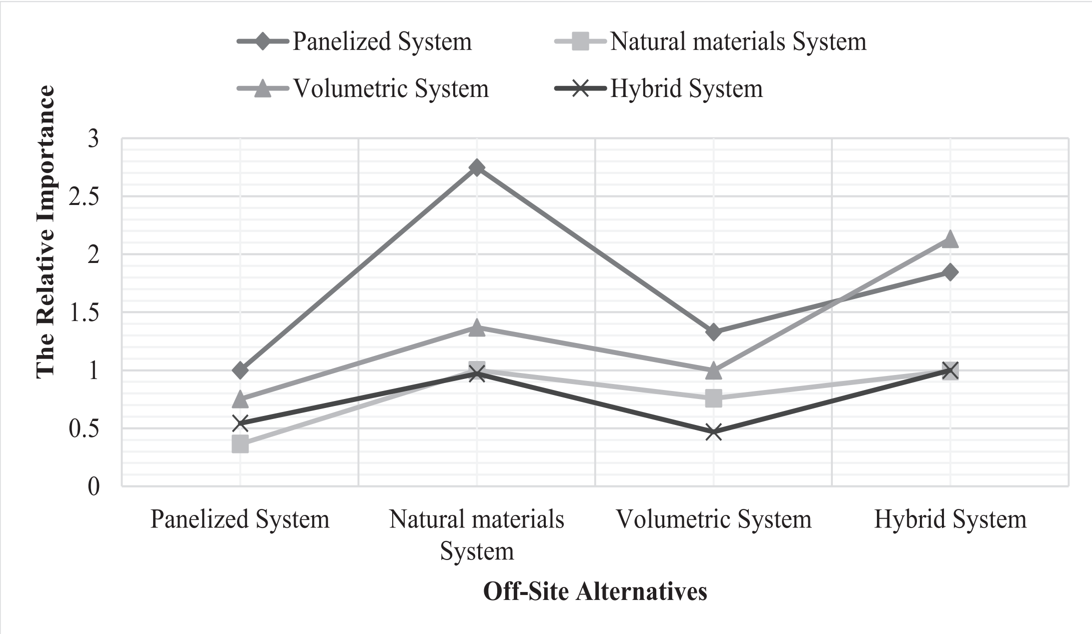


Figure 3: The pairwise comparison results with respect to the cost criterion

Other pairwise comparison results with respect to the time, quality, health and safety, sustainability and process criteria were also analyzed.

Another analysis was conducted to calculate the weighted average rating for each decision alternative. This rating helps in selecting the suitable off-site system based on the participant's objective. Table 5 and Figure 4 depict respective results.

Table 5: The weighted average rating for each decision alternative

Criteria	Cost	Time	Quality	Health and Safety	Sustainability	Process	Weighted Average Rating
Alternatives	0.085	0.054	0.209	0.334	0.194	0.123	
Panelized System	0.379	0.285	0.175	0.188	0.253	0.241	**22.56 %**
Natural Materials System	0.169	0.060	0.108	0.213	0.2178	0.066	**16.20 %**
Volumetric System	0.286	0.355	0.384	0.333	0.266	0.339	**32.86 %**
Hybrid System	0.166	0.299	0.333	0.266	0.264	0.354	**28.38 %**
Sum	1	1	1	1	1	1	**100 %**

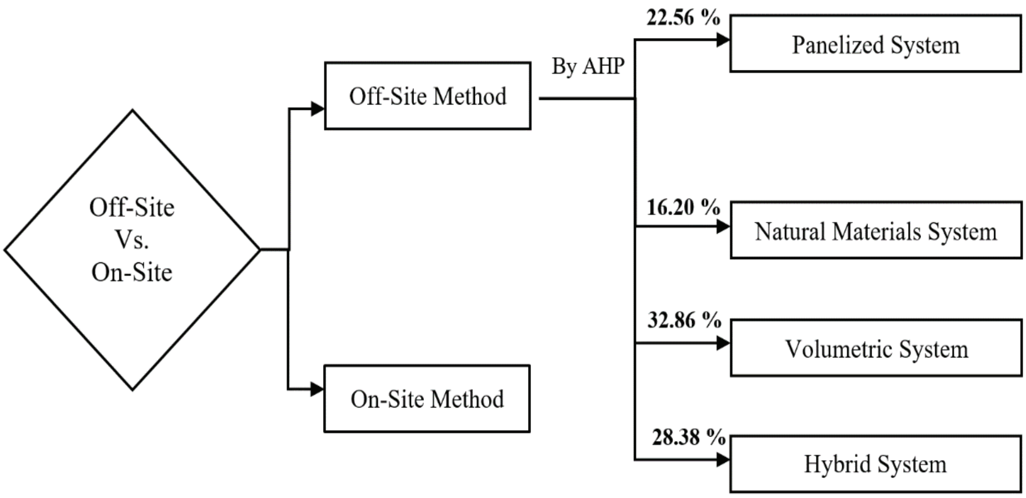


Figure 4: The decision tree for selecting from the four off-site systems

Results reveal that participants in Lebanon and Syria prefer to opt for the volumetric systems (rating about 32.86%) as opposed to other systems such as natural materials systems (16.20), panelized systems (22.56), or hybrid systems (28.36).

CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

Most construction practitioners consider that opting for any off-site method is risky and needs careful attention. Therefore, this research effort took the initial steps and aimed at providing a decision support tool to aid practitioners in identifying and selecting the optimal off-site methods given a certain project and based upon various factors (e.g. cost, time, waste, quality, health, safety etc.). The AHP technique was used and results from the survey revealed the benefits of each system with respect to the factors tested. Moreover, the AHP survey shows the need for optimally selecting off-site methods to drive more value into the construction process.

To increase value in future off-site projects, a shift in the decision making process is needed and a lean thinking approach should be applied. Off-site practitioners are encouraged to invest in the lean philosophy (e.g., Waste Minimization and Continuous Improvement) to decrease the non-value adding tasks when adopting off-site methods and to reduce cost and time, increase quality and safety, and deliver a sustainable building. Additionally, they should enhance communication among project stakeholders during the decision making process to explore different attributes of off-site systems. Using the proposed decision support tool while taking into account the various criteria will result in choosing the most convenient off-site system.

More importantly, the improvement suggestions for the off-site construction are parallel with the lean spirit of incremental improvement while encouraging the use of this technology (i.e. Off-site Construction). Therefore, practitioners working in off-site construction should align the project objectives to consider various customer requirements. Finally, the proposed study is not only limited to construction buildings in Lebanon and Syria but can be also applied elsewhere once the goal, criteria and alternatives are identified.

Further work is needed to study other off-site categories such as Sub-Assemble Systems, and Light Weight Facades, and the effect of other factors or constraints on the decision making process.

ACKNOWLEDGEMENTS

The presented work is supported by the AUB's University Research Board (URB) through Grant# 103604. Any opinions, findings, conclusions, and recommendations expressed by the authors in this paper do not necessarily reflect the views of URB. The authors would like as well to thank all the off-site construction companies who participated in the AHP survey.

REFERENCES

Antillón, E. I., Morris, M. R., & Gregor, W. (2014, June). A value-based cost-benefit analysis of prefabrication processes in the healthcare sector: a case study. In Kalsaas, BT, Koskela, L. & Saurin, TA, Proc. 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway(pp. 25-27).

Arditi, D.; Ergin, U., and Gunhan, S. (2000). Factors affecting the use of precast concrete systems, Journal of Architectural Engineering 6(3): 79–86. Doi: 10.1061/ (ASCE) 1076-04316:3(79).

Bekdik, B., Hall, D., and Aslesen, S. (2016). "Off-Site Prefabrication: What Does It Require from the Trade Contractor?" In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.8 pp. 43–52. Available at: <www.iglc.net>.

Deffense, J., & Cachadinha, N. (2011). Lean production in the precast concrete components' industry. IGLC-19, 557-567.

Ghazilla, R. A. R., Sakundarini, N., Abdul-Rashid, S. H., Ayub, N. S., Olugu, E. U., & Musa, S. N. (2015). Drivers and barriers analysis for green manufacturing practices in Malaysian SMEs: a preliminary finding. Procedia CIRP, 26, 658-663.

Gibb, A. G. (1999). Off-site fabrication: Prefabrication, pre-assembly and modularisation.

Goodier, C., & Gibb, A. (2007). Future opportunities for offsite in the UK. Construction Management and Economics, 25, 585e595.

Howell, G (1999). What is lean construction – 1999, Proceedings 7th annual conference of the International Group for Lean Construction (IGLC-7), pp 1-10, University of California, Berkeley, USA, July 1999.

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. Renewable and Sustainable Energy Reviews, 62, 1171-1183.

Li, Z., Shen, G. Q., & Xue, X. (2014). Critical review of the research on the management of prefabricated construction. Habitat international, 43, 240-249.

Mydin, M. A. O., Phius, A. F., Sani, N. M., & Tawil, N. M. (2014). Potential of Green Construction in Malaysia: Industrialised Building System (IBS) vs Traditional Construction Method. In E3S Web of Conferences (Vol. 3, p. 01009). EDP Sciences.

Pan, W., Dainty, A. R. & Gibb, A. G.(2012a). Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction, Journal of Construction Engineering and Management, 138(11), 1239-1250.

Pan, W., Gibb, A. G., & Dainty, A. R. (2012b). Strategies for integrating the use of offsite production technologies in house building. Journal of Construction Engineering and Management, 138(11), 1331-1340.

Pasquire, C. L., Gibb, A. G. F., & Blismas, N. (2004). Off-site production: evaluating the drivers and constrains.

Polat, G., & Ballard, G. (2005). Why is on-site fabrication of cut and bent rebar preferred in Turkey?. In 13th International Group for Lean Construction Conference: Proceedings (p. 449). International Group on Lean Construction.

Saaty, T.L., 1980. “The Analytic Hierarchy Process.” McGraw-Hill, New York.

Švajlenka, J., Kozlovská, M., & Spišáková, M. (2017). The benefits of modern method of construction based on wood in the context of sustainability. International Journal of Environmental Science and Technology, 14(8), 1591-1602.

Vernikos, V. K., Goodier, C. I., Nelson, R., & Robery, P. C. (2013). Implementing an offsite construction strategy: a UK contracting organisation case study.

Pikas, E., Koskela, L., Oehmen, J., and Dave, B. (2019). "From Checklists to Design Process Support Systems: Initial Framing." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 83–96. DOI: https://doi.org/10.24928/2019/0173. Available at: <www.iglc.net>.

FROM CHECKLISTS TO DESIGN PROCESS SUPPORT SYSTEMS: INITIAL FRAMING

Ergo Pikas[1], Lauri Koskela[2], Josef Oehmen[3], and Bhargav Dave[4]

ABSTRACT

Building project delivery is beset with many long-standing problems. Often, these problems, resulting in failures of facilities and cost-time overruns, are directly related to poor design and design management practices. This motivated the definition of the main aim to develop an initial framing for the design process support systems, incorporating ideas from the human error and performance management domains, and on checklists. In this conceptual paper, a literature review method is used. It is suggested that cognitive systems engineering could be used to conceptualize the designers work and to incorporate checklists into the design process. Then, key aspects and elements for the development of design process support systems are addressed.

KEYWORDS

Error management, checklist, design process, design support systems.

INTRODUCTION

Problems and accidents plague the delivery of construction projects. According to (Eurostat 2018), out of 3,876 fatal accidents at work in the 28 EU countries during 2015, 21% took place in the construction sector. Many accidents have been directly or indirectly related to the design factors. (Behm 2005) analyzed 224 fatal construction accidents from the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment Control and Evaluation (FACE) database and found that 42% of the accidents were associated with design factors.

Design errors have been considered the primary "contributor to building and infrastructure failures as well as project time and cost overruns" (Lopez et al. 2010). In the construction industry, checklists in the form of, for example, schedules (although not usually viewed as a checklist), templates, and review guidelines for organizing and managing the design activity have been used. These instruments have been theorized

1 Researcher, Department of Technology, Management and Economics, Technical University of Denmark, Denmark, ekas@dtu.dk

2 Professor, University of Huddersfield, Department of Architecture and 3D Design, UK, L.Koskela@hud.ac.uk

3 Associate Professor, Department of Technology, Management and Economics, Technical University of Denmark, Denmark, jooehm@dtu.dk

4 Senior Researcher, Department of Computer Science, Aalto University, Finland, bhargav.dave@aalto.fi

mainly from the managerial or organization perspectives but not necessarily from the human error and performance perspective.

In this paper, the aim is to develop an initial framing for the design process support systems based on the theoretical and the practical ideas and concepts related to human error and performance management and the use of checklists in aviation and design domains. Literature review method is used to clarify the underpinning ideas. Overall, this paper is divided into two major parts. In the second part, key aspects of the design support systems are discussed: product versus process-based support systems, central objects, and elements of support systems, process monitoring and the role of checklists in support systems.

HUMAN ERROR AND CHECKLISTS

In this section, the philosophy, approaches, and types of human error management are addressed first, and checklists devised in different industries to address human error and performance are addressed second. Finally, the main points are discussed.

HUMAN ERROR AND HUMAN ERROR MANAGEMENT

In 1935, at Wright Air Field in Dayton, Ohio, the US Army Corps held a competition that was supposed to be a formality to select the military's next-generation bomber. However, Boeing's Model 299, which was seen to be superior, crashed in a blazing explosion, killing two of the five crew members. The investigation revealed that the crash was caused by a 'pilot error' (Gawande 2010). The solution to the problem was not the redesign of the airplane or more training, but a simple pilot's checklist.

Furthermore, since the chemical plant explosion in Flixborough (1974), the failure of the second nuclear reactor on Three Mile Island (1979), and the explosion of the reactor's core in Chernobyl (1986), human errors and organizational failures have become to be considered as the primary contributors to accidents (Reason 1990). Nowadays, research on human error can be found in several disciplines, including construction (Behm 2005; Saurin et al. 2008).

Philosophy of Human Error

The philosophers (Gorovitz and MacIntyre 1975) addressed the nature of human fallibility and described two sources for "why humans fail in what they set out to do in the real world". The first source is the necessary fallibility: humans are not omniscient. In productive goal-directed activities, there are always particulars of a situation that cannot be reduced to the law-like generalizations and initial conditions. Even the best possible judgment can turn out to be erroneous (Gorovitz and MacIntyre 1975). The second source is the ineptitude, or human error, with the various degrees of seriousness, caused by the failure to apply existing knowledge (Gorovitz and MacIntyre 1975).

(Senders and Moray 1991) defined the human error as a deviation from intention, desire or expectations, from something that was "not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside its acceptable limits". However, this definition has limited value in the context of design, where ends and means, as well as the design process, are mutually dependent and in constant flux. Furthermore, creativity is at the core of designing, involving routine and non-routine, subject- and object-oriented activities (Love 2002). This implies that in design, it is rather difficult to distinguish between the erroneous and successful activity. (Woods et al. 1994) argued that ascribing "error to the actions of some person, team, or organization is fundamentally a social and psychological process".

Similarly, (Hollnagel and Amalberti 2001) argued that the dichotomization of human activity either 'correct' or 'error' is an oversimplification of a complex phenomenon. Instead of looking for "human errors" as either causes or events, human errors need to be considered as part of the normal range of human performance with various degrees of variability. Particularly, (Hollnagel and Amalberti 2001) proposed that management should "[…] find where performance may vary, how it may vary, and how the variations may be detected and – eventually – controlled". Also, to find out why and how things go right and amplify it.

Due to the complex nature of design (Lindemann et al. 2009), design activity being subject to uncertainties, tradeoffs, and emergencies, amplified by time pressure, irregular demand, and overcrowding, there will be a gap between 'work-as-imagined' (e.g., by managers who dictate procedures) and 'work-as-done' (Wachs and Saurin 2018). That is, actual work situations do not comply with pre-defined plans and procedures. According to (Suchman 1987), plans and procedures, as well as social and material environments, are better framed as "resources for action". A design agent and designing cannot be isolated from their context (Ullman 2002).

Approaches to Error Management

(Reason 1990) argued that there are two approaches for human error management: (1) the person approach and (2) the system approach. The person and system approaches subscribe to different views of error causation and philosophies of error management, and thus, have different practical implications.

In the person approach, the focus is on individual errors. However, according to (Reason 2000), the person approach has a significant limitation: focusing on individuals isolates errors from their context, which leads to the failure to identify the common patterns. In the system approach, in addition to human errors, the focus is on the environmental conditions of human work and the development of means to avert errors or mitigate their effects. It is assumed that humans are fallible and errors will occur. However, these errors are seen as consequences rather than causes, with their origin in systemic factors, "[including] recurrent error traps and organizational processes that give rise to them" (Reason 2000).

A more recent approach, named cognitive systems engineering, has been adopted to describe and analyze complex man-machine ensembles (Hollnagel and Woods 2005). A cognitive system is defined as "an adaptive system which functions using knowledge about itself and the environment in the planning and modification of actions" (Hollnagel and Woods 1999). In cognitive systems engineering, instead of operating on the level of physical or physiological, the focus is on the level of cognitive functions (Woods and Hollnagel 2006). That is, the emphasis is on the "joint cognitive systems, where human-machine are treated as interacting cognitive systems" (Hollnagel and Woods 2005). These interactions between the human (cognition) and its environment, including social, material and cognitive structures (such as conceptual symbolic artefacts; e.g., building information modelling), and how agents regulate and control their behavior and performance are the object of study and unit of analysis, respectively.

Artefacts, either tools or prosthesis, form a central constituent in the joint cognitive systems (Hollnagel 2002). According to (Hollnagel and Woods 2005), the artefact is "something made for a specific purpose". The distinction, whether the artefact is a tool or prosthesis, is dependent on the way it is used. That is, whether it is developed to enhance the user's abilities to perform tasks and solve problems (e.g., design decision support systems) or replace certain functions (e.g., wheelchair).

Levels of Cognitive Involvement and Types of Errors

It is well established that human performance involves different levels of control, a central premise in activity theory (Bedny and Meister 2014). Several concepts and models for theorizing on human performance and control of behavior exist, such as the distinction between the micro-, macro-, and metacognition (Klein et al. 2003; Woods 2009). However, probably one the most well-known, due to its longevity, breadth of use, and success, is the Rasmussen's Skill-Rules-Knowledge (S-R-K) model. It was initially proposed at the end of the 1970s and has served the human factors research community since (Woods 2009).

However, the S-R-K model developed based on the information processing view of cognition, pioneered by Newell and Simon, has been criticized in the cognitive systems engineering domain (Hollnagel 2002; Hollnagel and Woods 2005). The main criticism is that it isolates the human cognition from its environment (social, material and cognitive structures). Consequently, the overall system perspective was somewhat lost. In cognitive systems engineering, to overcome this limitation, the focus moved from internal functions and structures of human or machine to the external joint cognitive systems (Hollnagel 2002).

The different human performance levels have been associated with different types of errors. The development of an error taxonomy is the most common approach to transforming the theories of human error into a usable form (Senders and Moray 1991). (Reason 1990) proposed that the types of errors include slips, lapses, and mistakes. Slips refer to the attention failure of carrying out unintended or unplanned action(s) and lapses to the memory failure of omitting intended or planned actions. Mistakes are the result of using wrong rules, incorrect application of rules or failure to apply the correct rule; or the insufficient or incorrect knowledge or misapplication of existing knowledge to new situations. Finally, violations are deliberate deviations from standards, safe operating practices, and procedures (Reason 1990).

Checklists In Human Error/Performance Management

Various artefacts to avoid human error and assure the performance of designers have been developed, including checklists to increase the quality of outcomes and to reduce the risk of costly mistakes. For example, human error management and pilot's checklists are arguably the cornerstones of operational aviation safety. Although checklists might look simple, they are complex socio-technical interventions and need to be designed, developed and implemented consciously (Gawande 2010). In the following, the theoretical and the practical ideas and concepts related to the use of checklists are addressed.

General Concepts on Checklists

(Scriven 2000) defined the checklist as "a list of factors, properties, aspects, components, criteria, tasks, or dimensions, the presence or amount of which are to be separately considered, in order to perform a certain task". Unlike, for example, lessons learned, which tend to be descriptive, checklists by definition are prescriptive. That is, checklists constitute 'actionable' knowledge (Kokkoniemi 2006). "Checklists [guide] a user and act as verification after completion of a task, without necessarily leading users to a specific conclusion" (Ćatić and Malmqvist 2013). According to (Scriven 2000), checklists have the following benefits: help to reduce errors of omission; are relatively easy to understand and validate; reduce human biases ('halo effect' and 'Rorschach effect'); reduce the problem of double weighting in evaluative tasks; and help to capture and transfer knowledge.

The primary objectives of using checklists include error reduction or best practice adherence, standing anywhere in-between an informal cognitive aid (memory recall) and a protocol (standardization and regulation of processes or methodologies) (Hales and Pronovost 2006). (Scriven 2000) distinguished between five types of checklists: Arbitrary (e.g., simple shopping checklist), sequential, weakly sequential (for psychological or efficiency reasons), partly or entirely iterative (e.g., problem-solving flowcharts) and diagnostic (e.g., decision-trees) checklists. Different types of checklists support certain levels of human performance and problem-solving. In the following, the examples of instantiation of checklists in aviation and product development are briefly reviewed.

Checklists in Aviation

In aviation, checklists under most circumstances are considered a mandatory part of the practice. Checklists are the flight protocols that all pilots are required to use before, during, and after flights. Completing a checklist from memory is considered a violation or error (Helmreich 2000). The two categories of checklists used in the cockpit include (Clay-Williams and Colligan 2015): normal and non-normal (or emergency) checklists.

Normal checklists are used as part of a regular flight practice to ensure that all necessary has been done (Degani and Wiener 1993), especially when the list of tasks is long to be accessed from memory and tasks are subject to interruptions. The typical normal checklists include preflight, cockpit, starting engine, landing, and shutdown checks (Hales and Pronovost 2006). Normal checklists have two types of execution strategies (Degani and Wiener 1993): (1) Do-verify, where the task is performed from memory first and then verified against the checklist (used in contexts with limited time); and (2) Call-Do-Respond, where tasks are divided between two or three pilots for calling, performing or verifying procedures. Both methods include at least action and verification steps (Hales and Pronovost 2006).

Non-normal (emergency) checklists, not part of the normal flight protocol, are used to guide the correction of error situations and may include checks for ground operation emergencies, take-off emergencies, landing emergencies, and fuel system failures (Hales and Pronovost 2006). Emergency checklists may contain boldface, non-boldface or flowchart items, selected by the aircraft manufacturer depending on the likely severity of the problem and time available to solve it (Clay-Williams and Colligan 2015). Boldface items require immediate action, often executed from memory. Non-boldface checklists are used when the time is not critical. Checklists may also be instantiated as a flow chart or decision three (Clay-Williams and Colligan 2015).

Furthermore, checklists for airplane maintenance and pilots' physical, mental, and emotional status evaluation before a flight have been developed (Hales and Pronovost 2006). In recent decades, aircraft manufacturers have transitioned from paper-based to electronic checklist systems to guide pilots through both normal and emergency procedures. Electronic checklists have helped to reduce errors further when compared to the paper-based checklists (Boorman 2001).

Checklists in Product Development

In product development, errors cause cost and time problems and poor quality of products. Moreover, errors can cause safety issues for producers as well as for product users. Standardized procedures and checklists as a common strategy have been used to manage errors (Hales and Pronovost 2006). As Masaki Imai stated in his seminal work, there can be no *kaizen* (continuous improvement) without standardization (Imai 1996). Checklists can be used as the means to implement and improve standards. In the following, as Toyota has been considered one of the leading companies in process standardization and implementation of checklists, the focus will be mainly on the Toyota product development system.

(Ward et al. 1995) argued that the second Toyota paradox, the first paradox being the Toyota Production System, is the set-based concurrent engineering: "[…] delaying decisions, communicating ambiguously, and pursuing an excessive number of prototypes, enables Toyota to design better cars faster and cheaper". (Sobek and Liker 1998) described six organizational and managerial mechanisms underlying the second Toyota's paradox, including mutual adjustment, close supervision and integrative leadership as the social processes, and the standard skills, standard work practices and design standards as the means of standardization. Authors emphasize that these mechanisms are only useful when applied together.

Contrary to the US car manufacturers, Toyota has successfully standardized much of its development process (Sobek and Liker 1998). They have achieved it by carefully balancing the standardization of simplified work plans ("often fit on a single sheet") and the flexibility of the process concept implementation in each vehicle program. The simplicity and flexibility help to develop "common understanding, and continuous improvement, while hard deadlines keep the project on track" (Sobek and Liker 1998). The product and standard development processes are always considered and designed together. Standard work plans are developed, implemented and updated by the designers and departments that use them.

At Toyota, engineering checklists ("lessons learned books") are used by each participant to identify and record feasible design regions based on the current capabilities of the organization (Ward et al. 1995). Engineering checklists are highly visual and part or process specific for transferring experiences between vehicle programs (Morgan and Liker

2006). Engineering checklists comprise detailed information related to the aspects of, for example, functionality, manufacturability, government regulations, and reliability (Sobek and Liker 1998). Checklists also contain items on what can be done or not in an economic sense or items for incorporating new technologies for automation, cost reduction, quality improvement and so on (Morgan and Liker 2006). Checklists are used throughout the design process and particularly for design reviews. At the beginning of a new vehicle program, engineering teams exchange checklists to update each other on what is possible or not. In this way, assumptions are to be avoided.

According to (Sobek and Liker 1998), team members come to the review meetings with a prepared checklist of items they need to verify, and identified discrepancies between the checklists and designs become the points of discussion. When something new based on experience, analysis, experimentation, and testing is learned, it is added to the checklist. As such, checklists are continuously updated and become the means to explicate and transfer the accumulating knowledge of product development. The constant revision and updating of checklists, as part of the designers' work, also helps to develop a sense of ownership (Morgan and Liker 2006).

At Toyota, checklists are perceived to have the following benefits (Sobek and Liker 1998): improve face-to-face meetings, add predictability, facilitate organizational learning across vehicle programs, and make the knowledge to reside in the organization. Similar benefits have been recognized in other related domains, including the software engineering industry and engineering design in general.

In software engineering, although checklists have been mainly used for the inception processes of identifying defects and requirements engineering, (Kokkoniemi 2002) argued that checklists could also be used as part of the organizational memory system. Checklists can function as an experience-knowledge collection, experience-knowledge transferring and software process development tools (Kokkoniemi 2006). Similarly, according to (Firesmith 2005), checklists can support the software teams to make the state of the art the state of the practice by actually implementing the best known methods, techniques and knowledge.

The design of complex artefacts requires intensive knowledge-based activities to be carried out. For example, the questions-based approach has been proposed in engineering design literature. (Ahmed and Wallace 2001) proposed that questions-based design support system can aid novice designers to understand what they need to know in any given design context. (Grebici et al. 2009) developed five sets of generic questions that could guide the designers' inquiry into the subject matter. (Winkelmann and Hacker 2010) demonstrated that the use of interrogative questions stimulated reflection on solutions, which led to a significant improvement of the final solutions.

Common Characteristics of Checklists

Based on the literature review, checklists have been developed, implemented and maintained from three different perspectives: error reduction (Gawande 2010), process/performance (production) improvement (Ahmed and Wallace 2001; Grebici et al. 2009; Sobek and Liker 1998; Winkelmann and Hacker 2010) and knowledge management (Kokkoniemi 2006; Sobek and Liker 1998).

Benefits across the industries addressed above, include the error and human bias reduction (i.e., slips, lapses and mistakes); increased awareness of issues/aspects (e.g., safety issues); increased quality of services and products; improved team cohesion, communication and coordination; safer use of equipment and instruments; support for organizational learning.

The most elementary function of all checklists is that they are mnemonic devices (i.e., memory aids). Other functions of checklists depend on the use situation. In aviation, checklists for normal and non-normal (emergencies) situations have been developed. In the normal situation, the primary function of checklists is to avoid errors of omission and assure a best practice adherence (important for continuous improvement). In emergencies, checklists are used to support situation diagnosis and problem-solving. In the product development, checklists have been used to facilitate communication, coordination and team performance; to support quality improvement; and to provide the organizational memory system.

Five types of checklists for different use situations and functions have been proposed in the literature, including the arbitrary, sequential, weakly sequential (for psychological or efficiency reasons), partly or entirely iterative (e.g., problem-solving flowcharts) and diagnostic (e.g., decision-trees) checklists. Two common execution strategies include the "call-do-respond" and "do-verify". Checklists are often paper-based, but electronic checklists are used as well (Hales and Pronovost 2006).

Different studies have emphasized that checklists are complex interventions and require careful design, development, and updating. These studies have argued that the most challenging aspect of implementing checklists is to convince the users to implement and maintain checklists (Hales and Pronovost 2006). (Degani and Wiener 1993) argued that it is also important to consider human factors design principles for designing and implementing checklists.

DISCUSSION

Design is a complex human activity subject to the opportunity of errors, resulting in costly mistakes. However, instead of focusing on individual mistakes, the focus should be on the system level, including in addition to the individual also the context. Joint cognitive systems approach describes human performance as the product of multi-layered activity. Human performance control involves multiple concurrent phases and modes of control. Different levels of performance are associated with different types of error, including slip, lapse, mistake, and violation.

Cognitive systems engineering seems useful for developing interventions for incorporating checklists into the daily work of designers. Different modes of human performance control, extending from reflective (interpretative) to reactive modes of action control, require the use of different types of checklists. Nowadays, as is the case in the aviation industry, it is also common to integrate the checklists into the artefacts for aiding human operators.

Checklists could also be conceptualized from the three views of production (management) proposed by (Koskela 2000). Checklists encoding standardized work procedures can help to reduce process variation, thus, waste (e.g., the seven preconditions for the task and the seven wastes can be considered as checklists). Furthermore, checklists, when used for error reduction can help to improve quality, thus, value to the customer. Checklists as simple 'to-do' lists can define the necessary tasks to design an artefact, or part of the artefact

Before discussing the possibilities for developing support systems, it must be noted that human error management has roots in quality management (Shewhart 1931), although the term "human error" was not explicitly used there. Specifically, the approaches proposed by (Reason 1990) and Hollnagel and Amalberti (2001) overlap with ideas advocated in the quality management domain. Indeed, some of the main components of the Toyota error management include, for example, the mistake-proofing ('poka-yoke') and visual management (Shingo 1986; Ward et al. 1995).

DESIGN PROCESS SUPPORT SYSTEMS

The need for a systematic error and performance management has also been recognized in the building design context (Lopez et al. 2010). Inspired by the use of (electronic) checklists in the aviation industry, in this section, the main concepts relevant for developing a design (process) support system are addressed. The proposal relies on the premise that building designers use building information modelling (BIM).

DESIGN SUPPORT SYSTEM OR DESIGN PROCESS SUPPORT SYSTEM

(Ullman 2002) proposed the idea of 'ideal mechanical engineering design support system'. However, the focus was on the artefact, the inner conceptualization of technical parts (functions and structures) of the design application. However, the performance of building designer is the product of interactions between the designer and the environment, including artefacts one uses to perform goal-oriented tasks.

Instead of focusing on the principles of product and their implementation in the product design applications, the focus should be, not neglecting the product view, on the process of design. That is, the design is primarily concerned with interactions involving human(s), object(s) and contexts together with the general aim of bringing about changes that are enabled and mediated by the situated subject (addresses interpretation) and object oriented (addresses causality) activities (Pikas 2019).

CONSTITUENTS OF DESIGN PROCESS SUPPORT SYSTEMS

In the domain of building design, the main objects include the context(s) (problem domain (global and local) and solution domain), humans (clients, users, and designers), and objects (product, BIM and checklists). These are embodied in the design process, which itself contains the following elements (Pikas 2019): modes of activity (analysis and synthesis), the categories of design activities (subject- and object-oriented), stages and phases, causal structure of design transformations (problem and solution state changes), iterations, and mental and external activities. This means that the contexts, humans, and objects of design are brought together through the design process.

DESIGN PROCESS MONITORING

The effective control of the design process requires close monitoring of the design process and providing information back to designers and design managers. But there are limitations with the typical approaches (Yarmohammadi and Castro-Lacouture 2018). Often, the daily process monitoring is left to the sole responsibility of individual designers, which may lead to conflicting activities and decisions. In the managerial context, due to the manual processes of collecting data, there is a considerable monitoring lag between the actual design process and feedback (Pikas 2019).

For the design process support system, a real-time design process monitoring system needs to be developed (e.g., a plugin for Revit could be developed). Although the focus in this study was on the measurement of outputs (model elements), and not taking into account contextual matters and designers activities, the feasibility of this has been already studied (Yarmohammadi and Castro-Lacouture 2018). The real-time monitoring of the design process could be then used to integrate the checklists into the daily work of designers.

CHECKLISTS FOR DESIGN PROCESS SUPPORT SYSTEMS

Checklists are not a new invention in the building design context. However, checklists have been used relatively narrowly, mostly for design reviews and inspections; e.g., the design review checklists of the Whole Building Design Guide (Prowler and Vierra 2012) or (Sannwald 2009). Furthermore, clash detection, say by Solibri, and automated code checking, are in a way automated checklists (Sacks et al. 2018). These types of checklists are primarily focused on the static aspects of design, i.e., design outputs.

Also, the process needs to be taken into account, and checklists for these need to be developed, be they manual or computerized. Furthermore, the two issues of developing checklists for building design include the development of the substance (contents) of checklists, and developing the media (channels) to deliver them to the point of use. The context-aware design process support system would help to automate the detection of a relevant checklist, and relevant item on that list, and assure compliance to the standards.

CONCLUSION

An initial framing for design process support systems was developed in this study. The purpose of a design process support system would be to facilitate the error, performance and knowledge management; needed because design as a complex activity is prone to errors. Cognitive engineering systems together with the process perspective of design can facilitate the theoretical development framework for design process support systems. If the processes of BIM-enabled design can be monitored, then checklists could be incorporated into the design process to standardize work, facilitate communication and coordination, improve quality, and enable knowledge transfer between projects.

However, as this is only an initial framing, many aspects of the design process support systems still need to be addressed. For example, in this work, there was no room to specifically address the content and relationships between the different constituents of design process support systems. Also, how exactly the monitoring of designers work can be done and what kind of analytics (probably something along the lines of process mining) is required to make sense of the raw data. Similarly, the kinds of visualizations needed to communicate the checklists in real time to designers at work are also significant. All these are important questions and need further study.

REFERENCES

Ahmed, S., and Wallace, K. M. "Developing a support system for novice designers in industry." *Proc., International Conference on Engineering Design (ICED 01), Design Management–Process Information, IMechE*, 75-82.

Bedny, G., and Meister, D. (2014). *The Russian theory of activity: Current applications to design and learning*, Psychology Press.

Behm, M. (2005). "Linking construction fatalities to the design for construction safety concept." *Safety science*, 43(8), 589-611.

Boorman, D. (2001). "Today's electronic checklists reduce likelihood of crew errors and help prevent mishaps." *ICAO Journal*.

Ćatić, A., and Malmqvist, J. (2013). "Effective method for creating engineering checklists." *Journal of engineering design*, 24(6), 453-475.

Clay-Williams, R., and Colligan, L. (2015). "Back to basics: checklists in aviation and healthcare." *BMJ Quality & Safety*, 24, 428-431.

Degani, A., and Wiener, E. L. (1993). "Cockpit checklists: Concepts, design, and use." *Human factors*, 35(2), 345-359.

Eurostat (2018). "Accidents at work statistics - Fatal accidents at work, 2015." DG Employment and Social Affairs – Eurostat., URL: https://ec.europa.eu/eurostat/statistics-explained/index.php/Accidents_at_work_statistics, Access date: 05.02.2019.

Firesmith, D. (2005). "Quality Requirements Checklist." *Journal of Object Technology*, 4(9), 31-38.

Gawande, A. (2010). *Checklist manifesto*, Penguin Books India.

Gorovitz, S., and MacIntyre, A. (1975). "Toward a theory of medical fallibility." *Hastings Center Report*, 5(6), 13-23.

Grebici, K., Aurisicchio, M., and Bracewell, R. "Guiding engineering design activities through a question based approach." *Proc., ASME 2009 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, American Society of Mechanical Engineers, 1449-1459.

Hales, B. M., and Pronovost, P. J. (2006). "The checklist—a tool for error management and performance improvement." *Journal of critical care*, 21(3), 231-235.

Helmreich, R. L. (2000). "On error management: lessons from aviation." *Bmj*, 320(7237), 781-785.

Hollnagel, E. (2002). "Cognition as control: A pragmatic approach to the modelling of joint cognitive systems." *IEEE Journal of Systems, Man and Cybernetics*.

Hollnagel, E., and Amalberti, R. (2001). "The emperor's new clothes: Or whatever happened to "human error"." *Proceedings of the 4th international workshop on human error, safety and systems development*, Linköping University, 1-18.

Hollnagel, E., and Woods, D. (1999). "Cognitive systems engineering: new wine in new bottles." *International Journal of Human-Computer Studies*, 51, 339-356.

Hollnagel, E., and Woods, D. D. (2005). *Joint cognitive systems: Foundations of cognitive systems engineering*, CRC Press.

Imai, M. (1996). "KAIZEN: the key to Japan's competitive success. Editorial CECSA, Mexico." *Google Scholar*.

Klein, G., Ross, K. G., Moon, B. M., Klein, D. E., Hoffman, R. R., and Hollnagel, E. (2003). "Macrocognition." *IEEE intelligent systems*, 18(3), 81-85.

Kokkoniemi, J. (2002). "Checklists as a tool for collecting experience knowledge." *Proceedings of IASTED International Conference of Information and Knowledge Sharing (IKS 2002), St. Thomas, Virgin Islands, USA*, 223-228.

Kokkoniemi, J. (2006). "Experiences from generating checklists." *Proceedings of the IASTED International Conference on Knowledge Sharing and Collaborative Engineering (KSCE2006), St. Thomas, Virgin Islands, USA*, 51-56.

Kokkoniemi, J. (2006). "A preliminary model for generating experience knowledge based artifacts." *Proceedings of the 39th Hawaii International Conference on System Sciences (HICSS'06)*, IEEE, Hawaii, USA, pp. 10.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*, VTT Technical Research Centre of Finland.

Lindemann, U., Maurer, M., and Braun, T. (2009). "Complexity in the context of product design." *Structural Complexity Management:An Approach for the Field of Product Design*, Springer Berlin Heidelberg, Berlin, Heidelberg, 21-42.

Lopez, R., Love, P. E., Edwards, D. J., and Davis, P. R. (2010). "Design error classification, causation, and prevention in construction engineering." *Journal of Performance of Constructed Facilities*, 24(4), p. 399-408.

Love, T. (2002). "Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues." *Design Studies*, 23(3), 345-361.

Morgan, J. M., and Liker, J. K. (2006). "The Toyota product development system." *New York, US*.

Pikas, E. (2019). "Causality and Interpretation: Integrating the Technical and Social Aspects of Design." Doctor of Science (Technology), Aalto University, Espoo, Finland.

Prowler, D., and Vierra, S. (2012). "Whole building design." *Whole Building Design Guide*.

Reason, J. (1990). *Human error*, Cambridge University Press, Cambridge, UK.

Reason, J. (2000). "Human error: models and management." *Bmj*, 320(7237), 768-770.

Sacks, R., Eastman, C., Lee, G., and Teicholz, P. (2018). *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*, Wiley.

Sannwald, W. W. (2009). *Checklist of library building design considerations*, American Library Association.

Saurin, T. A., Formoso, C. T., and Cambraia, F. B. (2008). "An analysis of construction safety best practices from a cognitive systems engineering perspective." *Safety science*, 46(8), 1169-1183.

Scriven, M. (2000). "The logic and methodology of checklists." *Retrieved from: http://www.wmich.edu/evalctr/archive_checklists/methodology_dec07.pdf*.

Senders, J. W., and Moray, N. P. (1991). *Human Error: Cause, Prediction, and Reduction*, Taylor & Francis.

Shewhart, W. A. (1931). *Economic control of quality of manufactured product*, ASQ Quality Press.

Shingo, S. (1986). *Zero quality control: Source inspection and the poka-yoke system*, CRC Press.

Sobek, I., and Liker, J. K. (1998). "Another look at how Toyota integrates product development." *Harvard business review*, 76(4), 36-47.

Suchman, L. (1987). "Plans and situated action." Cambridge: Cambridge University Press.

Ullman, D. G. (2002). "Toward the ideal mechanical engineering design support system." *Research in Engineering Design*, 13(2), 55-64.

Wachs, P., and Saurin, T. A. (2018). "Modelling interactions between procedures and resilience skills." *Applied ergonomics*, 68, 328-337.

Ward, A., Liker, J. K., Cristiano, J. J., and Sobek, D. K. (1995). "The second Toyota paradox: How delaying decisions can make better cars faster." *Sloan management review*, 36, 43-43.

Winkelmann, C., and Hacker, W. (2010). "Question-answering-technique to support freshman and senior engineers in processes of engineering design." *International Journal of Technology and Design Education*, 20(3), 305-315.

Woods, D. "Rasmussen's SRK 30 Years Later: Is Human Factors Best in 3's?" *Proc., Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, SAGE Publications Sage CA: Los Angeles, CA, 217-221.

Woods, D. D., and Hollnagel, E. (2006). *Joint cognitive systems: Patterns in cognitive systems engineering*, CRC Press.

Woods, D. D., Johannesen, L. J., Cook, R. I., and Sarter, N. B. (1994). "Behind human error: Cognitive systems, computers and hindsight." Dayton Univeristy Research Insitute.

Yarmohammadi, S., and Castro-Lacouture, D. (2018). "Automated performance measurement for 3D building modeling decisions." *Automation in Construction*, 93, 91-111

Pikas, E., Koskela, L., Oehmen, J., and Dave, B. (2019). "From Checklists to Design Process Support Systems: Initial Framing." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 83–96. DOI: https://doi.org/10.24928/2019/0173. Available at: <www.iglc.net>.

STREAM 2: VALUE IN PROCUREMENT

Andenaes, E., Time, B., Torp, O., Kvande, T., and Lohne, J. (2019). "Risk Management in Procurement of Blue-Gren Roofs – A Project Owner Perspective" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 97–108. DOI: https://doi.org/10.24928/2019/0263. Available at: <www.iglc.net>.

RISK MANAGEMENT IN PROCUREMENT OF BLUE-GREEN ROOFS – A PROJECT OWNER PERSPECTIVE

Erlend Andenaes[1], Berit Time[2], Olav Torp[3], Tore Kvande[4] and Jardar Lohne[5]

ABSTRACT

Blue-green roofs are vegetated roofs used for stormwater management purposes. With the roof serving several different purposes at the same time, the risk that any of its functions could be compromised needs to be addressed. Risks related to roof defects may present a threat to the long-term operation of a building, and could lead to waste by making defective products. This article presents an investigation to explore how the Norwegian building sector handles and manages this risk.

Tender documents for green roof construction projects in the Norway are examined. Technical documents are studied to chart how the projects manage risks related to the integrity of the roofs in the tender phase. Findings suggest that risk in relation to building physics is not systematically analysed and managed in design and procurement phase of the project. Contractors are given significant control of design elements in certain common contract strategies. Risk is effectively not being managed in the early phase, with much of the risk management given to the contractors. The project owner will yield little control over decisions whose outcomes will only manifest long after the warranty period expires.

KEYWORDS

Blue-green roofs, risk management, contract strategy

INTRODUCTION

Blue-green roofs are roof assemblies where plants and various substrates are used to store water temporarily, gradually releasing it once the roof's capacity is reached. As such, they function as a mitigation measure against flooding from intense rain events, by detaining or

[1] Ph.D. candidate, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway, +47 926 84 110, erlend.andenas@ntnu.no

[2] Head researcher, Department of Materials and Structures, SINTEF Building and infrastructure, Trondheim, Norway, +47 970 72 083, berit.time@sintef.no.

[3] Associate Professor, Norwegian University of Science and Technology, Trondheim, Norway, +47 934 226 73, olav.torp@ntnu.no.

[4] Professor, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway, +47 902 55 434, tore.kvande@ntnu.no.

[5] Research scientist, dr. art. Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, Trondheim, Norway, +47 934 44 930, jardar.lohne@ntnu.no

delaying runoff from roofs. This frees up capacity in the drainage system to manage runoff from other impervious surfaces. Blue-green roofs differ from ordinary green roofs by being actively designed to deliver this stormwater management function.

In Norway, climate change is manifesting in the form of milder weather with increased precipitation(Hanssen-Bauer et al., 2015). A phenomenon of particular interest is an increased frequency of quick, intense showers, during which large amounts of precipitation fall within a short time span. The intensity of this rainfall can lead to a higher level of surface runoff than can be managed with existing drainage systems or ground infiltration, with the excess water causing flooding. According to numbers from Finance Norway, payouts for weather-related damages have more than doubled in the last ten years (Hauge et al., 2017). As such, there is a growing push towards climate adaptation.

POLITICS, STATE OF THE NATION.

The condition of stormwater pipes in Norway is far below par. The investment required to bring the existing wastewater and stormwater grids up to a good condition is expected to be around NOK 110 billion (RIF, 2015). The prohibitive cost of refurbishing the underground infrastructure, even without accounting for the cost of capacity upgrades, means that future climate challenges will primarily have to be addressed by on-site solutions including local retention and infiltration.

In densely developed urban locations, little space is left for green spaces on the ground level. Impermeable roads or buildings will cover most of the land surface. Blue-green roofs provide retention and detention capacity for stormwater, which would otherwise be hard to achieve without tying up highly contested ground space or excavating underground detention reservoirs at high costs (Johannessen et al., 2017).

However, adopting an active stormwater measure such as a blue-green roof on a building will imply a change in physical and operational conditions. Perhaps most notably, the literal burial of the roof membrane makes it much more difficult to detect damages or leakages. Additionally, moisture and temperature conditions at the roof membrane will change drastically. A roof with living vegetation will also require more intensive maintenance than conventional flat roofs. These aspects, and others, add risk elements to blue-green roof design compared to that of conventional roofs. Lean Construction includes focus on Transformation, Flow and Value (Koskela 1992). The main focus is on reducing waste, which comes in many categories. For example, Taiichi Ohno's seven wastes: overproduction, waiting, transportation, processing, inventory, movement, making defective products (Ohno 1988). Different categories of waste are relevant to the production of blue-green roofs. In this paper, risks for damages related to blue-green roofs are considered. This primarily relates to the seventh category of waste, making defective products. Reduced risk for damages will also increase the costumer value, thus supporting the principles in Lean Construction.

While blue-green roofs are adopted as a risk-reducing measure from the perspective of stormwater management, in other circumstances it adds to the overall risk picture. It is vital to determine the balance point between reduced and increased risk to assess the overall efficacy of blue-green roofs. Damages to the roof pose a threat to the long-term operation and thereby to the life cycle costs of the building.

This article aims to investigate how risk related to the building's quality is handled in practice, by examining documents from the design and procurement phase of construction projects featuring green roofs. The following research questions are examined:

What are the challenges and risks related to green and blue-green roofs?

What strategies are applied by project owners to control and manage risk related to green roofs in the procurement phase?

What improvements can be made?

The research is performed as a document study. Tender documents from recent construction projects featuring green roofs in Norway are examined to study how project owners manage the known technical risks associated with green roofs in design and procurement phase. Due to the inherent complexity of construction projects and the many actors involved, it has been decided to focus only on this phase and only from the project owner's perspective to provide a deeper, if narrower, understanding of these challenges.

The study is mainly limited to public projects whose tender documents were freely accessible, as it is difficult to gather detailed documentation on such cases. However, these projects are considered representative for the Norwegian building sector as a whole. A detailed study is expected to uncover issues that are relevant for green roof projects in general.

THEORY

Green roofs in Norway

Green roofs have been used in Norway for several centuries in the form of sod roofs, which provided insulation as well as weather protection. This roof type still sees use in a modernized form on buildings mimicking traditional architectural styles (Jim, 2017). Modern green roofs remain relatively uncommon in Norway, but have recently surged in popularity as a "green" feature in modern architecture. Blue-green roofs are still a novelty element, but some manufacturers already offer off-the-shelf blue-green roof solutions (Protan, 2019).

The most common form of green roof assembly is a lightweight sedum assembly mounted directly on top of a conventional, compact, flat roof, a so-called "extensive" green roof. "Intensive" green roofs are built to provide green outdoor spaces on rooftops, and can range from simple grassy lawns to landscaped parks with bushes and trees. Intensive green roofs require a much thicker and heavier green roof assembly, which makes them less commonly seen. A blue-green roof assembly will follow the same principles as ordinary green roofs, but have a higher capacity for water storage than what the plants need to survive. Note that all green roofs will inherently have some form of stormwater management properties, even if they are not designed with it in mind. The principal composition of a blue-green roof is shown in Figure 15.

Research published by Byggfakta (2018) estimates 17,000 new buildings to be built in Norway between 2018 and 2021, at a total cost of 3500 billion NOK. There exists a great potential for using roofs for stormwater management as well as providing outdoor space, but it is vital that risks are well understood before blue-green roofs are implemented on such a broad scale. If wrong strategies to handle risks are chosen, this could lead to waste for the project owner.

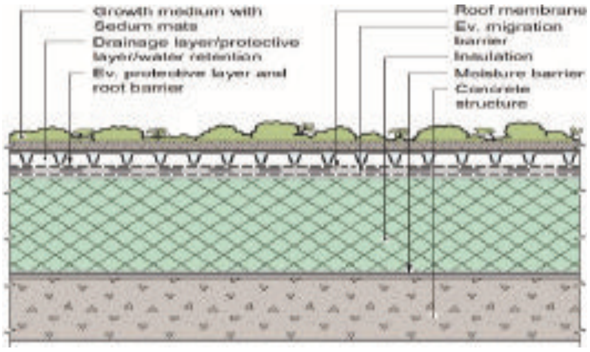


Figure 15: Composition of a green roof assembly on a compact, flat roof (Skjeldrum and Kvande, 2017).

MAIN PROJECT DELIVERY MODELS IN A NORWEGIAN CONTEXT

Several different contract strategies exist for construction projects, as outlined by Lædre (2009), from separation based to integration based approaches. The most commonly used in Norway are integration based approach like design build contracts and separation based approaches like design bid build. Strategies with Early Contractor Involvement are more and more applied.

In design build contracts, the project owner typically is responsible for the work until detail design, and then orders delivery from the contractor, essentially placing both detail design and build in the contractor's hands. The Norwegian rules for design build contracts are outlined in the standard NS 8407:2011. In design bid build contracts, the project owner has the responsibility for all the design and the construction, where suppliers are contracted individually.

The project owner of a construction project usually ends up owning and managing the building, and is thereby also responsible for facility management and life cycle costs. Private Public Partnership contracts transfer responsibility for financing, design, build and operation of the facility for a time period to the contractor (Lædre 2009).

RISK AND UNCERTAINTY

Uncertainty is an event that if it occurs, has a positive (potential upsides or opportunities) or negative (potential downsides or risks) effect on a project's objectives(Torp et al., 2018). Uncertainty management processes aim to reduce the risks and exploit the opportunities (Hillson, 2003). Risk is generally understood as a combination of the probabilities of unwanted events and their consequences, with some definitions following variations of "the likelihood and consequences of unintended outcomes" (Johansen, 2015). Several types of risk exist on several different analytic levels: The conceptual level, the processual level and the technical level. Uncertainty and hereby risk management addresses all types of uncertainty and risk, including risk related to cost, time, quality, scope, safety, customer satisfaction, company reputation, etc. (Torp et al. 2018). According to Torp et al. (2018), uncertainty management includes both proactive, interactive and reactive ways of thinking. Proactive uncertainty management is about analysing the uncertainty upfront to make actions before things happens. Interactive uncertainty management is about being able to handle things as they happen. Reactive uncertainty management is about understanding things that have happened, it is about repairing, exploiting opportunities and gathering experiences for future learning.

In the context of the construction industry, risk management commonly refers to the management of uncertainties related to processual matters, i.e. delivering the project within time and budget constraints (Lichtenberg, 2000). The health and safety aspects of risk are also fundamental and given much consideration in construction projects. However, the risk of compromising the quality, function and integrity of building components appears little studied. This article will attempt to dissect these technical risks rather than those that exclusively deal with costs, delays, or safety.

Statistics from the Norwegian building sector suggests that defects and leakages are common on flat roofs (Engebø et al., 2018), creating an issue of waste for project owners. The introduction of blue-green roof assemblies (in the form of additional layers on top of the existing roof structure) is not believed to cause more leakages, but leakages in a green roof will be much more difficult to detect and more expensive to repair as the roof membrane is covered.

To achieve a detail level suitable for a short article, a narrowing of the scope is required, concerning both the project timeline and the actors involved. Mainly, this article focuses on the building design and procurement phase, where the building is planned and designed. The final performance and quality of the blue-green roof will depend greatly on choices made in this phase. The consequences of such choices may only become apparent several years into the roof's lifetime, beyond the time of involvement by many actors in the project. As such, quality risk will largely be carried by the project owner, hence the focus on the project owner role in this article.

COMMON FAILURE MODES OF BLUE-GREEN ROOFS

The first research question asked in this paper is covering what challenges and risks that are related to blue-green roofs. The main forms of quality risk for green roofs are well known, and they are considered applicable for blue-green roofs as well. SINTEF Byggforsk (2013) lists technical recommendations and design flaws to avoid with green roofs. Additionally, most known risks concerning compact flat roofs tend to apply to green roofs as well, as they are usually mounted on a compact flat roof assembly. The main risk event is that of water leakage, which may compromise the integrity and functionality of the roof. Norwegian technical regulations stipulate that water intrusions should be avoided on all buildings (DiBK, 2017). Additionally, because of the living plants on the roof, poorly designed drains may be clogged with plant material, compromising the drainage function of the roof. The main critical points of vulnerability on blue-green roofs are schematically illustrated in Figure 16.

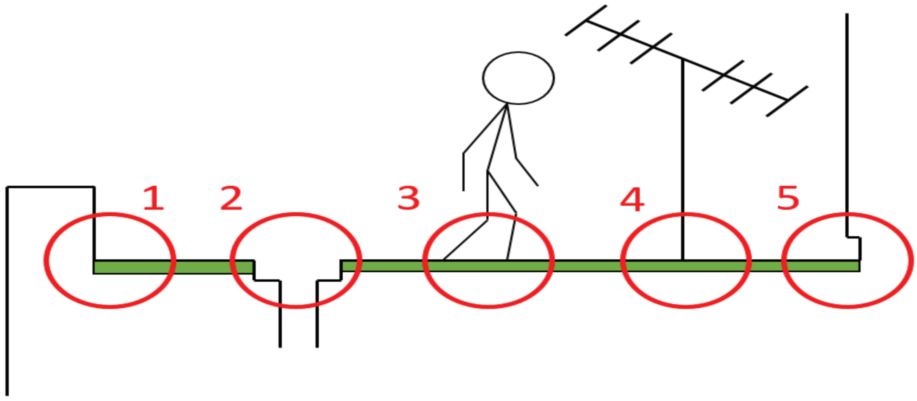


Figure 16: Critical vulnerable points of a green roof (also applicable for blue-green roofs): 1) Transitions between the roof and parapets. 2) Drains. 3) Traffic or work on the roof, including the use of tools such as landscaping tools or ladders. 4) Fastening points for technical equipment that perforates the roofing membrane. 5) Transitions between the roof and walls, particularly around doors.

KNOWLEDGE GAP

While failure modes and risk elements for green roofs are well known in theory, there exists a knowledge gap concerning how these risk elements are managed in practice. This relates to reducing waste related to making defective products (Ohno 1988). While building planners are generally aware of the vulnerable points of a roof structure, and strive to account for them when designing, there does not exist a framework defining how this risk is to be managed in the building process. The strategies of risk management will therefore vary between projects, depending on the companies or even the individual persons who author the building technical assessment reports in the pre-design phase. The strategies should include both proactive, interactive and reactive approaches (Torp et al. 2018). According to Hillson (2004), different strategies could be applied to handle uncertainty. Main strategies will be to avoid, reduce, share and accept risks and to share, exploit, accept and enhance opportunities. In relation to blue-green roofs, only risks are looked into. Then strategies to look into should be to avoid, reduce, share and accept risks related to blue-green roofs.

METHOD

Various actors in the public sectors were approached to provide data from the design and procurement phase of green roof projects built in the past few years. Respondents were asked to provide documents relevant to the design of the green roof, as well as give some context around the decision to build green roofs in the first place. Unfortunately, responses were only returned concerning three construction projects, for two of which technical documents were provided.

Additionally, some data was found at the Norwegian national notification database for public procurement (Doffin, 2019). Searches were performed in Norwegian using the key words “green roof”, “roof garden” and “sedum roof”. This yielded a further four results, two of which had technical documents available.

The project tender documents were examined with a focus on mentions of the green roof, including the stormwater management plan. Any recommendations or requirements were noted. This includes the overall assembly of the roof as well as any mentions of risk-reducing measures.

Where technical documents were available, they were examined in detail for mentions of the green roof. In particular, the pre-design reports and building physics notes contained information on the roof, showing what level of detail planning had been conducted before the tender was published.

RESULTS

Five main categories of risk have been identified as relevant to blue-green roofs.

1. Economical risk – covers matters of project cost, life cycle cost, and hereunder risks of delays in the construction process.

Health and safety risk – covers the physical safety and well-being of personnel on site, under all phases of the roof’s lifetime.

Environmental risk – covers matters of pollution and emissions, to air, soil and water as well as to organisms.

Process risk – covers the achievement of specific project goals and the fulfilment of general success criteria, i.e. those outlined by Samset (2001).

Quality risk – covers the integrity, quality and function of roof components as well as that of the entire roof assembly, both at the point of hand-over and throughout the lifetime of the roof.

While there is some overlap between categories (for instance, risk scenarios in any category will be likely to have consequences in the form of economic losses), they are considered distinct enough to define the scope of the further work. This article will mainly disregard the first four categories in favour of examining quality risk in more detail.

The examined construction projects are summarized in Table 3. The scope of green roofs are shown, as well as the intentions of building them, if available.

Table 3: General overview of examined projects.

Project	Type of green roof	Intention	Project phase[1]	Contract form	Project owner	Technical documents available
Molde high school (2014)	Roof terrace	Optional greenery on roof terrace	Call for turnkey contracts	Design build	Møre og Romsdal county administration	No
Nesbru nursing home (2014	Sedum roof (extensive)	Sedum roof for stormwater management and aesthetics	Call for contracts	General contract	Asker municipality	No
Vækerøveien municipal housing (2015)	Sedum roof (extensive)	Flat roof mandated by area plan, Sedum cover chosen for aesthetic reasons.	Call for turnkey contracts	Design build	Oslo municipality	Yes
Holmen swimming hall (2015)	Roof lawn, intensive green roof	Providing outdoor green space on building roof	Pre-project, call for build contracts	Build to order	Asker municipality	Yes
Bjørlien school (2016)	Sedum roof (extensive)	Optional sedum roof	Call for turnkey contracts	Design build	Vestby municipality	Yes
Kannik school (2016)	Sedum roof (extensive)	Optional sedum roof	Call for turnkey contracts	Design build	Stavanger municipality	No
Nordvoll school (2017)	Sedum roof (extensive)	Aesthetics	Call for turnkey contracts	Design build	Undervisningsbygg (Oslo municipal agency)	Yes

[1] Phase for which documents were available

Table 2 examines the projects where documents are available in closer detail. Contract documents are examined for mentions of membrane tightness, specifications about the design of drains, and the detail level with which the roof assembly is described. Additionally, stormwater management plans are examined to investigate whether the project aims to take advantage of the stormwater management properties of the roofs. This property is often used to justify the construction of a green roof, but it rarely appears to be taken into account in practice.

Table 4: Detailed specifications in project documents where those were available.

Project	Reference to membrane tightness	Drain specifications	Assembly specification in tender/pre-design documents	Green roof stormwater function
Vækerøveien municipal housing (2015)	None	Downpipes specified, but not drains	Detailed specification	Not mentioned in stormwater management plan
Holmen swimming hall (2015)	None	Drains shown in drawings	Detailed specification of entire roof assembly	Not mentioned in stormwater management plan
Bjørlien school (2016)	Integrity test recommended	Need for inspection drain highlighted	Detailed specification of roof assembly	No stormwater management plan available
Nordvoll school (2017)	Specifications given No mention of integrity test	Need for redundant drain highlighted	No detailed specification of green roof assembly	Not mentioned in stormwater management plan

In general, the matter of risk management does not appear to be treated in a consistent manner between the examined projects. For all of the projects listed in Table 4, a pre-design report lists some requirements and recommendations for the roof assembly. However, the level of detail in these reports varies. Some contain thorough assessments; others scarcely say more than “sedum mats will be put on the roof”. References are sometimes made to the SINTEF Byggforsk design guides, but these guides do not necessarily cover special cases such as building transitions. The thoroughness of the pre-design reports appears to rest entirely on the person who wrote them; this will vary wildly in practice when there is no specific framework to follow. Where green roofs are only included as an optional addition to the project, only general functional requirements seem to be given.

DISCUSSION

This article seeks to answer the following research questions: What challenges can be identified related to green roofs, what strategies are taken by project owners to control and manage risk related to green roofs, and what improvements can be made. The last question relates to how to reduce waste related to making defective products when constructing green roofs.

From risk management, different strategies to manage risks are avoid, accept, share or transfer (Hillson 2004). There does not appear to be any consistency to the technical risk management related to roofs.

Design and build contracts give contractors much freedom to choose the roof concept and plan it in detail. This is a strategy where the project owner transfers the risk related to the roof design and construction to the contractor. When green roofs are made optional, it is completely up to the contractor to design the roof, with the owner choosing whether to implement it once a suggestion is presented. Here exists a possibility to avoid the risk related to green roofs, if the contractor chose to design another type of roof construction. The aspect of roof-related risk appears to be completely absent from the tender documents in these cases. In other types of contract strategies with Early Contractor Involvement and or alliancing, one could choose a strategy of sharing the risk related to green roofs, where the project and the contractor share the risk among them. With a PPP (private-public partnership) solution, responsibility for financing, design, construction and operating the facility for a time period (20-25 years) would also be transferred to the contractor. The strategy would then be to transfer all risks related to the roof construction to the private party, typically a contractor.

A suggested improvement includes the development of a more rigid framework used when procuring green roofs, choosing a strategy to avoid, share or transfer the risk. This could take the form of a checklist that covers the basic questions that should be asked and answered when a blue-green roof is to be procured. The framework could include an overview of the most commonly problematic roof details as well as requesting the contract participants to agree on a common strategy for managing building technical risk.

CONCLUSION

The relation between building physics/technical solutions and process-related issues seems to be little explored. The management of quality risk is not treated explicitly or consistently in risk management processes, nor in contract strategies. While processual risks is a field of study in itself, technical risks are not given the same level of systematic consideration in project risk management.

While available data is limited, possibly to the point of insufficiency, it can be seen that none of the examined projects explicitly manage technical risks in a systematic way. Common technical risks are covered better in some pre-design documents than in others, but this appears to vary depending on their authors. With pre-design documents lacking detail, it will be up to the contractor to pick a concept, which might not be as robust as desired from the project owner’s perspective. It is up to the project owner to choose risk management strategy, either accept the risk, transfer the risk to the contractor, share the risk with the contractor or simply avoid the risk, by choosing an alternative roof construction.

FUTURE WORK

Work will continue on this subject, broadening the scope to look at the perspective of other actors and other phases of the building process. The risk category of process risk will also be investigated, focusing on the choice of green roof concept as opposed to the execution of a given concept. Finally, it will be sought to develop guidelines for managing technical risks related to green and blue-green roofs.

ACKNOWLEDGEMENTS

We would like to acknowledge and extend our gratitude to parties who for the moment will remain anonymous for the review process.

REFERENCES

Byggfakta (2018) Tak og fasade, rapport 2018. April. Byggfakta. Available at: https://gratisdemo.byggfakta.no/svimlende-summer-pa-tak-og-fasade.

DiBK (2017) Byggteknisk forskrift (TEK17), §13-9. Available at: https://dibk.no/byggereglene/byggteknisk-forskrift-tek17/13/vi/13-9/ (accessed 25 February 2019).

Doffin (2019). Available at: https://www.doffin.no/en (accessed 6 March 2019).

Engebø A, Andenæs E, Kvande T, et al. (2018) Governing Flat-Roof Constructions: A Case Study. In: 26th Annual Conference of the International Group for Lean Construction, 2018, pp. 1079–1089. Available at: http://iglc.net/Papers/Details/1502 (accessed 8 March 2019).

Hanssen-Bauer I, Drange H, Førland EJ, et al. (2015) Klima i Norge 2100. Kunnskapsgrunnlag for klimatilpasning oppdatert i 2015.

Hauge ÅL, Flyen C, Almås AJ, et al. (2017) Klimatilpasning av bygninger og infrastruktur - samfunnsmessige barrierer og drivere. Klima 2050 Report 4–2017, 28 February. Trondheim, Norway: SINTEF Building and Infrastructure.

Hillson D (2003) Effective Opportunity Management for Projects. Marcel Dekker New York.

Jim CY (2017) An archaeological and historical exploration of the origins of green roofs. Urban Forestry & Urban Greening 27: 32–42.

Johannessen BG, Hanslin HM and Muthanna TM (2017) Green roof performance potential in cold and wet regions. Ecological Engineering 106: 436–447.

Johansen A (2015) Project Uncertainty Management: A New Approach–The ‘Lost Opportunities’ Practical uncertainty management seen from a project joint perspective.

Koskela L. (1992) *Application of the new production philosophy to Construction*. CIFE Technical report #72, September 1992, Stanford University.

Lædre O (2009) Kontraktstrategi for bygg- og anleggsprosjekter. Bergen, Norway: Fagbokforlaget.

Lichtenberg S (2000) Proactive Management of Uncertainty Using the Successive Principle: A Practical Way to Manage Opportunities and Risks. Polyteknisk Press.

Ohno Taiichi. (1988). *Toyota production system.* Productivity Press, Cambridge, MA. 143 p.

Protan (2019) Mer enn bare et tak - Protan. Available at: https://www.protan.no/bluegreenroof/ (accessed 25 January 2019).

RIF (2015) Norges Tilstand 2015. Available at: https://www.rif.no/wp-content/uploads/2018/05/rif_stateofthenation_2015_lavopploeselig.pdf (accessed 31 January 2019).

Samset K (2001) Prosjektvurdering i Tidligfasen: Fokus På Konseptet. Tapir forlag.

SINTEF Byggforsk (2013) Byggforskserien 544.823 Sedumtak. SINTEF Byggforsk.

Skjeldrum PM and Kvande T (2017) Moisture-resilient upgrading to blue-green roofs. Energy Procedia 132: 417–422.

Torp O, Bølviken T, Aslesen S, et al. (2018) Is integration of Uncertainty Management and The Last Planner System a good idea? In: Proceedings of The 26th Annual Conference of the International Group for Lean Construction, 2018. IGLC.

Nygård, E. F., Wondimu, P., Lædre, O. (2019). “Best Value Procurement – Experiences from the Execution Phase” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 109–120. DOI: https://doi.org/10.24928/2019/0170. Available at: <www.iglc.net>.

BEST VALUE PROCUREMENT – EXPERIENCES FROM THE EXECUTION PHASE

Emil Fløvik Nygård[1], Paulos Wondimu [2], and Ola Lædre[3]

ABSTRACT

Best value procurement (BVP) is one of the approaches for early contractor involvement (ECI) in public construction projects. Despite an increased number of projects using the approach, there is a lack of knowledge regarding use of BVP in the Norwegian construction industry. Little research has been done on the consequences due to BVP, and the approach is often misinterpreted as only a procurement model. However, BVP provides an important mind-set for all parties involved, also during the execution phase. This paper study how BVP is practiced in two public kindergarten projects, what consequences that followed in the execution phase, and how BVP should be practiced in future projects. In addition to a literature study, the two projects were studied through a longitudinal study consisting of 8 in-depth semi-structured interviews and a document study. The findings show that how elements of BVP are practiced in the early phases influences both the execution phase and the final product. This study has developed important measures and improvements for how to practice BVP, and is among the first to document experiences from the execution phase. The identified measures can lead to a better execution phase, and thus a better product for the client.

KEYWORDS

Best value procurement (BVP), early contractor involvement, value, standardization, execution phase

INTRODUCTION

Statistics given by Statistics Norway (2018) shows a 10% decrease in productivity in the Norwegian construction industry since year 2000. Despite a large focus on project management and project analysis there are numerous projects being completed after deadline, over budget, not within project targets or aborted before completion (Samset, 2014). Several approaches are applied to turn this trend over, such as partnering and early

1 M. Sc. Student, Department of Civil and Environmental Engineering (DCEE), Norwegian University of Science and Technology (NTNU), Trondheim, Norway, emilfn@stud.ntnu.no

2 Researcher, DCEE, NTNU, NTNU / Senior Engineer, Norwegian Public Roads Administration, Norway, paulos.wondimu@ntnu.no / paulos.wondimu@vegvesen.no

3 Professor, DCEE, NTNU, Trondheim, Norway, ola.ladre@ntnu.no

contractor involvement (ECI). Partnering is characterized by trust, open and effective communication, common goals and early involvement of suppliers (Hosseini et al. 2018). There are several approaches for implementing ECI in the public sector and BVP is one of them (Wondimu et al. 2018b). BVP seeks to facilitate an efficient procurement where the vendor delivers according to the client's project ambitions, reduces the client's risk and minimizes the stakeholders' use of resources (van de Rijt et al. 2016). BVP is a part of the Best Value Approach (BVA) founded by Dean Kashiwagi in 1991, and consists of a procurement model, a risk managing model and a project management model (Kashiwagi, 2016). The available research is mainly related to the early phases of BVP, and minimal research has been done on the execution phase and how BVP can improve the final product. Therefore, this paper explores experiences from the execution phase of two Norwegian building projects and addresses the following research questions:

- How was BVP practiced through the projects?
- What consequences followed BVP in the execution phase?
- How should BVP be practiced to improve the execution phase and the final product?

The study is limited to two Norwegian public kindergarten projects and the results are limited to experiences from the winning actors. Both projects have the same client and the study is not extended to explore other actors' experiences such as the losing vendors, sub-contractors and consultants.

RESEARCH METHOD

The research was carried out based on a literature review and two longitudinal case studies. A qualitative case study provides tools for researchers to study complex phenomena within their contexts (Baxter & Jack, 2008), whereas a longitudinal study consists of continuous or repetitive measures to follow particular individuals over prolonged periods of time (Caruana et al. 2015). The method was chosen in order to reveal time-dependent patterns and document changes and experiences over time. A longitudinal study requires the presence of three conditions; (1) that data is collected during two or more time periods; (2) comparable individuals; and (3) that the analysis involves comparison of data from two or more time periods (Garcia-Pena et al. 2015). All conditions were fulfilled by the chosen case projects, and the two cases were chosen as they are among the first building projects in Norway using BVP. The two projects were of same size and scope with a conventional project organization, and easy to compare with other kindergarten projects built by the same client. Both case projects had the same client, but were conducted by two different vendors. The case projects were studied according to the recommendations by Yin (2009). The main characteristics of the case projects are presented in Table 1.

The literature review formed the basis for the theoretical background and was undertaken using the search engines Oria, Scopus and Google Scholar. Search words such as "best value procurement", "best value approach" and "early contractor involvement" were used. Oria is a Norwegian University library resource. Important documents were used for citation chaining, as described by Wohlin (2014). The objective of the literature study was to develop a theoretical background on how BVP should be performed and to gain insight into previous experiences with the approach.

Table 1: Case overview and the respective interviewee's position (C = client's organization, V = vendor's organization)

Project name	Description	Project start-finish	Cost (USD)	Interviewee's position
1) Munkerud Kindergarten	Kindergarten with six departments	2018-2019	$ 4.5 mill	Project director [C], project manager [C], construction manager/design manager [V], project legal advisor [C]
2) Vollebekk Kindergarten	Kindergarten with eight departments	2018-2019	$ 7.4 mill	Project manager [C, V] and construction manager [V, C], evaluation committee member [C]

A total of 8 interviews were conducted with key personnel from the case projects. Some of the individuals from the client's organization were involved in both projects, with multiple positions. All positions are listed in Table 1. The first interviews were held in the period October-November 2018 and the follow-up interviews were held in March-April 2019. The interviewees were selected based on their involvement in both the procurement and execution phase of the projects, and they all have managerial positions in the projects. The interviews were conducted through in-depth semi-structured interviews based on an interview guide. No changes were made to the interview guide during the process. All interviews were carried out face-to-face at the interviewee's offices and lasted between 45 minutes to 90 minutes. Each interview was recorded and later transcribed. To verify and quality assure the results, a summary of the interview was sent to the informants for reviewing. After the interviews, a document study was carried out in order to triangulate the results (Yin, 2009). The study included tender documents, contracts and project plans. Data from the interviews were hand-coded and analysed hand-in-hand with the data collection, and findings were written down based on the description of Creswell (2013).

THEORETICAL BACKGROUND

EARLY CONTRACTOR INVOLVEMENT

Many measures, systems, and approaches are introduced to improve the productivity of the construction industry. One of these measures is Early Contractor Involvement (ECI). ECI refers to the involvement of a contractor at an early stage of project development, to work together with the client and/or consultant, mainly to assist in planning and buildability (Rahman & Alhassan, 2012). It is recognized that the ability of the parties to influence project outcomes, including reduction of cost, creation of additional value, improvement of performance and flexibility to incorporate changes is much higher in the conceptual and design stages of the project (Mosey, 2009). ECI can be achieved by several approaches, and one of the approaches is BVP (Wondimu et al. 2018b).

Best Value Procurement

The overall purpose of BVP is to identify and select the most suitable vendor (the expert) through simple and dominant information (Atosa et al. 2018). The main objectives are to increase profit, minimize use of resources for all parties, minimize decision making and utilize expertise instead of management, direction and control (Kashiwagi, 2016). The main reference on how BVP should be implemented is the book written by the originator of the approach – Dean Kashiwagi (Kashiwagi, 2016). However, in the European context, the approach is adapted to fulfil EU public procurement legislation requirements (Högnason et al. 2018). This approach has been used on several Dutch projects and is the approach that Norwegian projects are based upon (van de Rijt et al. 2016). This approach will be further presented in this section.

BVP is separated into four phases: Pre-Qualification phase, Selection phase, Clarification phase, and Execution phase. **The Pre-Qualification phase** is according to Kashiwagi (2016) optional and consists of training and education in BVP for both client and vendor (Atosa et al. 2018). No solutions are presented during this phase, but all design is performed in the Clarification Phase. The design is performed by the vendor as in a conventional design & build-contract. Some key elements in this phase are selection and education of a core team, use of an external BV expert, pre-qualification of vendors, preparing a core document, training of client and vendor and calculating the owner's maximum price (Högnason et al. 2018).

The Selection phase is where the client identifies an expert vendor with the highest level of expertise for the lowest cost (Kashiwagi, 2016). The criteria to determine expertise are the Level of Expertise (LE) document, Risk Assessment (RA) document, Value Added (VA) document, project cost and interview of key personnel. Other important elements of this phase are a time-plan for the project, short listing of potential vendors, multiple grading groups and a dominance check of the vendors (Högnason et al. 2018).

The Clarification phase consists of three parts: a kick-off meeting, a clarification part and a contract award meeting. The Clarification phase is described by Witteveen & van de Rijt (2013) as the most important phase of BVP, and the purpose is to clarify what the vendor will deliver and how they will deliver it. An essential part is therefore to clarify what is in and outside the scope, as well as outlying technical solutions (Atosa et al. 2018). The goal is to clarify whether the offer is acceptable for the client, clarify expectations, identify key performance indicators (KPIs), and finally sign an agreed contract for the project (van de Rijt et al. 2016). KPIs are in many projects found to be difficult, and Kashiwagi (2016) prescribes little information on their design. Guidelines for using KPIs in BVP projects are given by Horstman & Witteveen (2013). Important elements in this phase are the kick-off meeting, risk management plan, scope document, elaboration of potential critical sub-contractors, KPIs, letter of intent, contract award meeting, involving the vendor in framing of contract, distribution of risk responsibility and risk contingency fund (Storteboom et al. 2017).

The Execution phase is where the project is realized. The overall goal for this phase is to deliver the service or the deliverable, but also to enhance transparency, communicate information quickly, assign accountability and create a supply chain approach in the project organization (Snippert et al. 2015). This is done by implementing Weekly Risk Reports (WRR), Directors Report (DR) and performance measurements using KPIs throughout the execution phase. During this phase, the vendor is also responsible for performing quality control and risk management (Atosa et al. 2018). These are the four main phases as stated by the theoretical framework. The phases with their related elements are summarized and presented in Table 2.

FINDINGS AND DISCUSSION

Despite the study being conducted as a longitudinal study, no significant differences or changes were found between the first and second round of interviews. Some additional elements and consequences were though added. The case study results are shown in Table 2 and Table 3. Both tables follow the framework earlier described and published by Högnason et al. (2018) and Storteboom et al. (2017). Table 2 shows that BVP was practiced quite similar in the two projects, and mostly as described by van de Rijt et al. (2016). Both projects implemented most of the elements identified in the literature review, and strived to practice all elements as recommended by Kashiwagi (2016). There are though some differences between the two projects.

In one of the projects the client's maximum price was announced, while the other project chose to announce the client's maximum budget. The difference was whether added value from the vendors were to be included in the tender price or not, and tenders over the maximum budget price were not rejected. The idea was that as a result, the vendors would offer added value as a part of the original tender and not as an additional cost. In the Vollebekk project, added value was therefore not included in the evaluation criteria as it is described by van de Rijt et al. (2016). The interviews displayed that no real added values were achieved in the project. Instead, the client got a kindergarten more or less as expected. The quality was higher than the minimum required, but nothing out of the ordinary. When offered added value, however, the client states they received a building unlike any other kindergarten they have built, with a high level of innovation. Two other important elements were the performance measurements and KPIs, as the vendor is a fairly small and new vendor, which normally do not get projects like this. The project was therefore very important for showcasing their expertise and a potential springboard for future project awards.

Table 2: Practicing of Best Value Procurement

Elements of BVP	Munkerud Kindergarten	Vollebekk Kindergarten
Pre-Qualification Phase		
Sponsor	No	No
Selection and education of core team	No	No
External BV expert	Yes	Yes
Pre-qualification	No	No
Use of all four phases	Yes	Yes
Training of owner	Yes	Yes
Core document / request for proposal	Yes	Yes
Open budget w/ceiling	Client's maximum price	Client's maximum budget price
Training of vendor	Yes	Yes

Selection Phase		
Evaluation criteria in MEAT:		
• **Level of expertise**	15%	30%
• **Risk assessment**	20%	20%
• **Added value**	10%	0%
• **Interview with key personnel**	30%	25%
• **Price**	25%	25%
Time-plan	Yes	Yes
Short listing	No	No
Multiple grading groups	No	No
Dominance check	Yes	Yes
Clarification Phase		
Kick-off meeting	Yes	Yes
Risk management plan	Yes	Yes
Scope document	Yes	Yes
Elaboration of potential critical sub-contractors	No	No
Key Performance Indicators (KPIs)	Yes	Yes
Letter of intent	No	No
Contract award meeting	No	No
Vendor involved in framing of contract	Yes	Yes
Owner financially responsible for all controllable risks	Yes	Yes
Risk contingency fund	No	No
Execution Phase		
Weekly risk report	Yes	Yes
Performance measurements	Yes	Yes
Director's report	No	No

How the different elements of BVP are practiced in the earlier phases has been found to have an impact on the execution phase. Several consequences depend on how BVP is practiced, and the consequences are presented in Table 3. Most of the consequences were positive, but some elements caused a number of challenges for the execution phase or the final product.

None of the projects used pre-qualification and the selection was based on an open competition. The evaluation criteria were thus a vital part of the procurement and has shown to have a large impact on both process and the final product. Including **added value as an evaluation criterion has resulted in more innovation**, whereas **a lack of added value has limited the innovation**.

The use of **price as an evaluation criterion has shown to be excessive** due to the open budget and the owner's maximum price. All tenders were placed on or near the maximum price, and did not contribute to differ the vendors. Price was weighted 25% in both projects. Future projects must see this as an opportunity to increase the weighting of quality, and hence achieve more quality in the project.

Among the challenges were a **lack of interviewees from the vendor participating in the execution phase**. In both projects, despite a large focus on using BVP in all four phases of the project, the construction manager first joined the project late in the clarification phase and the interviewees had limited involvement in the execution phase. Important performance from the execution phase was thus not evaluated in the interviews, which must be seen as an important part in the procurement of a vendor. In order to ensure evaluation of the vendor's expertise in the execution phase as well as in the earlier phases, the interviewees should include the construction manager as well as the project and design manager. Including key personnel from the execution phase in the early phases is a vital part of ECI. As earlier stated, BVP is just as much a mind-set as an approach, and needs to be shared by all participants. By including the construction manager in the interviews, this mind-set will be strengthened and shared by more personnel in the execution phase.

The interviews further raised an **inadequate periodic control and updating of the risk management plan** as a challenge. This led to low information regarding the overall project risk, along with the project's budget and time plan. Despite being the vendor's responsibility, it is important for the client to be aware of the overall project risk to minimize the need for control and project follow-up. The WRR has worked well in both projects, but the vendors have not reported weekly throughout the project. The result was a **minimal impact on the client's control need**. In terms of the overall project risk, it is important to practice a regular periodic control and update of the risk management plan. The goal is to reduce the owner's control needs, as proclaimed by Kashiwagi (2016).

Lastly, the interviewees revealed that an **inadequate standardization of KPIs** has made it challenging for the parties to develop and use performance indicators. It has especially shown to be difficult to measure innovation and quality in the execution phase – both important factors when evaluating a BVP project. The theory gives few recommendations on which KPIs to use, and Kashiwagi (2016) proclaims they must be established by the project itself. The theory does, however, highlight the contract award meeting as an important element in this process (van de Rijt et al. 2016). The purpose of the meeting is, among other things, to establish and clarify KPIs and project risk. Both projects held a traditional contract meeting, but failed to clarify these elements before the execution phase. Future projects should consider whether or not KPIs should be standardized, and it is important to sufficiently clarify and establish these indicators in the clarification phase, as stated in the theory. Guidelines provided by Horstman & Witteveen (2013) should be taken into account, and all KPIs must be jointly prepared by both vendor and client. Education and training in BVP plays an important part of this process. The performance measured by the indicators serve as an important evaluation factor in future BVP projects, and must provide dominant information regarding the vendor's performance. This is, as stated in the theory, a key element when selecting a vendor. More of the identified consequences are listed in Table. Only elements found to have an impact on the execution phase or the final product are listed. Elements not listed were still practiced as described in Table 2.

Table 3: Consequences of Best Value Procurement

Element of BVP	Effect	Consequences for the execution phase
Pre-Qualification Phase		

Use of all phases	+	Best Value Procurement becomes a mind-set, rather than a method. Sharing this mind-set leads to a collaborative environment in the execution phase
	+	More flexible and demand-controlled communication in the execution phase
Core document	+	More predictable solutions for the client
Open budget w/ceiling	+	Fewer change orders and added costs
Selection Phase		
Evaluation criteria	+	Higher weighting of quality leads to higher quality
	-	Weighting of price becomes excessive
	+	Added value leads to more innovation
	+	Opens for new and smaller vendors that normally would not get the project
	-	A lack of interviewees from the vendors participating in the execution phase may limit the evaluation of the vendor's project execution performance
	+	More weight on quality leads to a higher focus on investment and life cycle costs
Clarification phase		
Kick-off meeting	+	Gives the actors a common understanding of the project and leads to increased interaction between the parties
	+	Clarifies playing rules for conflicts and leads to increased construction progress in the execution phase
Risk management plan	-	Inadequate periodic control and update leads to low information regarding the overall project risk
Key Performance Indicators	-	Inadequate standardization makes it difficult to develop and use KPIs
	-	Difficult to measure innovation and quality in the execution phase
Contract award meeting	-	Lack of a contract award meeting may limit the benefits of KPIs and risk management plan in the execution phase
Execution phase		
Weekly Risk Report	+	More efficient communication in the execution phase
	-	Causes no reduction in the owners control needs

Performance measurements and director's report were not found to have a significant impact on the execution phase, but may be of a larger importance in future projects when practiced correctly. Further measures are given in Table 4. In addition to the consequences listed above, the approach has been found to create a strong collaborative mind-set in both projects. At first glance, BVP seems to be just another procurement model. The execution phase is completed according to a standard design & build contract, and with a normal project organization. However, this study has shown that BVP has improved both the process and product in terms of quality and progress. The vendor has a better understanding of the project and is more prepared when the execution phase is initiated.

Both projects had a delayed start-up due to a slow treatment process by the Planning and Building Services of Oslo Municipality, and for an extended time there was no unified overall time plan for the project. This could in many cases been a great cause of conflict, but the collaborative environment has in both projects contributed to overcoming this challenge in the best possible way. In both projects, the parties have shown flexibility and cooperativeness beyond normal, and the shared mind-set has shown to be a very important consequence of BVP in terms of project success.

CONCLUSIONS

This paper set out to explore experiences with BVP from two Norwegian public kindergarten projects, in order to answer the following research questions: 1) how was BVP practiced in the project, 2) what consequences followed BVP in the execution phase and 3) how should BVP be practiced in future projects. The study is limited to two public kindergarten projects for the same client. Both projects have proven to be successful, and no conflicts or disputes have arisen. The findings are nevertheless found to be transferable to other BVP projects. In general, both projects have practiced the approach as described in the theory. This is further described in Table 2. In many ways, the characteristics of BVP appeared in the earlier phases, and the execution phase was carried out as a conventional design & build contract. The difference from a conventional project, when it comes to the execution phase, was the mind-set created by the implementation of BVP.

BVP consists of several elements, and it is stated in the theory that the clarification phase is the most important phase before the execution phase. This study has though shown that there are several equally important elements from both the pre-qualification phase and the selection phase. These phases must therefore be seen as equally. How BVP is practiced in the earlier phases has shown to have a significant influence on the execution phase of the project, and thus also the final product. Added value will increase innovation, but may be limited by a specific core document. On the other hand, this may lead to a more predictable product for the client. Despite the execution phase being completed more or less like a conventional execution phase, BVP can improve both the process and product in terms of quality and progress when practiced the correct way. BVP provides a unique mind-set and helps to create a collaborative and flexible project environment among the project parties. Most of the elements have shown to have a positive effect, but some may cause challenges for the execution phase. All consequences are presented in Table 3.

This study has shown that, along with being a procurement model, BVP is also a mind-set. This mind-set must be shared by all participants, and especially by those involved in the execution phase. Integrating key personnel from the execution phase is therefore an important measure, and can be achieved by including the construction manager in the selection interviews. This practice will strengthen the evaluation of the vendor's project execution performance - an important part of the procurement process. Education and training of project participants in the BVP method, use of a BVP expert, as well as a thorough and well planned kick-off-meeting, has proven to strengthen this collaborative mind-set. An important part of the kick-off-meeting is to establish trust between participants, an equal understanding of the project's scope, as well as playing rules for potential conflicts. All of them are important measures in future BVP projects.

Other important elements are the core document, time plan, added value, risk management plan, dominance check, KPIs, WRR and performance measurements. Further important measures and improvements for future BVP projects are displayed in Table 4.

Table 4: Improvements and measures for future BVP projects

Element of BVP	Measure/improvement
Pre-Qualification Phase	
Core document	A clear and precise core document leads to more predictable solutions for the client but may limit the innovation. Important to early clarify what is more important for the client.
Education of project participants	BVP is a mind-set more than a method. This mind-set must be shared by all participants regardless of project phase. Future projects should have an extensive focus on education in BVP.
External BV expert	Frequently involve the BV expert. Costs should be covered by the owner, not the vendor.
Selection Phase	
Price	Price should not be a part of the evaluation criteria when the owner's maximum budget is specified. Tenders over the maximum price must be declined.
Time plan	May be included as an evaluation criterion when a faster execution phase is desirable.
Dominance check	Perform as early as possible to avoid waste of project resources on a non-expert
Interview of key personnel	Key personnel from the execution phase must be included. The practice will make it easier to evaluate project execution performance and implement the BVP mind-set in the execution phase
Added value	Open for vendors to offer Added Value. This will lead to more innovation in the project.
Clarification Phase	
Kick-off-meeting	Establish playing rules for conflicts, trust and an equal understanding of the project scope. Important actions for preventing potential conflicts
Risk management plan	Periodically control and update of the plan in order to provide an overview of the overall project risk
Key Performance Indicators	Must be sufficiently clarified and established early in the clarification phase. Establish clear indicators for how to measure innovation and quality. Formed after guidelines by Horstman & Witteveen (2013). Must be periodically evaluated and updated during the execution phase.
Contract award meeting	Clarify and establish final KPIs and expose all risk factors in the project to achieve a better practice of these elements in the execution phase.
Execution Phase	

Weekly Risk Reports	Must be formed to help reduce the client's control needs
	Must be completed and sent weekly, whether or not new information has occurred.
Performance measurements	All actors should measure their own performance in order to gather dominant information for future projects.

BVP is still fairly new and unknown in the Norwegian construction industry, and there is a need for more experiences from future BVP projects. In this study, both projects have proven to be successful, and there is little knowledge on how BVP handles conflicts. Furthermore, clients have proven to find it difficult to lose control of the project. To introduce better KPIs and properly use WRRs are therefore important measures for future projects in order to reduce the client's control needs.

This study has been limited to two public kindergarten projects for the same client. Further studies should explore experiences from both private and public clients, and actors such as sub-contractors and consultants. BVP cannot guarantee a successful project and conflicts will always arise in some projects. However, by introducing and following the measures given in Table 4, the chances of a successful project and a better product will increase in future projects.

REFERENCES

Atosa, J.; Breivik, I. B.; Wondimu, P.; Houck, L. D. *(2018) "Experience with Best Value Procurement in Norwegian Infrastructure Projects" Procedia Computer Science 138, pp. 783-790.*

Caruana, E.J.; Roman, M.; Hernández-Sánchez, J.; Solli, P. (2015) "Longitudinal Studies". *Journal of Thoracic Disease,* vol. 7(11), s. 537-540

Creswell, J. W. (2013) *Research Design: Qualitative, quantitative, and mixed methods approaches,* Sage Publications

Carcía-Pena, C.; Gutierérrez-Robledo, L. M.; Pérez-Zepeda, M. U. (2015) *Aging Research - Methodological Issues*. Cham: Springer International Publishing.

Horstman, A.; Witteveen, W. (2013) "Performance Indicators in the Best Value Approach" *Journal for the Advancement of Performance Information and Value,* vol. 5(2)

Hosseini, A.; Wondimu, P.; Klakegg, O.J.; Andersen, B.; Lædre, O. (2018) "Project Partnering in the Construction Industry: Theory vs Practice" *Engineering Project Organization Journal, vol.* 8, pp. 13-35

Högnason, O.; Wondimu, P. A.; Lædre, O. (2018) "Best Value Procurement – The First Experiences from Norway". Proceedings of the Creative Construction Conference

Kashiwagi, D. (2016). *Best Value Approach*. Mesa, Arizona: Kashiwagi Solution Model (KSM).

Mosey, D. (2009) *Early Contractor Involvement in Building Procurement: Contracts, Partnering and Project Management.* 1. edition. John Wiley and Sons.

Narmo, M.; Wondimu, P. A.; Lædre, O. (2018) "Best Value Procurement (BVP) in a mega infrastructure project." *Proc. of the 26th Annual Conference of the International Group for Lean Construction*, vol. 1, pp. 23-33

Rahman, M. & Alhassan, A. (2012), "A contractor's perception on early contractor involvement", *Built Environment Project and Asset Management*, Vol. 2 No. 2, pp. 217-233.

Samset, K. (2014) *Prosjekt i tidligfasen. Valg av konsept*. 2. edition. Bergen: Fagbokforlaget Vigmostad Bjørke AS

Snippert T, Witteveen W, Boes H, Voordijk H. (2015) "Barriers to realizing a stewardship relation between client and vendor: The Best Value approach." *Construction Management and Economics*, vol. 33(7), pp. 569-586.

Statistics Norway (2018) *Productivity decrease in the building industry* [web page] Available from: https://www.ssb.no/bygg-bolig-og-eiendom/artikler-og-publikasjoner/produktivitsfall-i-bygg-og-anlegg. Downloaded: 24.01.19

Storteboom, A.; Wondimu, P.; Lohne, J.; Lædre, O. (2017) "Best Value Procurement – The Practical Approach in The Netherlands." *Procedia Computer Science 121, pp. 398-406*

Tjora, A. (2012) *Kvalitative forskningsmetoder i praksis*. 2. edition. Oslo: Gyldendal Norsk Forlag AS

Van de Rijt, J.; Santema, S.; Soilammi, A. (2016). *Best Value Procurement – Prestasjonsinnkjøp*. (3. edition – translated from Dutch). Oslo: Rådgivende Ingeniørers Forening.

Witteveen, W.; van de Rijt, J. (2013) "Possible Barriers to a Successful Further Diffusion of the Best Value Approach in the Netherlands: Observations of Major Understandings on the Concept and Theory" *Journal for the Advancement of Performance Information and Value 5(2)*

Wohlin, C. (2014) *Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering*. Karlskrona: Blekinge Institute of Technology.

Wondimu, P. A.; Klakegg, O. J.; Lædre, O.; Ballard, G. (2018a) "A Comparison of Competitive Dialogue and Best Value Procurement." *Proc. International conference of the international group for lean construction.*

Wondimu, P.; Hosseini, A.; Lohne, J.; Lædre, O. (2018b). "Early contractor involvement approaches in public project procurement." *Journal of Public Procurement*, vol. 18(4)

Yin, R. K. (2009) *Case Study Research: Design and Methods*. 4. Edition. Thousand Oaks (California): SAGE Publications

Lesjø ES, Lædre O., and Wondimu, P. (2019). "Best Value Procurement from a Contractor Point of View." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 121–132. DOI: https://doi.org/10.24928/2019/0190. Available at: <www.iglc.net>.

BEST VALUE PROCUREMENT FROM A CONTRACTOR POINT OF VIEW

Emilie Sofie Lesjø[1], Paulos Abebe Wondimu[2], Ola Lædre[3]

ABSTRACT

Best Value Procurement (BVP) was introduced in Norway in 2016. Since then, more than ten pilot projects have tested the method. So far, limited research has been carried out to explore the contractors' experiences on BVP to improve the method for future projects. The purpose of this paper is to fill part of this research gap by exploring a contractor's experiences from several projects using the method. By looking at five road projects that have tested out the BVP method, a trend can be seen in how the evaluation of the offers was conducted. Data was collected from five pilot road projects through three in-depth interviews with key persons and a document study. The results show how the evaluation of the price aspect has changed over time. In three of the five projects, a formula was used that urged the contractors to set prices low in order to score additional points. This formula gained criticism from both the contractors and the BVP experts hired to help the contractors. BVP has contributed, to a certain extent, to Lean implementation. However, the practice should be improved to increase value and transparency and minimize conflict and waste.

KEYWORDS

Best value procurement, BVP, lean construction, value, early contractor involvement, ECI

INTRODUCTION

Best Value Procurement was created by Dean Kashiwagi at Arizona State University. The method urges the client to look for the best value at the lowest cost. Contractors must prove that they can deliver with regard to the project objectives and that they understand the risks and will implement actions to mitigate the risks (Kashiwagi et al. 2012).

The construction industry is accountable for 16% of the GDP (Gross domestic product) in Norway, the largest measured percentage to date (Brekkhus 2017). GDP is an indicator for the gross value added in a country over a certain period of time, often annually (Focus Economics 2018). Changes concerning productivity in this sector will, therefore, have significant impact on the Norwegian economy. Best Value Procurement (BVP) aims to

1 M.Sc. Student, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), +47 943 83 498, emilie.lesjo@gmail.com

2 Researcher, Department of Civil and Environmental Engineering (DCEE), Norwegian University of Science and Technology (NTNU), Trondheim, Norway/Senior Engineer, Norwegian Public Roads Administration, Norway, +47 901 11 814, paulos.wondimu@ntnu.no/paulos.wondimu@vegvesen.no

3 Associate Professor, DCEE, NTNU, ola.ladre@ntnu.no

streamline the procurement phase and thus increase total productivity in the construction industry (Difi 2016).

BVP was introduced in Norway in 2016. Since then, more than ten pilot projects have been started with the goal of finding out whether the method creates higher value and decreases costs and use of resources in Norway. The pilot projects were initiated by the Norwegian Directory of Procurement and ICT, called Difi (Direktoratet for forvaltning og IKT). The pilot projects vary from mega-infrastructure projects to kindergartens. So far, limited research has been carried out to explore the contractors' experiences with BVP and to improve the method for future projects. This paper fills part of this research gap by addressing the following research questions:

How was BVP implemented in practice?

What were the contractors' experiences with the BVP method?

How can the method be improved in the future?

This study has some limitations. First, the study is based on only five case studies and all of them are infrastructure projects conducted by the same client. Second, experiences from only one contractor are explored. Third, the study is based on the primary contractor's experiences with BVP, but it was not extended to explore the experiences of sub-contractors. Fourth, all cases are ongoing projects at different phases. Since the projects still in progress, the results are not final.

A theoretical background is presented where the BVP process is described. Furthermore, results from document study and interviews will be presented along with a discussion. Finally, the findings will be summarized.

METHOD

Initial research was carried out by literature review and case studies. The cases are analyzed based on a document study and interviews. The literature review was conducted to learn about the method, explore previous experiences on the method and to develop a theoretical background. Search words used include Best Value Procurement, lean, value, early contractor involvement and ECI. These terms were applied in search engines such as Google Scholar and Oria. In order not to miss important literature, both forward and regular snowballing were used (Wohlin 2014). Forward snowballing was applied to find newer articles, first by searching for core documents such as Kashiwagi (2016), thereby finding newer articles that cite the book.

In this paper, five infrastructure projects were studied to address the three research questions. These five infrastructure projects were selected for the following reasons: they are all mega-projects, the contractor in focus is involved in all of the case projects, and BVP was used as the procurement method in all of the projects. Furthermore, each case project has gone through the clarification phase, enabling them to answer the research questions in this paper. Descriptions of each of these case project are listed in Table 5.

Table 5: Descriptions of case projects

Project name	Cost (USD)	Year
E18 Rugtvedt – Dørdal	210,000,000	2017 –2019
E6 Arnkvern – Moelv	280,000,000	2017 –2020
E39 Kristiansand west – Mandal east	530.000,000	2018 –2022
E39 Mandal east – Mandal city	21,000,000	2020 –2022
E6 Ranheim – Værnes	59,000,000	2019 – 2024/2025

The first project (E18 Rugtvedt – Dørdal) was the first project to use BVP in Norway. The client for all projects in this paper is New Roads, a Norwegian government-owned company established to build roads worth $17.5B USD over the next 20 years (New Roads 2017). The three first projects shown in **Error! Reference source not found.** are all in the execution phase, while the two last projects have just been signed. All of the projects are located in Norway.

Three semi-structured interviews were conducted according to the method described by Yin (2013). All of the interviewees are from the contractor's perspective. These personnel have had a central role during the procurement phase of the five projects. The interviewees are experienced in the construction industry and are promoters of BVP in their firm.

In the document study, procurement protocols from the five cases were retained from the client, New Roads. Procurement protocols from each of the five projects were studied in order to explore how BVP was practiced and to look at what has changed with the practice over time. These protocols specify each contractor's price and their final scores for the evaluation criteria described in the theoretical framework section. Furthermore, the protocols include descriptions of the grading system and the basis for evaluating price. Data from these protocols were collected and systemized into Excel to retain one document that provides all scores for each project. In addition to procurement protocols, one censured version of the core document from the first project (E18 Rugtvedt – Dørdal) is also used. This document describes the project objectives. The core document for the other project was requested as well, but was not provided.

THEORETICAL BACKGROUND

LEAN AND BVP

Lean construction seeks to minimize waste, time and effort in order to maximize value in projects (Koskela et al. 2002). Early contractor involvement (ECI) gives the contractor an opportunity to influence project planning and assist in the creation of buildable solutions (Song et al. 2009). Wondimu et al. (2016) describes several success factors of ECI that, among others, includes involving contractors early enough and managing risk transfer to the contractors.

ECI is one of the measures that can be taken to implement lean in the construction sector. A BVP core principle is to involve the contractor at an early stage in order to help the client identify the risks. BVP can therefore be used as a means to implement Lean in the construction sector since it contributes to the maximization of value by involving the contractor early and using contractor expertise to identify the project risk and minimize waste of material, time and effort during the project execution phase (Wondimu et al. 2018).

BVP method has been carried out in 31 states in the U.S. and has spread to other countries worldwide. By 2016, over 1800 projects worth $6B USD in contracts were completed using BVP (Kashiwagi 2016). The method is based on the philosophy that the contractor is the expert on how to execute the project, relying on contractors to perform their tasks without micromanagement from the client (Van de Rijt and Witteveen 2011). This philosophy encourages transparency and simplicity throughout the project. In the European context, the Norwegian approach on BVP is based on the Dutch version (Högnason et al. 2018).

THE PHASES IN BVP

The BVP method typically consists of four phases. It is important to understand the four phases used to conduct the BVP method, and to achieve the best value contractor for a specific project (Van de Rijt et al. 2016). The phases are *Preparation*, *Selection*, *Clarification,* and *Execution*. The phases and their core elements are presented in the following sections.

The Preparation phase is the phase where the client and contractor prepare for the BVP process by education and training in the method (Kashiwagi 2016). In addition, a pre-qualification can be used. Pre-qualification serves to sort potential bidders by requesting financial and legal documents from bidders, but pre-qualification is not mandatory (Kashiwagi 2016). In this first phase, a core document is created. The document contains information regarding the project such as project objectives, scope, and specifications. The criteria to be discussed in the *Selection* phase should be listed with a weighting for each one (Van de Rijt et al. 2016). Lastly, the budget framework for the project is released. It is not standard practice to disclose information regarding the budget ceiling. However, in the BVP method, this information is useful because it gives the contractors the opportunity to assess whether the project is within their capacity before starting to prepare an offer (Van de Rijt et al. 2016).

The Selection phase aims to find the best value contractor (Van de Rijt et al. 2016). In order to find this contractor, there are several steps that must be conducted. First, the contractors' written offers are evaluated. The written offer covers three criteria: Project Capability, Risk Assessment, and Value Added (Kashiwagi 2016). Each criterion should be at most two pages. The price is provided in a separate document and reviewed last (Kashiwagi and Kashiwagi 2011). The written offers are anonymized in order to maintain an unbiased assessment. After evaluation of the criteria, an interview with key personnel is executed. The interviewees must be persons who directly influence the project from start to finish. These may be the project manager, design manager and/or site manager (Van de Rijt et al. 2016). After the interviews, the price is evaluated. If the price is over the budget framework, the contractor is eliminated from the competition (Kashiwagi 2016). There are several ways to evaluate price. Van de Rijt et al. (2016) propose to transform the score given by the evaluation into the price. Contractors are evaluated individually pursuant to fixed scores. Lastly, all data are collected to summarize which contractor best meets the criteria and is selected as the best value contractor.

The Clarification phase begins when one contractor is chosen. During this phase, the contractor should concretize and elaborate on the offer (Van de Rijt et al. 2016). From this point on, the contractor leads the meetings and creates solutions for the project, showing that the offer consists of low risks and meets the project criteria. The client's role shifts to a passive listening role where open and critical questions are asked, leaving the contractor to be the expert. According to Norwegian law, the *ban on negotiation* must be maintained. Specifically, this ban is broken if there is a change in the characteristics of the offer that were decisive in choosing this contractor, a change in the distribution of risks between client and contractor, or changes outside the boundary of the offer (Andersen et al. 2018). Therefore, the core content of the offer must not be changed. This requirement is due to the fact that it should be clear which contractor delivered the best offer, and by changing the offer itself this distinction is lost. When the *Clarification phase* ends, the contractor should have a detailed plan for the execution of the project (Van de Rijt et al. 2016). The primary purpose of the *Clarification phase* is to foresee eventual challenges before the execution begins, making it easier to control these challenges when discovered and addressed early on. If the C*larification phase* reveals that the contractor is not able to deliver the terms of their offer, the client can choose to proceed with the contractor that came second (Kashiwagi 2016). When the phase is completed, the contract can be signed and the *execution phase* can begin.

The Execution phase begins when the contract is signed. The execution should be characterized by openness between the parties. Candid communication and a clear distribution of responsibility are key (Van de Rijt et al. 2016). According to the BVP philosophy, the contractor remains the expert. This expectation results in minimal disturbance and micromanagement from the client. To keep track of progress, the contractor delivers weekly risk reports to the client (Kashiwagi 2016). In this weekly report, the contractor lists risks that influence the progress along with the impact on scope, cost and quality. In addition, the reports contain strategies for risk management, which demonstrates to the client that the contractor has the project under control. Provided that weekly reports are done correctly, these reports should be sufficient for the client to maintain oversight of the project (Kashiwagi 2016).

BVP in Norway

The BVP method was introduced in Norway in 2016 by the Directory of Procurement and ICT, called Difi (Direktoratet for forvaltning og IKT). Difi personnel arranged testing of the method on more than ten pilot projects. They also contributed to judicial clarification on the method and arranged pilot seminars and courses. Their role is to document and evaluate results from these pilot projects that are expected to eventually result in best-practice guidance on BVP in Norway. The goal of the pilot projects is to determine whether the BVP method creates higher value, increases effectivity and reduces costs and use of resources (Difi 2016).

New Roads is a government-owned company that aspires to build roads worth $17.5B USD in Norway over the next 20 years (New Roads 2017). The company uses both BVP and Early Contractor Involvement (ECI) in their procurements. For all five of the projects in this paper, New Roads is the client.

RESULTS AND DISCUSSION

In this paper, we set out to address how the BVP was implemented in practice, what experience the contractors had and how the method can be improved in the future.

BVP IN PRACTICE

The implementation of BVP in Norway has its basis in the Dutch method as a result of the Dutch adopting the BVP method from the U.S. and altering it to comply with Dutch and EU legislation (Van de Rijt and Santema 2012). BVP in Norway aligns closely with the theoretical approach set by the Dutch.

In every project, we studied, all four phases of the method were used. Pre-qualification was used to sort out the bidders before starting each project's competition. The implementation of BVP in Norway aligns with how Van de Rijt et al. (2016) propose it be conducted.

Three of the five projects are in the execution phase to date, so it is not known what effects the BVP process will have on the final outcomes. All three projects have moved to a standard Norwegian contract designated NS 8407 in the execution phase. Kashiwagi (2016) states that the only report needed during the execution phase is the weekly risk reports. Regardless of this expectation, the interviewees reported that the weekly report was added to other reports required by the contract (NS 8407). The additional reporting results in using extra resources and does not align with the BVP philosophy where a key factor is less management from the client. This understanding is supported by Narmo et al. (2018), who stated that the contract NS 8407 does not support use of the weekly risk report alone. This result indicates that BVP is being used only in the procurement phase.

EXPERIENCES WITH BVP

In general, the view of BVP has been positive from a contractor's point of view. The primary emphasis in the interviews was on the challenges in following the method. In Table 6 a summary of the pros and cons of BVP is provided.

Table 6: Pros and cons with BVP

Pros	Cons
Improves the efficiency in producing an offer	Learning the method is time consuming
Reduces costs and resources in producing an offer	Vagueness regarding evaluation of price
Able to influence the project early	Detailed management from client in execution phase

The interviewees were clear in their opinion that BVP improves efficiency and reduces the costs and use of resources involved in producing an offer. Nevertheless, learning how the BVP process is carried out is time consuming but well worth the time according to the interviewees.

The opportunity to influence the project at an early stage gave contractor personnel a feeling of being the expert and allowed them to develop buildable solutions.

The contractor experienced a high amount of inspection and control from the client during the execution phase. The interviewees stated that "the client has an extreme amount of detail management in this phase – we do not see any of the BVP philosophy, on the contrary, this regime means we need more resources and costs to follow up on their demands."

Additionally, interviewees felt that the evaluation regarding the price criterion was not consistent in each project, so we investigated and describe the evaluation of price in detail in the following sections.

Evaluation of price

Even though the general view of the BVP method was positive, some elements of the evaluation of price criteria were found to be a challenge by the contractors. Results from procurement protocols and interviews are presented and discussed below to highlight these challenges.

The procurement protocols show how the prices were evaluated. Van de Rijt et al. (2016) proposed a method of evaluating price that involves converting points into price. A different method was used in these five projects to evaluate price. The evaluation was based on two different formulas, shown in Table 7.

Table 7: Two methods of evaluating price

Name	Formula used
A	$\frac{Budget\ frame + maintenance - actual\ price}{Budget\ frame + mainenence - lowest\ price} \times 100$
B	$\frac{Lowest\ price}{Actual\ price} \times 100$

After using formula A in the first three projects, a shift to formula B was implemented for project *E19 Mandal east – Mandal city*. This change is shown in Table 8. One of the interviewees described the following regarding formula A: "I thought the formula was weird, and our BVP expert from The Netherlands also thought so. It was implied that the intention behind the formula was to motivate to give the lowest possible price. You should offer a very low price in order to gain many points."

Table 8: Overview of which method was used in each project

Project name	Formula used
E18 Rugtvedt – Dørdal	A
E6 Arnkvern – Moelv	A
E39 Kristiansand – Mandal east	A
E39 Mandal east – Mandal city	B
E6 Ranheim – Værnes	B

In order to visualize how formula A and B differed with regard to price evaluation, data from three projects are used. The results can be seen in Table 9.

Table 9: Weighted scores given with formula A and B

Project name	Offer	Formula A	Formula B	Difference
E18 Rugtvedt – Dørdal (Max score: 25)	Price 1	25	25	**0**
	Price 2	7	19.4	**12.4**
	Price 3	0	17.9	**17.9**
E6 Arnkvern - Moelv (Max score: 25)	Price 1	25	25	**0**
	Price 2	16	23.9	**7.9**
	Price 3	10	24.3	**14.3**
E39 Kristiansand – Mandal east (Max score: 25)	Price 1	25	25	**0**
	Price 2	18.69	24.87	**6.18**

As Table 9 shows, the two formulas produce different scores for each price offer. The high score does not differ because the lowest price automatically gets the full score. In these projects, full score in price equals 25 points. Nevertheless, the other offers differ in scores from formula A to B; e.g., one of the offers has a difference of 17.9 points. All of the scores were increased by using formula B. The smallest increment was 6.18 points. Therefore, there is no doubt that by using formula A, the scores are lower and the difference between offers is greater. This discrepancy aligns with comments from the interviewee who stated that pricing very low would result in many points with these projects. The worst-case scenario would be losing the project due to a method that is unfair. Formula B is also used to rank offers for the other four criteria, which was used throughout all of the projects.

A shift in the pricing model

As shown in Table 8, a shift from using formula A to B was first carried out in the project *E39 Mandal east – Mandal city*. In this project, a new method for pricing was also introduced because that the contractors were responsible for developing the project by producing the zoning plan. This new method is based on two factors that together would represent the contractor's price. First, the contractor sets a man-hour rate and then multiplies this rate with the given number of hours used to develop the project. Second, the contractor sets a profit percentage that is multiplied with the budget ceiling. This result represents the payment during the execution phase. The two prices are then added, and together they make the contractor's price. This method of pricing was also used in the last project, *E6 Ranheim – Værnes*, where the contractor also developed the zoning plan. In the previous projects, the fixed sum pricing model was used.

The interviewees were positive about this updated pricing model and thought that formula B seemed to be a fair way to rank the offers. Formula B did not calculate their offers against the budget ceiling. It made the differences in price between the offers more realistic with regard to achieved points. It is unknown if there is a link between the new pricing model and the evaluation of the price.

BVP IN THE FUTURE

There are several findings in this paper that could be implemented to improve BVP in Norway. The following suggestions are developed from the cons found in Table 6.

The evaluation of price: Two different formulas were used to evaluate price. One method was criticized by the contractors because it motivated contractors to price very low in order to gain many points. The second method (formula B) was considered more reasonable and should be used in future projects.

The execution phase*:* In practice, the weekly reports and mandatory reports due to contract NS 8407 increase the need for resources and cost in the projects. One interviewee stated, "the client has many controls and inspections. It is far more than we are used to in previous contracts." This practice directly contradicts the BVP philosophy. A solution could be to move forward with the weekly risk report and discard the other reports. This would require a change in contract.

Learning the method is time-consuming: Learning the BVP method takes time. The interviewees stated that the first BVP offer was time-consuming and that they used a lot of recourses developing the 6 pages required. The contractor also hired a BVP expert from The Netherlands to minimize the need for education and benefit from the expertise. Nevertheless, the second offer proved to require fewer resources because they had already gone through the process before. It gets easier every time.

CONCLUSION

This paper set to answer 1) How BVP was implemented in practice 2) what the contractors' experiences are with BVP method and 3) how the method can be improved in the future.

1) How was BVP implemented in practice?

All of the case projects followed the four phases of the method described by the founder of the method. Pre-qualification was also used in all of the case projects in order to sort the bidders before starting the competition. In the execution phase, the contract NS 8407 has taken over for the execution phase. None of the case projects have finished to this date.

2) What are the contractors' experiences with the BVP method?

The contractors' experiences are mostly positive with regard to the method. However, they were doubtful regarding how the evaluation of price was used. This paper has shown how two different formulas (A and B) were used to evaluate price. Examples show how the end score differed when shifting from formula A to B. This difference could have awarded the project to a different contractor, proving the interviewee's point regarding getting more points by lowering the price when formula A was used.

In the execution phase, all case projects were subject to a NS 8407 contract in addition to the weekly reports. This implementation results in an increased need for recourses and greater costs in this phase, and this does not align with the BVP philosophy.

The interviewees expressed confidence that the implementation of the BVP method will improve with experience and will spread in the Norwegian construction industry.

3) How can the method be improved in the future?

In order to facilitate the implementation of Lean in future projects by using BVP, the practise of the method should be improved. Improvement measures include implementing BVP philosophy and methods during the execution phase, minimizing micromanagement of the contractor and having a transparent evaluation method. These measures could reduce the probability of ending up in conflict. Conflict is one of the major sources of waste of time and resources. By improving the practice of BVP, it may be possible to improve lean practice. Formula B should be used to evaluate price in the future.

In the future, it is recommended that interviews with New Roads and insight into core documents be done to enlighten some of the questions raised in this paper. Also, the effects of BVP should be studied during and after the execution phase. Finally, more studies about the evaluation of price and criteria should be conducted for comparison with this paper.

REFERENCES

Andersen, A. T., Arendt, T., and Ramstad, J. (2018). "Legal issues due to Best Value Procurement (BVP)."

Brekkhus, A. (2017). "The construction industry has never had such a large share of GDP." <http://www.bygg.no/article/1310113>. (11.15, 2018).

Difi (2016). "Pilot of BVP in Norway." <https://www.anskaffelser.no/hva-skal-du-kjope/bygg-anlegg-og-eiendom-bae/best-value-procurement-bvp-prestasjonsinnkjop/pilotering-av-bvp-i-norge>. (09.01, 2019).

Focus Economics (2018). "Economic Growth (GDP, annual variation in %)." <https://www.focus-economics.com/economic-indicator/gdp>.

Högnason, G. O., Wondimu, P. A., and Lædre, O. (2018). "Best Value Procurement - The First Experience from Norway." *Creative Construction Conference 2018*, Ljublijana, Slovenia, 329-336.

Kashiwagi, D. T. (2016). *2016 Best Value Approach*, KSM.

Kashiwagi, D. T., and Kashiwagi, J. (2011). "Case Study: Performance Information Procurement Systen (PIPS) in the Netherlands." *Malaysian Construction Research Journal*, 8(1).

Kashiwagi, D. T., Kashiwagi, J., Smithwick, J., and Kashiwagi, I. (2012). "Changing the paradigm." *International Public Procurement Conference*, 1074-1095.

Koskela, L., Howell, G., Ballard, G., and Tommelein, I. (2002). "The foundations of lean construction." *Design and construction: Building in value*, 211-226.

Narmo, M., Wondimu, P. A., and Lædre, O. (2018). "Best Value Procurement (BVP) in a Mega Infrastructure project." *Group for Lean Construction (IGLC 26)*Chennai, India, 23-33.

New Roads (2017). "Our procurements methods." <https://www.nyeveier.no/om-nye-veier/slik-gjoer-vi-vaare-anskaffelser/>. (20.09, 2018).

Song, L., Mohamed, Y., and AbouRizk, S. M. (2009). "Early Contractor Involvement in Design and Its Impact on Construction Schedule Performance." *Journal of Management in Engineering*, 12-20.

Van de Rijt, J., and Santema, S. C. (2012). "The Best Value Approach in the Netherlands: A reflection on Past, Present and Future." *Journal for the Advanced of Performance Information and Value*, 4(2), 14.

Van de Rijt, J., Santema, S. C., and Soilammi, A. (2016). *Best Value Procurement - Prestasjonsinnkjøp*, RIF, translated from Dutch.

Van de Rijt, J., and Witteveen, W. (2011). "Contractor selection using BVP in the construction industry. Case studies at the Dutch Ministry of Infrastructure." *IPSERA 2011*Maastricht, 7.

Wohlin, C. (2014). "Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering." *Proceedings for the 18th International Conference on Evaluation and Assessment in Software Engineering*, ACM, London, England, United Kingdom, 1-10.

Wondimu, P. A., Hailemichael, E., Hosseini, A., Lohne, J., Torp, O., and Lædre, O. (2016). "Success factors for early contractor involvement (ECI) in public infrastructure projects." *SBE16; Build Green and Renovate Deep*Tallinn and Helsinki, 845-854.

Wondimu, P. A., Klakegg, O. J., Lædre, O., and Ballard, G. (2018). "A comparison of competitive dialogue and best value procurement." *Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC)*Chennai, India, 13-22.

Yin, R. K. (2013). *Case study research: Design and methods*, Sage publications.

Lesjø ES, Lædre O., and Wondimu, P. (2019). "Best Value Procurement from a Contractor Point of View." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 121–132. DOI: https://doi.org/10.24928/2019/0190. Available at: <www.iglc.net>.

Sarhan, S., Pasquire, C., Mossman, A., and Hayes, A. (2019). "The Prevailing Procurement System as a Source of Waste in Construction: A Case Study." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire, C. and Hamzeh, F. (ed.)*, Ireland, pp. 133-145. DOI: https://doi.org/10.24928/2019/0270 Available at: www.iglc.net.

THE PREVAILING PROCUREMENT SYSTEM AS A SOURCE OF WASTE IN CONSTRUCTION: A CASE STUDY

Saad Sarhan[1], Christine Pasquire[2], Alan Mossman[3] and Alan Hayes[4]

ABSTRACT

Prevailing project procurement processes and strategies are thought to be the root cause for many of the reported criticisms of the construction industry, such as lack of trust and collaboration and short term adversarial and transactional relationships. However, very few studies have sought to examine the relationship between the organisational, commercial and institutional environments influencing construction procurement and the generation of process waste in construction projects. This study addresses this gap in knowledge by providing findings from a case study of a major UK infrastructure project.

The study identifies a number of prevailing, yet counterproductive, procurement and contractual governance practices that lead to a 'network of causal wastes'. The study provides a conceptual model which exposes the complex, dynamic, interconnectedness and reciprocal nature of waste at the procurement and supply-chain level. The authors believe that this is the first study to expose the nature of waste at this level of analysis. It uses an integrated grounded theory case-study methodology that is demonstrably effective and can be useful for supporting studies seeking to investigate the concept of waste within the construction procurement context. The study concludes by suggesting that future studies focus on pre-procurement processes.

KEYWORDS

Procurement; Waste; Institutions; Contractual Governance; Grounded Theory

INTRODUCTION

The construction industry is often criticised for being confrontational, lacking trust and capacity for learning and improvement, and for being wasteful compared to other industries (see for example, Koskela, 2000; Sarhan *et al*., 2018). Numerous industry reports have

[1] Lecturer / Programme Leader in Construction Management, Lincoln School of Architecture and the Built Environment, University of Lincoln, LN6 7TS, Tel: +44 (0)1522 83 5395, ssarhan@lincoln.ac.uk

[2] Professor of Lean Project Management, School of Architecture Design and the Built Environment, Nottingham Trent University, NG1 4BU, Tel: +44 (0)115 848 2095, christine.pasquire@ntu.ac.uk

[3] Director, The Change Business Ltd, 19 Piccadilly, Stroud, GL5 1HB, UK; +44 7968 485 627, alanmossman@mac.com

[4] Director, Really Good Ideas Ltd, The Old Counting House, 82E High Street, Wallingford OX10 0BS, United Kingdom, alan@reallygoodideas.biz

been commissioned by the United Kingdom (UK) Government and industry organisations, over the past eighty years, with the aim of highlighting concerns and calling for industry reform (for example see Bossom, 1934; Simon, 1944; Banwell, 1964; Latham, 1994; Egan, 1998; Wolstenholme et al., 2009; Farmer 2016; Construction Leadership Council, 2018). In 2013, the UK Government challenged construction to achieve 50% faster delivery and a 33% reduction of clients' capital costs by 2025 (HM Government, 2013). Similarly, in 2016, the Government Construction Strategy 2016-20 was produced with an ambition of achieving efficiency savings of £1.7 billion over the course of the current Parliament (Infrastructure and Projects Authority, 2016). All these reports call for productivity improvements and a shift away from traditional short-term, adversarial, and transactional procurement and business models.

In October 2016, Farmer's report highlighted various inefficiencies within the UK construction sector, including its lack of innovation and collaboration. The report urged the need for the introduction of new business models that align with innovative production delivery approaches (e.g. offsite construction). Of interest, the report collected evidences that many innovative approaches to construction design and construction processes stall or get immediately refused, due to negative and deeply-rooted perceptions of risk in the industry. According to the report, these perceptions often stem from the commissioning clients and their advisers, architects, building control inspectors, the wider supply chain, and ultimately, insurers and funders (p. 35). This assertion aligns with a previous warning provided by Paul Morrell, the former Chief Construction Officer, who argued that the standing and perceived value of the various professions involved in the construction industry is challenged, "*with detractors seeing in their conduct and practice a tendency towards protectionism, resistance to change, the reinforcement of silos and the preservation of hierarchies*" (Morrell, 2015, p. 5). It is also consistent with work of Sarhan *et al*. (2017) who explained how and why inefficient construction-procurement safeguarding arrangements prevail in the industry, due to institutional pressure exerted on clients from third parties (e.g. consultants, quantity surveyors, lawyers, insurance companies and banks). These professionals do not "*take a central stake in the project outcome, only a stake in the process by which the project is delivered*" (p. 570).

The prevailing project procurement processes are thought to be a root cause for many, if not all, of these aforementioned issues and problems (Latham, 1994; Osipova and Eriksson, 2011; Sarhan *et al*., 2018). A small but growing number of studies have attempted to investigate the influence of procurement processes on the generation of waste in construction projects (for example see Jaques, 2000; Gamage et al., 2009). However, most of these studies, if not all, have limited their attention to physical (material) waste; other important considerations such as process waste and value-creation or loss in relation to project procurement have been hardly explored. Work by Sarhan *et al.* (2018) introduced the concept of 'institutional waste' within the construction procurement context, stressing the importance of investigating the institutional factors influencing procurement, and how these contribute to the generation and persistence of process waste in construction projects.

The authors are unaware of any empirical studies that examine the relationship between institutions, project procurement and process waste in construction. The purpose of this study is to explore this apparent gap in knowledge through an integration of both interpretative case-study and grounded-theory methodologies. In general, both terms `procurement system' and 'contractual arrangement' are closely related and are often used synonymously (Love *et al.,* 1998). For convenience, this study focusses on 'construction project procurement and governance arrangements', as defined and conceptualised in work by Sarhan *et al.* (2018, pp. 7-11). In the next section, the research methodology adopted for the study will be explained. Following this, an analysis and discussion of emerging findings will be presented, and finally the conclusion and recommendations for clients and decision-makers will be provided.

RESEARCH METHODOLOGY

The main aim of this study is to contribute to the concept of waste as understood in construction by exploring the prevailing construction procurement and commercial contexts that surround the design and delivery of construction projects. The methodology for such a study should enable to a holistic explanation of the underlying motives and behaviours associated with the use of wasteful construction procurement and commercial arrangements.

'Accurate shared-learning' is rarely obtainable in relation to commercial issues. People will generally share good news but not necessarily the bad, and the links between cause-and-effect in the case of both are rarely accurately assigned. These considerations along-side both the exploratory and explanatory natures of the study pointed the authors towards the use of a Straussian GT approach in conjunction with case study research, under interpretivist epistemological assumptions, as an integrated methodology. In simple terms, the study used a deductive-inductive GT methodology using Strauss and Corbin's (1998) rigorous coding procedures to analyse data collected from a case-study. Similar research approaches for integrating GT and case-study have been used in the fields of information technology and systems (for e.g. see Halaweh *et al.,* 2008 and Halaweh, 2012). Few, if any, studies have adopted this integrated approach for conducting empirical construction management research.

EXPLORATORY CASE STUDY

This paper presents findings from an investigation into a major UK public-sector infrastructure project, worth around million. This case-study was explored in 2015- 174£ 16, while the first author was conducting a wider-study (Sarhan, 2018) "*seeking evidence for practical examples of waste or value-loss arising from construction procurement and commercial practices*". The project-team involved in the afore-mentioned infrastructure project found the research topic of relevance and significance to their needs. They were willing to collaborate and engage in a shared-learning exercise, in order to identify the root-causes of the problems they generally experience in UK public-sector construction projects. This openness and desire to 'learn as a team' has helped the study to overcome the methodological challenges previously explained. All participants were assured that all identities and collected information will remain anonymous and be treated confidentially. In this paper, a gender-neutral language will be used when referring to participants.

DATA COLLECTION AND ANALYSIS

This study relied on the use of qualitative semi-structured interviews, as part of an integrated grounded theory case study methodology. All interviews were conducted over the telephone rather than face-to-face. Telephone was more time and cost effective, but also, when the interviewer is not physically present it can help interviewees to feel less threatened or distressed when answering sensitive questions (Bryman, 2012, p. 488). The first interview was conducted with a representative of the Main Contactor in Nov 2015 when the project had been running for just over a year. The aim of this study was to ask about the typical problems experienced in their current project. The terms ‘problem’ or ‘examples of value-loss’ were both used instead of ‘waste’, based on feed-back obtained from industry practitioners during pilot studies of a semi-structured interview guide prepared for this study.

After initial data collection and analysis of this interview was completed, the study employed *theoretical sampling* to determine who to sample next and what questions to ask during interviews, until theoretical saturation was achieved. Glaser and Strauss (1967, p. 45) define *theoretical sampling* as a “*process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses his data and decides what data to collect next and where to find them, in order to develop his theory as it emerges*”. Table 1 provides an overview of the sample characteristics of this study. So, data was not collected from a pre-determined sample; instead it was subject to an evolving and iterative processes and controlled by theoretical categories emerging from analysis of data already collected.

Table 1: Sample information (in non-corresponding order)

Professional Role / Title	Organisation	Duration (mins)	Data Collection*
Senior Design Coordinator	Main Contractor	45	P+D
Senior QS		39	P
Site Agent (CEng)		40	P+F+D
Sub-Agent		27	(S+E+D)
Project Planner			
Director and Project Manager	Specialist Subcontractor	33	P
Principal Design Engineer	Designer	40	P
ECC Project Manager (CEng, MICE)	Employed by the Client	36	P
Deputy Project Manager (CEng, MICE)		33	P+E
Senior Consultant	Financial Governance Consultancy	35	P+D

* S= skype, P= phone, E= follow-up questions by e-mail, F= follow-up by phone, D= supporting docs sent

The participants were also asked to provide supporting evidence whenever possible. Examples of supporting documents received and analysed in this study include:

- Form of agreement and contract data (268 pages)
- Samples of planning sheets related to resource quantities and scheduling

- Samples of weekly work plans and consolidated as-built Percentage Plan
- Charts and diagrams of Percentage of Plans Completed (PPC), including analysis of reasons for noncompletion (RNC).
- Template of tool-kit used for measuring supply-chain performance

MAIN PROBLEMS REPORTED IN THE CASE-STUDY

THE LARGE NUMBER OF REQUESTS FOR INFORMATION (RFI) BEING RAISED

One of the main problems found in this project was the large number of technical queries (Also known as: RFI) that were being raised by the contractor. The Site Agent reported "*883 RFI have been raised to date. Majority of these have been raised for design clarification where either insufficient information has been provided or the current design is not very clear*". When the designer was asked about how they were affected by the large number of RFIs raised in such a short period of time, the participant said:

> *"If there are a lot of RFIs being raised and we don't believe they were all warranted, and believe that the contractor should be able to adapt to the design and does not need the level of details which they are requiring. We'll then make a case to the client and ask for additional resources…you'll be looking at any compensation events, so we can increase what could have been our original target cost or give us another additional sum of money to recover the additional work undertaken in responding to the RFIs".*

A recent study, based on data collected from 168 projects, found, that the average cost of processing RFI on a project in Australia and New Zealand is around US$656 and US$243 respectively (Aibinu *et al*., 2018).

CLIENT VARIATIONS AND CHANGE ORDERS

The whole supply-chain suffered from receiving numerous Project Management Instructions during early stages of the project (Also known as: Client Variations or Change Orders). Examples of responses received concerning this problem include:

- Project Manager: *"We are subject to quiet a lot of change post contract and that's not ideal for an NEC type contract".*
- Design Coordinator: "*Well, so far we are probably just over a year into the contract now, so we've had over 350 project management instructions. And we've had 150 odd supervisors' instructions. So, that's five-hundred instructions that we've had on this scheme since we've started… So those instructions all have to be evaluated and obviously tie the QSs up*".
- Specialist Subcontractor: "*Contractors' and clients' change orders cause us lots of risk and pressure due to our commitments and plans of delivery with our manufacturers - we need at least 3 months of notice prior to delivery*".
- Financial Consultant*: "One of the problems on this particular job was that the client was eager to let it before the old framework expired. And consequently, it was you might say less well defined at the time it was let than it ought to be, and that resulted in an awful lot of change in the early days…We have on this particular scheme successfully obtained compensation events for increased resources as a result of the sheer volume of change".*

When the researcher asked the Deputy Project Manager about the reasons for the huge amounts of change orders, the participant simply said: *"They [the contractors] are having a lot of change in the scope of the works...Why?! Hmm, well, it's due to the client really!"*. The researcher then referred to the contractor once again and asked the Site Agent for explanations; the participant said:

> *"To start off, the project has been live for nearly a year now. And it has been a very slow process of getting responses back for RFIs. And this has been highlighted to the client in our meetings with the client, and with the designer: 'You know your response time to our RFIs is very slow.' And they will say that we don't have the resources. And one said, they were accusing us of raising too many RFIs. And we conquered that argument saying: 'well the reason we are raising so many RFIs is because the design is not clear'. So, which has a sort of indirect impact on the number of PMIs getting raised".*

Further investigation revealed that there were commercial misalignments, onerous contractual clauses and other procurement processes, which contributed to the generation of these wasteful behaviours, conflicts and arguments.

SUB-OPTIMISATION AND COMMERCIAL MISALIGNMENTS

The client used procurement mechanisms which focused on optimising the target fees of each main project party (e.g. Main Contractor and Designer), while overlooking how this may influence overall project performance and target cost. This led to self-interest as the main contractor and designer found no incentive to collaborate together to reduce overall project costs; instead each party focused on finding ways to reduce their own costs, even if this came at the expense of overall project performance. Of interest, the Deputy Project Manager was not aware himself or herself of how this commercial misalignment might impact on project performance. For instance, the participant said:

> *"I see, yes, but everyone is not affecting the other. Like they both have, hmm, the target cost. Hmm, there is one target cost for the whole project, then within this overall target cost, we have separate items for the contractor's cost, and separate items for the designers and the QSs and others – these are part of the auxiliary costs. So, although the total target cost will be increased by each party, but they both have to manage their own. So, really at the end, each one is not affecting the other"*

Further, the client had a predetermined choice and preferred the use of a 'collaborative' form of contract (NEC option D – Target Cost Contract with Activity Schedule) regardless of the procurement approach adopted for the project. This has been described by the Financial Governance Consultant as follows:

> *"The principle with the Client's Schemes was that the designs are relatively generic. So, the client keeps that design in-house. Unfortunately, it then uses a form of contract which pre-supposes, you know the NEC, that it's a contractor design. So, it's an uneasy alliance there which leads to a lot of variations".*

EXCESSIVE NON-VALUE ADDING REPORTING AND CONTRACT ADMIN WORK

The project participants raised concerns about the excessive and, in some cases duplicated, reports required by the client from the supply-chain for monitoring and measuring the accuracy of monthly financial projections on spend. These prevailing non-value-adding performance monitoring and reporting arrangements contribute to the generation and entrenchment of process waste in construction projects. Obviously, they led to an unnecessary increase in client's transactional costs. They also led to an adversarial environment which can lead to feelings of mistrust that, in turn, hinder collaboration and encourage opportunistic behaviours. Interestingly, these inefficient cost control practices also led to hidden costs that the client may not be aware of as highlighted by the Contractor's Quantity Surveyor:

> *"We have a Commercial Manager who deals with the reporting of this project. And we all feed him our information into him. He has to collate it and prepare it into several different formats basically for the client's requirements. So, it is excessive. It does take a long time and it is not necessarily a value to the client to have all this information, because we are paying for this person to provide all this work...It's just not efficient…it is a waste! So, reports that are duplicated is the answer".*

It can be argued that these inefficient practices are more likely to exist in a contract exercise that tries to compensate for failing to spend enough time creating certainty before procuring a contract. Further, these excessive non-value-adding reporting and admin requirements lead to waste of human potential and value-loss. For example, the QSs spent most of their time in this project evaluating client's change orders, collecting information required for reports, administering subcontracts, early warning notices and requests for compensation, rather than finding means for maximising value delivery. Similarly, the NEC Project manager's effort was mainly focused on administering the contract rather than managing production flow. The whole supply-chain, in general, spent considerable time and resources providing evidence for claims and compensation events, in comparison to what they spent on managing production.

INEFFICIENT SAFEGUARDING AND ONEROUS CONTRACTUAL ARRANGEMENT

The project contract included a Z-clause that implies that if a fatality occurred on the site of the scheme, the contractor loses his share in any savings gained for delivering the project below the target cost. As a fatality occurred during the beginning of the project, the contractor lost commercial incentive to collaborate with others to beat the scheme's target price. The commercial misalignments mentioned above made the problem worse.

> 'If the Scheme Outturn Cost is greater than the Scheme Target Price, the Contractor pays his share of the excess. If the Scheme Outturn Cost is less than the Scheme Target Price, two-thirds of the Contractor's share of the saving is retained and contributed to the Programme Level Incentive Fund and the remaining one third (the "remaining Contractor's share") is paid to the Contractor, provided that the remaining Contractor's share is paid to the Employer if there is a fatality on the site of the Scheme as a result of a reportable incident, is paid to the Employer in the event of termination for any of reasons R1-R15 or R18 and is reduced for late Completion in accordance with the table below' **(Z-Clause, NEC3, 2016).**

Additionally, during the review of the contract documents, the following disclaimer clause was found. These disclaimer clauses, which unfairly push risks to others, have been reported by various studies (e.g. see Zaghloul and Hartman, 2003; Sarhan *et al*., 2017) as a major reason for increasing the total cost of a project - in the form of insurance or contingencies, adversarial relationships and potential claims and disputes.

> ‘The Contractor’s total liability to the Employer for all matters arising under or in connection with this contract is unlimited’ **(Disclaimer Clause, NEC3, 2016).**

PREVAILING INEFFICIENT PROCUREMENT PRACTICES

The inductive bottom-up coding and analytical procedures adapted in this study led to the conceptualisation of various inefficient procurement practices (Figure 1), which, evidence from the data has shown, contributed to the generation of wasteful behaviours, performances and outcomes in the project.

It was found in the study that these prevailing procurement arrangements have a negative influence on the way that project-parties behave and perform throughout the project, leading to consequential wastes. The following section illustrates the impact of these inefficient procurement practices on project team performance and behaviour, and it reveals the nature of waste that exists at the procurement and supply-chain levels of analysis.

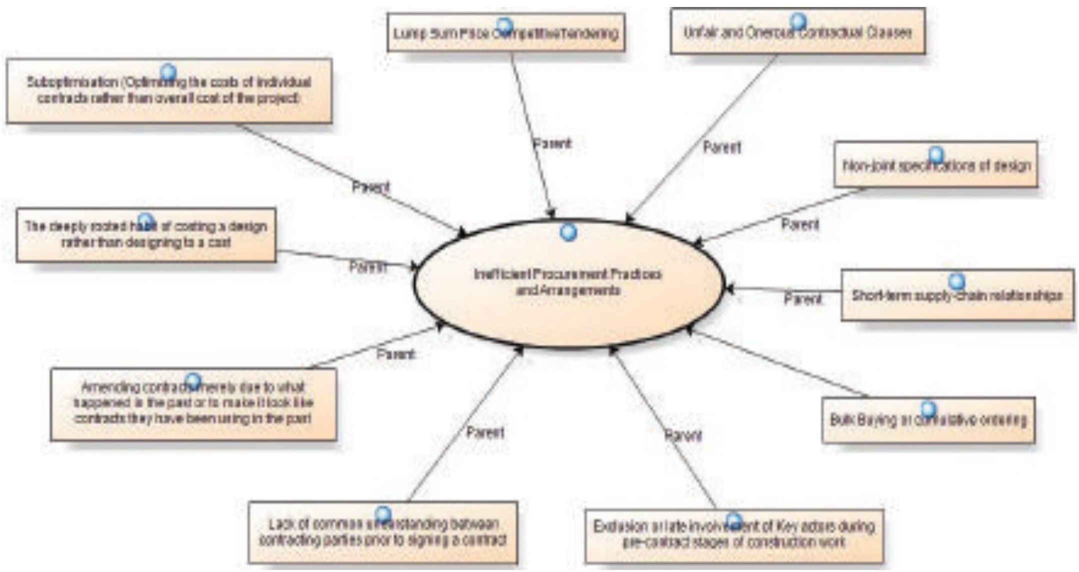


Figure 1: Coding structure for ‘inefficient procurement practices and arrangements’

THE COMPLEX AND DYNAMIC NATURE OF WASTE AT THE PROCUREMENT LEVEL

Construction processes are non-linear, interrelated and take place within a dynamic environment that includes lots of variables. Thus, relationships between different kinds of waste are very complex (Formoso *et al*., 2015). Figure 2 shows the interconnectedness and dependencies between different causes of waste, which result from the prevailing procurement practices and mindsets (Figure 1). This diagram was developed using NVivo matrix-coding query (in association with a careful data-verification of the resulting patterns) and sketched using Insights Maker (a web-based modelling tool) to reveal the complexity and interactive nature of waste existing at the procurement and supply-chain level. It was also found that this dynamic 'causal network of wastes' (Figure 2) leads to consequential wastes (at the production level), which are conceptualised in this study into four main categories: (1) financial losses and cost overruns; (2) time waste; (3) quality or value loss in design, and (4) waste of human potential.

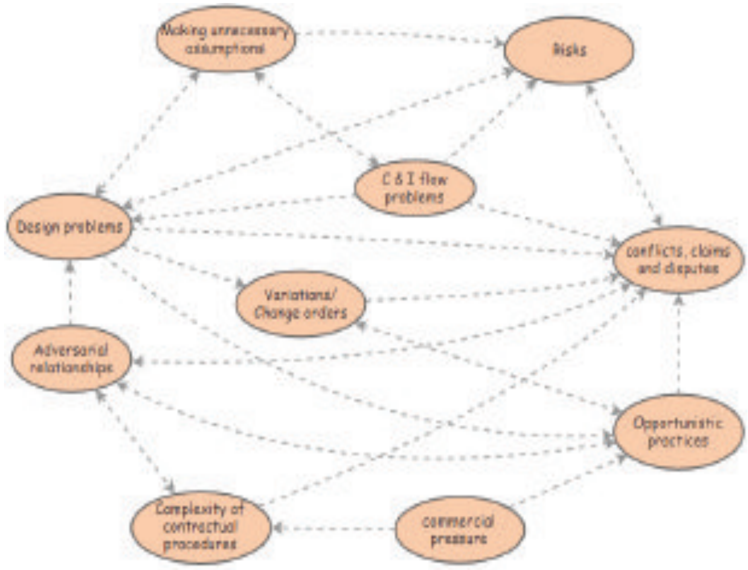


Figure 2: The nature of waste at the procurement / supply-chain level

This phenomenon is relatively similar to what Koskela *et al.* (2013) referred to as a 'chain of wastes', with one waste acting as a 'core' or 'lead' waste. In their study they argued, 'Making-do', in particular, is a core waste in construction (at the production-level of analysis) with substantial negative impact on the production system. Subsequently, Formoso *et al.* (2015) suggested that by attacking this core, one can also eliminate the wastes caused by it. According to them, the causal connections between wastes are not necessarily uni-directional; they can also be reciprocal (A leads to B while at the same time B leads to A). Thus, devising operational strategies focusing on the reduction of the effects would still be useful, as it can help to generate a root-cause analysis leading to the core wastes in the system (for example, this could be achieved using Last Planner System for production control). They concluded their study by offering a preliminary causal analysis of waste generated on site, with a focus on the production (design and construction) stage. They reflected on their reasoning approach, as follows:

> *"Our line of reasoning has taken us from the conceptualization of a linear chain with clear causes and effects to a complex network with both uni-directional and interactive connections between the nodes. In such a complex network, we may not be able to identify and analyse all the connections. We see a pattern, but are not able to decompose or decode the network in all its components and interconnections"* (Formoso *et al*., 2015, p. 457)

The conceptual model of waste developed in this study (Figure 2) is relatively consistent with the conceptualisations offered by Koskela *et al.* (2013) and Formoso *et al.* (2015). However, this study adds to their work by offering different perspectives and explanations; hence, this study is based on a different level of analysis (i.e. procurement and supply-chain level) and is approached using a reflexive grounded-theory methodology. In line with their arguments, it makes sense to propose that if clients stopped adhering to prevailing inefficient procurement practices, they could eliminate or reduce the substantial negative impacts of these procurement arrangements on the production system; thereby enhancing process-flow, eliminating or reducing the consequential wastes and minimising total project costs (both transactional & production). That said, it is arguably more crucial to address the institutional factors and underlying fundamental paradigms, which influence construction procurement choices and lead to the persistence of waste in construction. In other words, it would be unwise to tackle procurement processes alone, without first investigating the institutional factors and underlying paradigms that influence early-project decisions and condition project procurement & governance strategies (Sarhan *et al*., 2018).

CONCLUSIONS AND RECOMMENDATIONS

The nature of waste within the construction procurement context is complex, dynamic, interrelated and reciprocal. This study has shown how prevailing procurement practices can lead to a complex 'causal network of wastes' at the procurement/supply-chain level, leading to the generation of consequential wastes.

This study has identified various prevailing project procurement practices, which are taken-for-granted yet impede efficiency and improvement efforts in construction. The study also revealed some of the unnecessary waste that clients and decision-makers embed into their projects by adhering to counterproductive contractual governance arrangements.

The findings of this study suggest that much of the waste generated in construction projects stems from prevailing project procurement practices and governance arrangements. These construction procurement practices are shaped by institutional structures, beliefs and attitudes as well as project characteristics (Sarhan *et al*., 2016, 2017, 2018). For this reason, it has been stressed in this study that tackling inefficient procurement processes, without examining the wider institutional forces and underlying paradigms influencing procurement choices, may lead to some productivity improvements but won't address the root-cause(s) of the problem. The prevailing procurement system is not necessary the villain; it is only a malformed messenger of an inevitable outcome due to poor pre-procurement processes. Future studies are therefore recommended to investigate the institutional factors influencing buyers' approaches to construction project procurement.

The methodology used in this study can be useful for future studies seeking to understand and identify the causes and effects of process waste within construction procurement and supply-chains. The original and empirical findings that emerged from this study provide some evidence of the effectiveness of the methodology.

REFERENCES

Aibinu, A., Carter, S., Francis, V., and Vaz Serra, P. (2018) ‘Necessary evils: Controlling Requests for Information (RFIs) to reduce cost and improve margins’, *Construction Research and Innovation,* 9(4), 103-108

Bryman, A. (2012) 'Social Research Methods', 4th Ed., New York: Oxford University Press

Formoso, C., Bølviken, T., Rooke, J., and Koskela, L. (2015) 'A Conceptual Framework for the Prescriptive Causal Analysis of Construction Waste', *23rd Annual Conference of the IGLC.* Perth, Australia, 29-31 Jul 2015. pp 454-461

Gamage, I.S.W., Osmani, M. and Glass, J. (2009), ‘An investigation into the impact of procurement systems on waste generation: the contractors' perspective. In: Dainty, A. (Ed) *Procs 25th Annual ARCOM Conference*, Sep 2009, Nottingham, UK, 1031-40.

Glaser, B. and Strauss, A. (1967) The Discovery of Grounded Theory, New York: Aldine

Halaweh, M. (2012) ‘Integration of Grounded Theory and Case Study: An Exemplary Application from e-Commerce Security Perception Research’, *Journal of Information Technology Theory and Applications’*, 13(1), 31-51

Halaweh, M., Fidler, C., and McRobb, S. (2008) ‘Integrating the Grounded Theory Method and Case Study Research Methodology Within IS Research: A Possible 'Road Map'’, *ICIS 2008 Proceedings*, 165.

HM Government (2013). "Construction 2025 - Industrial Strategy: government and industry in partnership"; Available at: www.official-documents.gov.uk

Infrastructure and Projects Authority (2016) ‘Government Construction Strategy 2016-20’, available at: https://assets.publishing.service.gov.uk

Jaques, R. (2000) 'Construction waste generation - The influence of design and procurement', *Architectural Science Review*, 43(3), 141-146

Koskela, L. (2000) *An Exploration towards a Production Theory and its Application to Construction,* Degree of Doctor of Technology, Helsinki University of Technology

Koskela, L., Bolviken, T., and Rooke, J. (2013) ‘Which are the Wastes of Construction?’, *Proceedings for the IGLC-21*, Brazil

Osipova, E. and Eriksson, P. (2011) ‘How Procurement Options Influence Risk Management in Construction Projects’, *Construction Management and Economics*, 29(11), 1149-1158

Sarhan (2018) *Institutional Waste within the UK Construction Industry: An Exploratory Study*, PhD Thesis, Nottingham Trent University, available at: https://core.ac.uk/download/pdf/159754488.pdf

Sarhan, S., Pasquire, C.L., Manu, E. and King. A. (2016) ‘Are Tier-one contractors making their money out of wasteful procurement arrangements?” In: *Proc. 24th Ann. Conf. of the Int’l. Group for Lean Construction*, Boston, MA, USA, sect.3 pp. 83–92.

Sarhan, S., Pasquire, C., Manu, E. and King, A. (2017) ‘Contractual governance as a source of institutionalised waste in construction: a review, implications, and road map for future research directions’, *International Journal of Managing Projects in Business*, 10(3), 550-577

Sarhan, S., Pasquire, C., King, A., and Manu, E. (2018) 'Institutional Waste within the Construction Procurement Context', *The Engineering Project Organisation Journal*, Volume 8 (January 2018), 36-64

Strauss, A., and Corbin, J. (1998) Basics of Qualitative research techniques and Procedures for Developing Grounded Theory, USA: Sage

Yin, R (1994) Case study research: Design and methods, Sage Publishing, CA.

Zaghloul, R. and Hartman, F. (2003) 'Construction contracts: the cost of mistrust', *International Journal of Project Management*, 21, 419

Fürstenberg, D., and Lædre, O. (2019). "Application of BIM Design Manuals: A Case Study." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 145–156. DOI: https://doi.org/10.24928/2019/0147. Available at: <www.iglc.net>.

APPLICATION OF BIM DESIGN MANUALS: A CASE STUDY

David Fürstenberg[1] and Ola Lædre[2]

ABSTRACT

A problem often encountered by contractors is that the information provided is not always equal to the information needed in the Building Information Model (BIM). Somewhere between the BIM design manual and the final BIM information is omitted. The purpose of this paper is to identify the source of the information loss. Therefore, the relation between model information requirements in BIM design manuals, tender documents and the final BIM was investigated. The research included a literature study, a document study and a case study. In detail, three discipline models (road, construction and lighting) were investigated from a design-bid-build project in Norway. The results showed that the requirements were mostly complied with (sometimes with a pragmatic approach). However, the requirements represent the client's focus on the design and the in-use phase. Whereas the contractor's focus on the production phase is not given the same attention. From that perspective, the results are twofold; 1) some of the required information is not provided in an exact and reliable form, while 2) resources are spent on providing not required information. This applied research showed that design manuals should reflect new project delivery methods to support lean principles for all parties involved in the project.

KEYWORDS

BIM design manual, infrastructure, lean construction, waste, standardization.

INTRODUCTION

BIM is a widely used term in the architecture, engineering and construction (AEC) industry. The acronym is used for both an action (Building Information Modelling) and a result (Building Information Model). While both descriptions of the term are true in most contexts, BIM is most of all a method for object-based computer modelling with attached information. According to Williams (2015), the term "Building" is misleading, because "BIM models are not exclusive to building projects". However, the term describes the current situation well as BIM is still mainly applied to buildings and the infrastructure sector is left behind (Shou et al. 2015).

As public infrastructure is mainly owned by governments, public initiatives are necessary to increase the usage of BIM in infrastructure projects. In Norway, public clients

1 PhD candidate, Department of Civil and Environmental Engineering (DCEE), Norwegian University of Science and Technology (NTNU), Trondheim, Norway/BIM specialist, COWI Norway, +47 482 35 793, david.furstenberg@ntnu.no/ dafu@cowi.com

2 Professor, DCEE, NTNU, Trondheim, Norway, ola.ladre@ntnu.no

such as the Norwegian Public Roads Administration (NPRA) have published BIM design manuals. While the usage of the design manual (and BIM) is not mandatory yet, the NPRA can force the AEC industry to use BIM for infrastructure projects. It is an important tool to stimulate and contribute to the digitalization of this industry.

The NPRA's design manual V770 (Vegvesen 2015) was first published in 2012 and has since then been applied to many road projects. Most recently, the NPRA started projects requiring only a limited number of drawings. The information that is normally conveyed in drawings must therefore be included in the BIM. A problem often encountered for the contractor is that the information provided is not always equal to the information needed in the BIM (Eastman et al. 2011). Somewhere between the BIM design manual and the final BIM information requirements are omitted. The results are twofold; 1) some of the required information is not provided, while 2) resources are spent on providing not required information.

Womack and Jones (1996) described the five principles of lean thinking (value, the value stream, flow, pull and perfection) based on the concepts and principles of the Toyota Production System (TPS) developed by Ohno (1988). Other researchers investigated the application of the TPS concept on the AEC industry and introduced lean construction (Koskela 1992, Ballard and Howell 1994, Howell 1999). Lean construction focuses on waste reduction; value increase and continuous improvement (Sacks et al. 2010). Hicks (2007) mapped the seven wastes of manufacturing reported on in Womack and Jones (1996) to information management. This is especially interesting, as recently "Better Information Management" was introduced as an alternative explanation of the acronym BIM (Borrmann et al. 2018, UK Roads Liaison Group 2018). This alternative understanding of BIM stresses the importance of information in AEC projects and the value that lies within BIM. While BIM and lean can be applied independently on AEC projects, Sacks et al. (2010) revealed several interactions, which were demonstrated by Fosse et al. (2016) through a case study.

The study presented in this paper identified the lean construction principles *waste reduction, value increase and improvement of the information flow*. To the authors' knowledge there is little empirical research on the relation between model information requirements in BIM design manuals and tender documents, and between tender documents and the final BIM. To examine this, the paper addressed the following research questions:

What is the difference between the model information requirements in the BIM design manual and the tender documents?

What is the difference between the model information requirements in the tender documents and the BIM model?

One design-bid-build project from Norway was studied. The project covered the concept development and detailed designing phase like outlined in Knotten et al. (2016). Other delivery methods like design-build or integrated project delivery (IPD) were not evaluated.

CASE STUDY DESCRIPTION AND METHOD

A qualitative research design was selected instead of a quantitative because requirements in BIM design manuals are a novel topic. Therefore, the research reported on in this study included a literature study, a document study and a case study. A literature study was carried out according to the steps described by Blumberg et al. (2014): 1) build information pool, 2) apply filters to reduce pool size, 3) rough assessment of sources to further reduce pool size, 4) analyze literature in pool and 4) refine filters or stop search.

Thereafter a case was selected. The case was a road project (Fv47 Åkra sør – Veakrossen) in western Norway, consisting of 7 km highway and 3 km secondary roads. This case was chosen because it was one of the first road projects from the NPRA not demanding any drawings in the tender documents except legal binding ones. In fact, the ambition was to deliver the project with no drawings at all. One of the requirements in the tender documents was the usage of the client's BIM design manual (V770). The core element of this manual is a mandatory BIM approach for infrastructure projects.

Concerning the usage of BIM, the client and the designers agreed early upon waste reduction, one of the principles of lean construction as adapted by Koskela (1992). BIM was the means for this principle. In the examined case, drawings should only be produced when they conveyed the information more effectively than the BIM. Is must be mentioned that the project's design phase was not finished yet when it was studied. However, the authors regarded the models to be valid for the research intention and fresh results could be presented to the IGLC community.

The prescriptions as outlined by Yin (2018) were followed during the case study and documentation was used as the source of evidence. The BIM was examined, and relevant documents were studied. The first author was part of the project team and obtained the documents and had access to the BIM. In detail, the client's tender documents and an additional document clarifying the mutual understanding of the level of information in the discipline models were studied. This document was agreed on after the contract was signed and replaced those parts of the original tender documents concerning the level of information. Furthermore, a BIM execution plan (BEP) solely produced for the construction discipline model was examined. A BEP describes "how the information modelling aspects of a project will be carried out" (British Standards Institution 2013). All of these documents were chosen because they described the requested level of information in the models for the case study.

Thereafter, the discipline leaders for the three discipline models were interviewed. They were chosen because they were responsible for compliance with the information requirements. The reason for the interviews was to confirm that the authors' impression of the available information in the BIM was correct and to find out why some requirements were not complied with. The interviews were semi-structured and lasted between 15 and 30 minutes.

THEORETICAL BACKGROUND

BIM FOR INFRASTRUCTURE

According to Williams (2015) there are a variety of different terms used to distinguish the application of BIM to vertical and horizontal constructions, like "Civil BIM, CIM, BIM for infrastructure, Heavy BIM, etc.". The authors' impression is that the term "BIM for infrastructure" is mainly used, especially in Scandinavia, and they decided to use it in this paper. The main difference between BIM for infrastructure and "vertical" BIM is its geographical extend and its dependency on geospatial data and coordinate systems. In BIM for infrastructure projects real-world coordinates are assigned to all objects (EUREF89 NTM in the presented case) instead of local coordinates and a reference point like in "vertical" BIM. Something unique to BIM for infrastructure in Scandinavia, especially in Norway, is the wide use of a BIM tool which handles information and models comparable to a GIS tool, namely Trimble Novapoint (2019).

DIGITALIZATION

There are different definitions of the digitalization process used by practitioners and researchers. One definition, which the authors regard precise is from i-scoop (2018). They used the terms "digitization", "digitalization" and "full transformation".

"digitization": *"transformation from analog to digital (…) with the goal to digitize and automate processes or workflows"*.

"digitalization": *"use of digital technologies and of data (…) to create revenue, improve business, replace/transform business processes and create an environment for digital business, whereby digital information is at the core."* In other words, using the digitized data to create an improved product.

"digital transformation": builds upon digitization and digitalization and *"encompasses all aspects of business, regardless of whether it concerns a digital business or not, … ultimately leading to a new economy."*

DESIGN MANUAL V770

The design manual V770 was first published in 2012 and revised in 2015. The NPRA invited designers, contractors, surveyors and software developers to contribute. The purpose of the manual is to reduce the number of errors in the production phase by using BIM in the design phase. It defines delivery requirements for models of the existing and designed situation. These delivery requirements describe both the model data and the model content. However, it does not explicitly prescribe that all information must be included as property data on the object level in the models. Drawings and external documents are mentioned as an alternative. This was mainly due to the fact that infrastructure projects with only a limited number of drawings were not common at the time the V770 was published. The manual classifies models of the existing situation into four types and models of the designed situation into 19 discipline models. Besides the delivery requirements there are also process requirements, like multi-discipline collaboration, clash detection and the extraction of stakeout data from the discipline models. Finally, it requires as-built models to be delivered to the national maintenance base.

For the purpose of this paper three of the 19 discipline models were selected and investigated. In particular, the required information of the discipline models road, construction and lighting was examined. Table 1, column 2 shows the model information requirements for the three models investigated.

DESIGN PROCESS

The Norwegian approach called Next Step was used for the classification of project phases, reported on in Knotten et al. (2016). In design-bid-build projects for the NPRA designers usually are involved in step 3 (concept development) and step 4 (detailed designing). The deliverables are different types of plans. In the concept development phase designers deliver legally binding (municipal) zoning plans. If these zoning plans describe the project with enough detail no further permit is needed prior to construction. However, constructions (bridges and culverts) always have to be approved by the Directorate of Public Roads. In the detailed designing phase, designers deliver a construction plan. The construction plan is based on the zoning plan and is the foundation for the contractors in the production phase.

FINDINGS

This paper investigated the relation between requirements in BIM design manuals and tender documents, and between tender documents and the final BIM by answering the following questions.

What is the difference between the model information requirements in the BIM design manual and the tender documents?

What is the difference between the model information requirements in the tender documents and the BIM model?

DIFFERENCE BETWEEN BIM DESIGN MANUAL AND TENDER DOCUMENTS

A comparison of the BIM design manual and the tender documents (see table 1, column 2 and 3) revealed that there were no deviations for the road and the lighting discipline model. However, major deviations could be found for the construction model. Only two requirements from the design manual were reflected in the tender documents, but four extra requirements were added. One of these additional requirements were "all other information that is normally conveyed in drawings".

The reason for the deviations for the construction model are a changed approval mode by the Directorate of Public Roads. This was especially true for the "all other information" requirement. At all times, constructions needed to be approved by the Directorate. A special set of drawings had to be produced. However, when the tender was sent, the Directorate opened for model-based approval requiring only a minimal number of drawings. The basic principle of the model-based approval was that models should have at least the same level of detail as drawings used to have. This new approval mode was neither reflected in the design manual V770 nor in the tender documents. Instead, the Directorate required a detailed BIM Execution Plan (BEP) specific for the construction discipline model. The BEP contained one chapter describing information requirements which were much more detailed than the requirements in the V770 or the tender documents. This makes the construction discipline model somewhat special since it is based on requirements that were not part of the tender documents.

DIFFERENCE BETWEEN TENDER DOCUMENTS AND BIM

Varying deviations were observed between the tender documents and the final BIM for the three discipline models (see table 1, column 3 and 4). While there were no deviations for the construction model and only minor deviations for the lighting model, there were major deviations for the road discipline model.

There was only one requirement complied with in the road model (design criteria). Some of the requirements that were not met (slope, camber and super elevation) were due to technical limitations in the BIM software. The designers had access to these data in the design process, but they could not be implemented as property data on the object level. This information is typically included in drawings. However, having the lean principle of waste reduction in mind, the client and the designers agreed to not produce drawings. Instead, they chose to convey the information to the client directly through the BIM software in meetings.

Information about visibility (line of sight) was not included either. This could be technically implemented in the BIM software, but – thinking of waste reduction – the designers decided not to. They had access to this information in the design process and it was visually conveyed in the zoning plan. However, it was not regarded as important information for the following phases.

Information about masses was not available in the BIM either. The designers had access to these data and delivered it in Excel sheets. Even though one could argue that this information would add value for the client, the requirement was not complied with since the V770 does not explicitly state that all information must be conveyed as property data on the object level. At this point it must be noted that the road discipline model was slightly less mature than the other two discipline models. This was due to a delay in the legal process which made extra design loops necessary for this specific discipline. However, the interview results indicate that the above-mentioned facts are still valid.

The only missing information in the lighting discipline model were the mounting details. These details are supplied in an external document.

Table 1: Model information requirements and their compliance in the BIM

Discipline model	Model information requirements set in the BIM design manual V770	Model information requirements set in the tender documents	Compliance in the BIM
Road	Design criteria	Design criteria	Yes
	Visibility	Visibility	No (in zoning plan)
	Mass haul balance	Mass haul balance	No (in Excel sheets)
	Mass overview	Mass overview	No (in Excel sheets)
	Slope	Slope	No
	Camber	Camber	No
	Super elevation	Super elevation	No
Construction	Road information	-	No (in drawing)
	Cross-reference to bridge design manual	-	No (in drawing)
	Cross-reference to detailed drawings and other models	Cross-reference to detailed drawings and other models	Yes
	Quality of materials	Quality of materials	Yes
	Type and weight of pavement	-	No (in drawing)
	Water level	-	No (in drawing)
	Ship impact load	Not applicable	Not applicable
	Rivers' direction of flow	-	No (in drawing)
	Clearance height	-	No (in drawing)
	Distance from road center line to nearest construction part	-	No
	-	Object code	Yes
	-	Object type	Yes
	-	Toponym	Yes
	-	"All other information that is normally conveyed in drawings"	Yes (geometry details, tolerances)
		[Specific BIM Execution plan (88 specific attributes)]	Yes

Discipline model	Model information requirements set in the BIM design manual V770	Model information requirements set in the tender documents	Compliance in the BIM
Lighting	*Light poles*		
	Pole number	Pole number	Yes
	Pole height	Pole height	Yes
	Type of pole	Type of pole	Yes
	Type of lighting	Type of lighting	Yes
	Type of foundation	Type of foundation	Yes
	Distance from shoulder	Distance from shoulder	Yes
	Station number	Station number	Yes
	Hight of bulb	Hight of bulb	Yes
	Color	Color	Yes
	Effect	Effect	Yes
	Lighting class	Lighting class	Yes
	Course number	Course number	Yes
	Mounting details	Mounting details	No (external documentation)
	Pull manhole		
	Number	Number	Yes
	Type	Type	Yes
	Dimension	Dimension	Yes
	Other technical installation		
	Number	Number	Yes
	Toponym	Toponym	Yes

DISCUSSION

In the presented case BIM supported the following lean principles; waste reduction, improvement of the information flow and value increase. Several types of waste were reduced by improving the information flow. Overproduction, waiting (Womack and Jones 1996), mass electronic communication and legacy databases (Hicks 2007) were diminished by direct access to information through the BIM instead of drawings. BIM created value for both the client, the designers and the contractor. BIM enabled the designers to remove some non-value adding activities by automating time consuming manual tasks. Value was also created downstream for the customer by preparing the information for the contractor. Instead of paying extra for the creation of data for machine control the contractor could extract the necessary information directly from the BIM.

The lean principle of waste reduction had a strong stand in the presented case. It was reflected in a pragmatic approach towards the compliance with the model information requirements. The client and the designers agreed that only necessary information was provided in the models. Drawings and documents were preferred when they were more effective to produce. This resulted in deviations from the requirements for the road discipline model. For this specific model, the geometry is most important in the production phase. Moreover, there are no specific parts that need to be changed in the in-use phase which would make detailed information about assets necessary (like for the discipline model lighting and construction).

The results showed that the requirements set in the BIM design manual were reflected in the tender documents to a varying extend. While both the road and the lighting model fully complied, the construction model had major deviations. However, a closer look revealed that these deviations were due to a changed approval mode after the tender documents were sent. In this respect, the construction model was not generally representative for this comparison.

Disputes between clients and designers often root in diverging interpretations of the content of the deliverables. Contracts and tender documents with clear requirements are necessary to establish a common understanding between them. In the presented case both parties agreed on a document clarifying the requirements from the design manual and the tender documents for all discipline models. Thus, they created reliability which is one of the principles in lean construction (Howell 1999).

Legal requirements seem to have the biggest impact on the BIM application in AEC projects. On the one hand, this could lead up to obstacles like continued demand of drawings (zoning plans and overview drawings in the presented case). On the other hand, it could also raise the level of information. The discipline model construction had the highest level of information because a specific BEP was required by the Directorate of Public Roads for the approval process.

Requirements set in the tender documents were only partially reflected in the final BIM, varying between the three discipline models investigated. The discipline model lighting and construction complied with most requirements while the discipline model road had major deviations. These deviations are partly based on limitations in the BIM software used and partly based on pragmatic decisions by the designers thinking of waste reduction.

All requirements from the tender documents were fulfilled in the construction discipline model. While this model only had four requirements in the tender documents it is actually the model with the highest level of information. The BEP has approximately 80 different properties on the object level though providing "all other information that normally conveyed in drawings". The higher level of information is due to the fact that the construction discipline model is the only one that needs to be approved by the Directorate of Public Roads. At the same time this model is the only discipline model that has additional, obligatory drawings. Even though the Directorate has opened for model-based approval, one overview drawing per construction is still mandatory and detail drawings might be requested. Some of the required information (cross-references, type and weight of pavement, river's direction of flow and clearance details) is therefore only included in drawings. This puts the construction model in a special position.

CONCLUSION

In this paper, the relation between requirements in BIM design manuals and tender documents on the one hand and between tender documents and the final BIM on the other hand was investigated. The results showed that the requirements were mostly complied with (sometimes with a pragmatic approach). However, both the BIM design manual and the tender documents were made by the client and thus represent the client's perspective. It seems like the focus of the NPRA is on the design and the in-use phase. Especially the detailed requirements for the lighting and construction discipline model indicate this. Whereas the contractor's focus on the production phase is not given the same attention in the requirements. From that perspective, the results are twofold; 1) some of the required information is not provided in an exact and reliable form (mass balances are only conveyed as Excel sheets, not directly in the BIM), while 2) resources are spent on providing not required information (lighting details for the in-use phase).

Contractors need exact and reliable information about the planned assets, especially on cost drivers like masses or constructions. Providing the necessary information in one single source lays the foundation for a digital transformation of the AEC industry. Single source in this respect means either all information is available directly in the BIM, like for the construction discipline model, or by using a linked data approach where the same data is used in different ways. If the NPRA wants the AEC industry to be digitally transformed and not just digitalized, the manuals have to reflect this. In short, the contractors' perspective must be given more attention. Having in mind the trend towards design-build projects, not just in Norway (Eriksson et al. 2017; Ma et al. 2018), where the contractor is responsible for both the design and the production, this finding is even more relevant.

The design manual V770 was an important step to force the AEC industry into using BIM for infrastructure. However, since it's first publication in 2012 BIM software has evolved and new project delivery methods have been applied to projects in Norway. The manual should reflect these new delivery methods and have more focus on the contractor and their need for information.

It was the intention of the authors to present results of an ongoing industry PhD project to the IGLC community to get feedback. It is not yet clear whether the mismatch of the information requested and provided is a systematic problem or was unique to this case. The presented case was the first of a series of case studies covering different delivery methods (design-bid-build, design-build and integrated project delivery (IPD). Future work should focus on the contractor's perspective and investigate the following; 1) relevance of information for the contractor, 2) evaluation of experiences with delivered information and 2) comparison of the available information in different delivery methods.

REFERENCES

Ballard, G., and Howell, G. (1994) "Implementing Lean Construction: Stabilizing Work Flow." *Proc., 2nd Annual Meeting of the International Group for Lean Construction,* Santiago de Chile, 1-10.

Blumberg, B., Cooper, D. R., and Schindler, P. S. (2014). *Business research methods*, McGraw-Hill Higher Education, London.

Borrmann, A., König, M., and Koch, C. (2018). *Building Information Modeling*, Springer.

British Standards Institution (2013). "PAS1192-2:2013." *Specification for information management for the capital/delivery phase of construction projects using building information modelling*.

Eastman, C. M., Teicholz, P., and Sacks, R. (2011). *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors*, John Wiley & Sons, Hoboken.

Eriksson, P. E., Lingegård, S., Borg, L., and Nyström, J. (2017). "Procurement of railway infrastructure projects–a european benchmarking study." *Civil Engineering Journal*, 3(4), 199-213.

Fosse, R., Spitler, L., and Alves, T. (2016) "Deploying BIM in a Heavy Civil Project." *Proc., 24th Annual Conference of the International Group for Lean Construction,* Boston, USA, 43-52.

Hicks, B. J. (2007). "Lean information management: Understanding and eliminating waste." *International Journal of Information Management*, 27(4), 233-249.

Howell, G. A. (1999) "What Is Lean Construction - 1999." *Proc., 7th Annual Conference of the International Group for Lean Construction,* Berkeley, USA, 1-10.

i-scoop (2018). "Digitization, digitalization and digital transformation: the differences." <https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/>. (2019-01-10).

Knotten, V., Hosseini, A., and Klakegg, O. J. (2016) "“Next Step”: A New Systematic Approach to Plan and Execute AEC Projects." *Proc., CIB World Building Congress 2016*, Tampere, 484-495.

Koskela, L. (1992). "Application of the new production philosophy to the construction industry." *Technical Report No. 72*, Center for Integrated Facilities Engineering, Dept. of Civil Engineering, Stanford University, CA.

Ma, L., Le, Y., Hongyang, L., Jin, R., Piroozfar, P., and Liu, M. (2018). "Regional Comparisons of Contemporary Construction Industry Sustainable Concepts in the Chinese Context." *Sustainability*, 10.

Ohno, T. (1988). *Toyota production system : beyond large-scale production*, Productivity Press, New York.

Sacks, R., Koskela, L., Dave, B. A., and Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." *J. Constr. Eng. M. ASCE*, 136(9), 968-980.

Shou, W., Wang, J., Wang, X., and Chong, H. (2015). "A Comparative Review of Building Information Modelling Implementation in Building and Infrastructure Industries." *Arch. Comput. Methods Eng., 22(2), 291-308.*

Trimble (2019). "Novapoint." <https://www.novapoint.com/>. (2019-04-09).

UK Roads Liaison Group (2018). "BIM guidance for infrastructure bodies." Department for Transport, 156.

Vegvesen (2015). *Modellgrunnlag, Krav til grunnlagsdata og modeller (Håndbok V770)*, Vegdirektoratet, Oslo.

Williams, P. (2015). *Managing Measurement Risk in Building and Civil Engineering*, John Wiley & Sons, Incorporated, Hoboken.

Womack, J. P., and Jones, D. T. (1996). *Lean thinking : banish waste and create wealth in your corporation*, Free Press, New York.

Yin, R. K. (2018). *Case study research: design and methods*, Sage, Thousand Oaks, California.

STREAM 3: PEOPLE, CULTURE AND CHANGE

Demirkesen, S, Wachter, N., Oprach, S., Haghsheno, S. (2019). "Identifying Barriers in Lean Implementation in the Construction Industry" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 157–168. DOI: https://doi.org/10.24928/2019/0151. Available at: <www.iglc.net>.

IDENTIFYING BARRIERS IN LEAN IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

Sevilay Demirkesen[1], Nadia Wachter[2], Svenja Oprach[3], and Shervin Haghsheno[4]

ABSTRACT

With the rising attention on the topic of Lean construction and its benefits, more and more companies aim to implement the Lean philosophy in their culture. Together with changing the companies' culture multiple challenges occur. Hence, it is of utmost importance to identify factors, which lead to poor management in Lean construction activities. Therefore, this paper intends to identify and categorize barriers leading to poor implementation of the Lean philosophy. In this respect, a set of barrier groups comprising a total of twenty-seven components were identified. A questionnaire was designed and administered to Lean construction professionals in order to rank the importance level of the selected barriers. The paper proposes that lack of 'top management support', 'misperception about Lean practices', 'lack of information sharing and integrated change control' are the top three barriers for Lean implementation. The findings of the study indicate that Lean implementation might be conducted with higher efficiency and productivity by removing the barriers for implementation. This study might guide Lean professionals to align their strategies with Lean practices by knowing and recognizing the main barriers.

KEYWORDS

Lean construction, culture, collaboration, continuous improvement, barriers.

INTRODUCTION

Construction is a risky endeavor and it requires the application of well-set practices. Bringing a new insight to construction industry, Lean construction appears as a new branch of construction management (Ballard and Howell, 2004). Due to a lack of experience, Lean construction projects are sometimes troublesome and challenging for contractors.

[1] Assistant Professor, Dept. of Civil Eng., Gebze Technical University, Kocaeli, Turkey. Phone +90 5340540364, demirkesen@gtu.edu.tr.

[2] Research Fellow. Karlsruhe Institute of Technology (KIT), Institute of Technology and Management in Construction, Gotthard-Franz-Str. 3 (Am Fasanengarten), Bldg. 50.31, D-76131 Karlsruhe, Germany. Phone +49 (0) 721 608 45476, nadia.wachter@kit.edu.

[3] Research Fellow. Karlsruhe Institute of Technology (KIT), Institute of Technology and Management in Construction, Gotthard-Franz-Str. 3 (Am Fasanengarten), Bldg. 50.31, D-76131 Karlsruhe, Germany. Phone +49 (0) 721 608 45476, svenja.oprach@kit.edu.

[4] Professor. Karlsruhe Institute of Technology (KIT), Institute of Technology and Management in Construction, Gotthard-Franz-Str. 3 (Am Fasanengarten), Bldg. 50.31, D-76131 Karlsruhe, Germany. Phone +49 (0)721 608 42646, shervin.haghsheno@kit.edu.

Meadows (2011) indicates that processes in the construction industry are more wasteful than processes of any other industry. Hence, eliminating non-value adding activities is of utmost importance in the construction industry to stay competitive. The Construction Industry Institute (CII) reports that according to studies 57% of the construction work results in waste (Aziz and Hafez, 2013; Lean Construction Institute, 2004). This necessitates the effective implementation of strategies to minimize waste and promote competitiveness (Porter, 1995).

Introducing Lean thinking to the construction industry is not only beneficiary for practitioners but also for customers regarding the transparency and stability of the project. Koskela (1992) considers Lean principles in the construction context and proposes methods to manage construction projects accordingly (Koskela, 1992). Nevertheless, it is still troublesome to accurately transfer Lean principles to construction projects and achieve an efficient implementation by construction professionals. Moreover, most contractors are reluctant to apply Lean principles since the implementation is perceived as expensive and time consuming (Almanei et al. 2017; Okere 2017). Therefore, Lean implementation is sometimes evaluated as a disadvantage for short term projects despite its advantages in long-term. Hence, it might become difficult for contactors to recognize the benefits of Lean practices.

To refute the idea that Lean construction principles are not beneficiary or only have limited benefits for construction practitioners, a better understanding of Lean practices and a clear definition of Lean implementation barriers is required. Thus, this study aims to identify main barriers preventing construction practitioners from the benefits of Lean practices. Additionally, the positive influence of an effective implementation of Lean practices is outlined. In this respect, seven factor groups were identified comprising twenty-seven components. The factor groups identified are namely the following: political, economical, managerial, workforce, culture, communication, and technical. The study also presents the results of a questionnaire administered to Lean professionals in the USA in terms of ranking the identified barriers based on the order of importance.

RESEARCH METHOD

In the first step, an in-depth literature review was conducted in order to identify barriers for Lean implementation in construction. In the second step, an online survey was designed and administered to the members of the Lean Construction Institute (LCI) (https://www.leanconstruction.org/membership/members-sponsors/#Corporate%20 Members). The members were selected considering their level of expertise in practicing Lean. A comprehensive list was generated after careful investigation of members' expertise and experience in Lean construction. Then, the survey was delivered online to come up with a better response rate. The survey consisted of two sections: (1) general information about the respondent, company, and project and (2) the barriers associated with Lean implementation. After a brief overview of Lean Implementation in construction, findings from literature review and the survey are presented in the following.

LEAN IMPLEMENTATION IN CONSTRUCTION PROJECTS

The construction industry is a dynamic and fragmented industry, which requires the adoption of various tools and techniques for the effective management of construction projects. In this respect, Lean techniques are useful in terms of promoting efficiency in the industry and increasing productivity rates (Sundar et al. 2014). When the Toyota company developed its production system (TPS) in the 1950s, the company increased its profits every year from 1950 to 2008 until the global recession and the oil price spike (Liker and Convis, 2012). According to the two pillars of the TPS, not only processes but also the people's mindset is fundamental for a successful development. Lean production was then offered as a term by Krafcik, a member of the team of the International Motor Vehicle Programme at the Massachusetts Institute of Technology (MIT) in 1988 (Krafcik, 1988). Womack et al. (1990) further studied this concept in their book "The Machine That Changed the World".

Koskela (1992), one of the Lean pioneers, brought up Lean principles for the fact that these principles aim to maximize value for customers while minimizing waste (Koskela 1992, Sarhan and Fox 2013). Womack and Jones (1996) further mentioned the five principles of Lean production namely specify value, identify the value stream, make the remaining value-creating flow continuously, allow customers to pull, and reach perfection for a continuous improvement process. This theoretical foundation is called 'Lean Thinking' and it helps differentiating production activities in value adding and non-value adding activities (Terry and Smith 2011; Sarhan and Fox 2013). In this respect, Lean production and construction introduce eight types of waste, namely the "transportation, inventory, motion, waiting, over-production, over-processing, defects, and skills misuse" respectively (Terry and Smith 2011; Sarhan and Fox 2013).

The use of Lean thinking in construction projects has already proven its benefits. These benefits include but are not limited to productivity improvement, increased reliability, quality improvement, increased customer satisfaction, realistic schedules and reduced durations, less waste, and design as well as safety improvements (Mossman 2009). However, industry practitioners still find Lean implementation challenging due to lack of information related to Lean principles. This proves that there are certain barriers in adopting Lean concepts and successfully apply them (Mossman 2009, Sarhan and Fox 2013). Several other studies also pointed out that Lean implementation is challenging for the construction industry (Ayarkwa et al. 2012, Wandahl 2014). Therefore, this paper aims to reveal barriers of Lean construction implementation in order to provide a set of core barriers that industry practitioners should investigate for getting the maximum benefit from applying Lean practices.

BARRIERS OF LEAN IMPLEMENTATION

Several studies identified a set of barriers in Lean implementation generally focusing on a specific region. For example, Devaki and Jayanthi (2014) studied the barriers of Lean implementation in the Indian construction industry and identified 11 barriers, some of which are "lack of exposure regarding the need for Lean construction", "uncertainty in the supply chain", and "the tendency to apply traditional management methods". Similarly, Ayarkwa et al. (2012) studied the barriers existing in the Ghanaian construction industry and listed “fragmented nature of the industry”, “extensive use of subcontractors”, “lack of long-term relationship with subcontractors” as the top ranked barriers. Sarhan and Fox (2013) identified “fragmentation and subcontracting”, “procurement and contracts”, and “lack of adequate Lean awareness and understanding” as the key barriers in their study.

In this in-depth literature review, barriers of Lean implementation were identified and a total of thirty-two barriers were developed. To come up with valid barriers, several pilot studies were conducted. In these pilot studies, the barriers were discussed with three university professors and four industry practitioners and some of the barriers were revised to best reflect their corresponding factors. After careful consideration of barriers, some of the barriers were either synthesized or removed where necessary. For example, lack of information sharing and integrated change control were mostly listed as two separate barriers in Okere’s (2017) study. However, these two barriers are strongly interrelated with managing uncertainties and changes. Hence, the study evaluated these two as one barrier. A similar approach was adopted for the remaining barriers. The barriers were carefully determined considering most up-to-date data in construction projects. Moreover, barriers were grouped with a systematic approach called PEST. With the PEST analysis, influencing factors on an organization were systematically structured. PEST is an acronym for ‘political’, ‘economical’, ‘socio-cultural’ and ‘technological’ (Steinmann and Schreyögg 2006).

Based on this model and the literature study, twenty-seven barriers were identified for Lean implementation. The factor groups and the respective barriers are shown in Figure 1. These barriers are identified as the key barriers causing challenges in Lean implementation in construction projects. As seen in Figure 1 most of the detected barriers can be found in the socio-cultural area consisting of the managerial, cultural, communication and workforce barriers. The definition of each barrier along with the evidence from literature is presented in the following.

Political Barriers

Stringent requirements and approvals: Information flow and procedural documents might take time and lead to deficiencies in Lean processes. This makes governmental organizations hesitant about the benefits and applications of Lean practices. Hence, stringent requirements and approvals might be a burden for governmental organizations (Shang and Pheng 2014, Almanei et al. 2017).

Lack of knowledge in Lean: The Lean philosophy is still not yet entirely understood by most of governmental authorities, so benefits are not conceived in turn. This might negatively affect investment decisions in construction projects, where Lean practices are planned to be applied (Sarhan and Fox 2013).

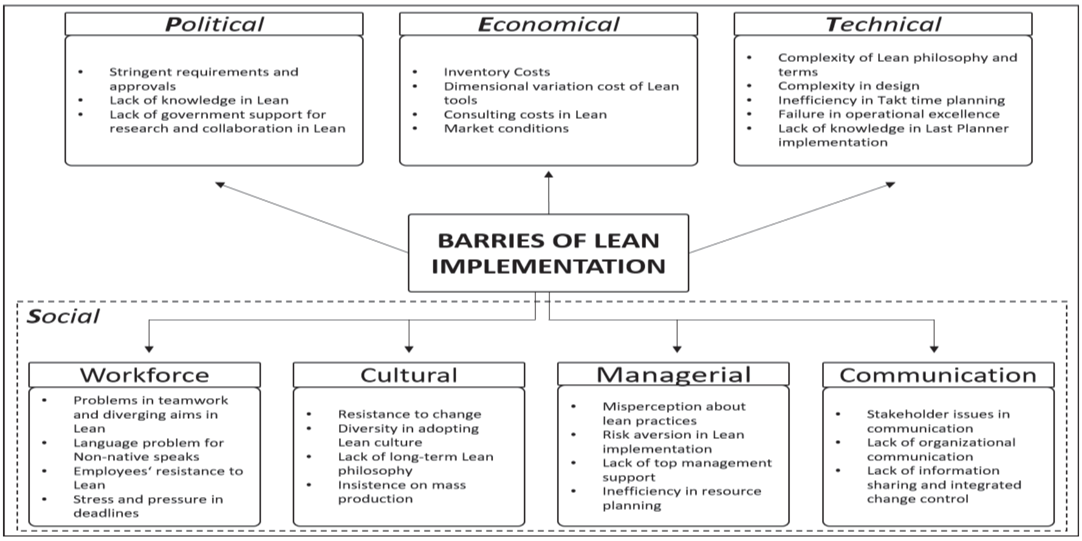


Figure 1. Barriers of Lean Implementation

Lack of government support for research and collaboration in Lean: Limited funding opportunities for research and collaboration in Lean practices lead to a narrower spectrum of Lean activities and scarcity of project specific applications of Lean (Shang and Pheng 2014).

Economical Barriers

Inventory costs: Inventory costs refer to the cost of storing the inventory. Often the inventory is calculated based on predictions and compensates uncertainties. The bullwhip effect even increases inventories. High inventories lead to slower processes in Lean implementation negating Lean activities (Kumar 2013, Jadhav et al. 2014, Almanei et al. 2017). Pulling (according to the Lean philosophy) the materials and information to the next work step allows the reduction of the inventory but requires a higher flexibility in the whole value chain.

Dimensional variation cost of Lean tools: Some Lean tools and methods lead to design variations resulting in extra cost. This might trigger the reluctance in implementing Lean tools (Kumar 2013, Jadhav et al. 2014).

Consulting costs in Lean: Consulting costs sometimes appear as financial burden for Lean implementation in construction projects, especially in smaller construction projects. This might lead to lower efficiency in implementation processes (Sarhan and Fox 2013, Ogunbiyi 2014).

Market conditions: Lean implementation brings the need to clarify objectives in terms of successful project execution and thus a stable construction process is sought. However, fluctuations in market conditions demand a constant flexibility of all involved companies. A communication structure supporting stability as well as flexibility in all processes is difficult to set up for companies implementing Lean construction the first time. This has potential to negate firms' willingness towards applying Lean practices and achieving excellence in their projects (Aziz and Hafez 2013, Sarhan and Fox 2013, Jadhav et al. 2014, Okere 2017).

Workforce Barriers

Problems in teamwork and diverging aims in Lean: Lack of coordination and collaboration among team members might be observed when there are diverging aims within the firm. This results in inefficient processes in Lean practices (Aziz and Hafez 2013, Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav et al. 2014).

Language problem for non-native speakers: Language is a barrier for most of the construction workers. This makes e.g. some safety tips difficult to understand and results in lower safety performance (Demirkesen and Arditi 2015). Educating construction workers about language barriers and providing some tips might lead to enhanced Lean performance. Thus, firms might develop ways to integrate non-native speakers in Lean processes to overcome this barrier (Jadhav et al. 2014).

Employees' resistance to Lean: Employees might resist to changes and this leads to inefficient performance in Lean practices. Some lean tools such as poka yoke devices or Kanban cards might be of interest to employees for the fact that they are not beware of benefits of using these tools. Thus, resistance to change is a major barrier for firms aiming to enhance Lean implementation performance (Aziz and Hafez 2013, Jadhav et al. 2014).

Stress and pressure in deadlines: Struggling with deadlines might create stress and pressure for construction workers. This might lead to wrong or missing practices in Lean (Aziz and Hafez 2013, Sarhan and Fox 2013, Howell et al. 2017).

Cultural Barriers

Resistance to change: Lean is a relatively new concept in the construction industry and this makes Lean adoption lower than expected by the industry practitioners. This also leads to lack of knowledge about the benefits of using Lean practices. Therefore, employees develop resistance to change for the fact that they are either unfamiliar with the Lean tools or its benefits. A company and project culture that is open for changes is required in order to lead all employees in the Lean transformation process. The resistance to change stems generally from the cultural background and is therefore listed as a major cultural barrier (Kumar 2013, Sarhan and Fox 2013, Jadhav et al. 2014, Ogunbiyi 2014, Shang and Pheng 2014, Almanei 2017).

Diversity in adopting Lean culture: Diversity in cultural background generally leads to different learning curves for differing groups. This leads to different levels of knowledge about Lean practices. Some construction workers have a hard time to adopt a Lean culture due to their diverse backgrounds and therefore they prefer to apply the conventional working practices they are familiar with. Therefore, diversity might appear as a cultural barrier for Lean implementation (Jadhav et al. 2014, Almanei et al. 2017).

Lack of long-term Lean philosophy: The adoption of the Lean philosophy is difficult for industry practitioners due to the dynamic nature of the construction industry. Industry practitioners mistrust the benefits that they will get by the use of Lean tools and this makes Lean implementation rare due to challenges with time and budget (Ogunbiyi 2014, Shang and Pheng 2014).

Insistence on mass production: Mass production is affected by its repetitiveness. Here, nearly automatically, a "Lean" structure is built in the project-planning phase and a Lean implementation seems obvious (Demirkesen and Tommelein 2016). In contrast, most of the construction projects are unique and complex. Therefore, the rules of mass production cannot be applied easily. This reluctance towards Lean implementation is embedded in a firm's culture.

Managerial Barriers

Misperception about Lean practices: There is a common perception that Lean practices are costly to apply. This makes firms reluctant towards adopting the Lean way considering that the practices also require special expertise (Jadhav et al. 2014, Almanei et al. 2017).

Risk aversion in Lean implementation: Firms might have concerns in terms of investing in Lean applications, which might be in a transparent and pre-aligned form due to uncertainties in construction projects. This might stem from the fact that benefits of Lean are not well understood by the majority of firms (Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav et al. 2014, Almanei et al. 2017).

Lack of top management support: Top management's support for Lean practices is of utmost importance in terms of successful application of Lean in construction projects. When top management is reluctant towards adopting Lean thinking, some deficiencies might arise in Lean implementation (Kumar 2013, Sarhan and Fox 2013, Ogunbiyi 2014, Shang and Pheng 2014, Jadhav et al. 2014, Almanei et al. 2017, Okere 2017).

Inefficiency in resource planning: Inefficient planning of resources has the potential to generate waste and negatively impact Lean practices. Therefore, resource planning takes an important part in the successful management of Lean activities. When managed inefficiently, resource planning acts as a barrier for Lean implementation from a managerial perspective (Jadhav et al. 2014, Demirkesen and Tommelein, 2016).

Communication Barriers

Stakeholder issues in communication: Stakeholder engagement is crucial for the success of construction projects. Failure to engage stakeholders in project processes might lead to ineffective communication resulting in lower Lean performance (Sarhan and Fox 2013, Jadhav et al. 2014, Shang and Pheng 2014, Okere 2017).

Lack of organizational communication: Organizational communication is an effective way to circulate Lean concepts and terms. Lack of organizational communication leads to lower performance in Lean implementation (Salem et al. 2005, Kumar 2013, Jadhav et al. 2014, Ogunbiyi 2014, Howell et al. 2017, Okere 2017).

Lack of information sharing and integrated change control: Managing uncertainties and changes in the project are only possible with effective communication channels and lack of information sharing can break the Lean learning chain resulting in defective processes (Okere 2017, Howell et al. 2017).

Technical Barriers

Complexity of Lean philosophy and terms: There is still lack of understanding in Lean construction terms and philosophy. A common understanding of concepts to better practice

Lean and perform more effectively in construction projects is needed. Hence, firms might need to remove this barrier in order to experience higher rates of performance in Lean projects (Salem et al. 2005, Kumar 2013, Sarhan and Fox 2013, Shang and Pheng 2014, Jadhav et al. 2014, Ogunbiyi 2014).

Complexity in design: Designing for Lean and safe operations is more challenging than traditional methods and this might lead to complexity in design, which makes design a barrier for Lean projects (Aziz and Hafez 2013, Sarhan and Fox 2013). Nevertheless, it has to be considered, that higher effort in design due to Lean practices results into stable working processes on site since design and processes are accordingly aligned from the beginning.

Inefficiency in Takt time planning: Multiple stakeholders and numerous interfaces might lead to poor planning in terms of Takt time. This negates Lean activities for the project and appears as a barrier for construction operations (Sundar et al. 2014).

Failure in operational excellence: Operational excellence is one of the objectives of Lean practices. Failure in operational excellence is likely to yield deficiencies in Lean processes. Therefore, it is considered as a technical barrier that firms need to address to better perform in Lean implementation (Salem et al. 2005, Sarhan and Fox 2013).

Lack of knowledge in Last Planner implementation: Last planner is a critical tool of Lean construction and failure to apply Last planner leads to unsuccessful operations in Lean implementation. Thus, it is listed as one of the technical barriers that firms need to consider aiming to achieve higher performance in Lean implementation (Aziz and Hafez 2013, Salem et al. 2005).

SURVEY FINDINGS AND DISCUSSION

As stated above a survey was conducted to understand the relevance of the barriers to Lean Implementation in construction. The survey was administered to large-scale engineering, construction and architectural firms in the U.S. The respondents were requested to rank Lean implementation barriers using a 1–5 point Likert scale (1 = very low, 2 = low, 3 = medium, 4 = high and 5 = very high). The survey was sent out to 205 corporate members of the LCI. A total of 72 out of 205 surveys were returned, representing a response rate of 35%. To increase the response rate, some of the respondents were either called or invited for online meetings for the further explanation of the survey content. The response rate must have been a little higher but some of the e-mail addresses or contact information of respondents were either outdated or incorrect reducing the sample size less than 205. There are also research studies conducted with lower response rate but with valid justifications (Habermann et al. 2015). Hence, 35% response rate is considered as a valid rate for evaluating survey data.

Table 1 presents the respondent profile. According to Table 1, it is shown that average years of experience of the companies in the construction industry is 42 years, whereas average years of experience in Lean implementation is 13, and the average number of employees of the respondents is 282.

Table 1. Respondent Profile

	Average	Median	Maximum	Minimum
Years of Experience in the Construction Industry	42	48	125	12
Years of experience in Lean implementation	13	17	20	3
Number of Employees	282	38	10000	2

Table 2 presents the results for the ranking of barriers for Lean implementation by Lean practitioners. According to Table 2, it is shown that "Lack of top management support" was rated as the top barrier (mean: 4.61). Secondly, "Misperception about Lean practices" and "Lack of information sharing and integrated change control" were rated as the following top barriers with average ratings of "4.14" and "4.09", respectively. "Lack of government support for research and collaboration in Lean" (mean: 3.04) and "Language problem for non-native speakers" (mean: 3.30) were rated as moderately important in terms of affecting Lean implementation.

Table 2. Ranking of Barriers for Lean Implementation

• **Barrier**	• **Mean**	• **Rank**
Lack of top management support	• 4.61	• 1
Misperception about Lean practices	• 4.14	• 2
Lack of information sharing and integrated change control	• 4.09	• 3
Stakeholder issues in communication	• 4.04	• 4
Inefficiency in resource planning	• 4.00	• 5
Failure in operational excellence	4.00	6
• **Barrier**	• **Mean**	• **Rank**
Lack of organizational communication	4.00	7
Employees' resistance to Lean	3.96	8
Resistance to change	3.96	9
Problems in teamwork and diverging aims in Lean	3.91	10
Diversity in adopting Lean culture	3.91	11
Lack of knowledge in Lean	3.83	12
Inventory costs	3.74	13
Lack of long-term Lean philosophy	3.67	14
Market conditions	3.65	15
Stress and pressure in deadlines	3.65	16
Complexity of Lean philosophy and terms	3.64	17
Risk aversion in Lean implementation	3.61	18
Complexity in design	3.57	19

Inefficiency in Takt time planning	3.57	20
Stringent requirement and approvals	3.57	21
Dimensional variation cost of Lean tools	3.52	22
Lack of knowledge in Last Planner implementation	3.52	23
Insistence on mass production	3.52	24
Consulting costs in Lean	3.43	25
Language problem for non-native speakers	3.30	26
Lack of government support for research and collaboration in Lean	3.04	27

As survey findings indicated lack of top management was previously listed as a major barrier by several researchers (Jadhav et al. 2014, Almanei et al. 2017, Okere 2017). This proves the importance of top management support in conducting an efficient Lean implementation program. When top management is involved in the processes of Lean, implementation becomes smoother and more transparent leading to higher efficiency in processes. The survey findings also implied that misperception about Lean practices is a major barrier for construction firms in implementing Lean. This proves that the benefits of implementing Lean has not yet well understood by the majority of construction professionals. This might stem from the fact that Lean implementation is thought to be costly and require special expertise for practicing efficiently (Jadhav et al. 2014, Almanei et al. 2017). Lack of information sharing and control was also listed among top barriers of Lean implementation by the survey respondents. This finding is in line with the statement that uncertainties and changes in the project might be handled with effective communication channels and lack of information sharing might lead to defective processes in Lean implementation (Howell et al. 2017).

CONCLUSION

Lean implementation is a relatively new practice in the construction industry. Therefore, certain concerns emerge for those, who aim to implement Lean in their projects. This study focuses on determining the barriers hindering a successful Lean implementation. In this respect, an in-depth literature review was assessed to reveal the barriers of Lean implementation in the construction industry. Then, an online questionnaire was sent out to members of the LCI for ranking the barriers based on a Likert scale. The questionnaire results indicated that most important barriers can be found in the socio-cultural background. The top three listed barriers are: ‘Lack of top management support’, ‘misperception about Lean practices’, ‘lack of information sharing and integrated change control’. The study is expected to provide a roadmap for construction practitioners to best practice Lean concepts.

ACKNOWLEDGMENTS

The authors would like to thank the members of Lean Construction Institute (LCI), who took time responding the online questionnaire.

REFERENCES

Almanei, M., Salonitis, K., and Xu, Y. (2017). "Lean implementation frameworks: the challenges for SMEs." *Procedia CIRP*, 63, 750-755.

Ayarkwa, J., Agyekum, K., Adinyira, E., and Osei-Asibey, D. (2012). "Barriers to successful implementation of lean construction in the ghanaian building industry." *Journal of Construction* < http://dspace.knust.edu.gh/bitstream/123456789/10837/1/BARRIERS%20TO%20SUCCESSFUL%20IMPLEMENTATION%20OF%20LEAN%20CONST..pdf> (Jan 14, 2019).

Aziz, R.F., Hafez, S.M. (2013). "Applying lean thinking in construction and performance improvement," *Alexandria Engineering Journal*, 52(4), 679–695.

Ballard, G., Howell, G. (2004). "Competing Construction Paradigms." *Lean Construction Journal*, 1(1), 38-45.

Demirkesen, S., and Arditi, D. (2015). "Construction safety personnel's perceptions of safety training practices." *International Journal of Project Management*, 33(5), 1160-1169.

Demirkesen, S., and Tommelein, I. D. (2016). "Lean Management Methods for Design and Construction : Built-in-Quality and Safety-by-Design", *In Proceedings of Advances in Civil Engineering Conference (ACE2016)*, Istanbul, Turkey.

Devaki, M. P., and Jayanthi, R. (2014). "Barriers to implementation of lean principles in the Indian construction industry." *International Journal of Engineering Research & Technology*, 3(5), 1189-1192.

Habermann, M., Blackhurst, J., and Metcalf, A. Y. (2015). "Keep your friends close? Supply chain design and disruption risk. " Decision *Sciences*, 46(3), 491-526.

Howell G., Ballard G., and Demirkesen S. (2017). "Why Lean Projects Are Safer", *In LC3 2017: Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC)*, Crete, Greece.

Jadhav, J., Mantha, S., and Rane, S. (2014). "Exploring barriers in lean implementation." *International Journal of Lean Six Sigma*, *5*(2), 122-148.

Koskela, L. (1992). "Application of the new production philosophy to construction", *Technical report No. 72*, Centre for Integrated Facility Engineering, Stanford University, CA.

Krafcik, J. F. (1988). "Triumph of the lean production system." *MIT Sloan Management Review*, 30(1), 41.

Kumar S. (2013). "Enablers of Lean Six Sigma Implementation in Business Environment : A Review" In *Proceedings of International Conference on Smart Technologies for Mechanical Engineering*, 409–417, Delhi Technological University, New Delhi, India.

Lean Construction Institute (LCI) (2004). "What is Lean Construction?" <http://www.leanuk.leanconstruction.org/whatis.htm> (Feb 24, 2018).

Liker, J. K., and Convis, G. L. (2012). *The Toyota way to lean leadership*. McGraw-Hill, New York.

Meadows, D. (2011). "Designing out Waste." *Environmental Design and Construction Magazine*, <http://www.modular.org/marketing/documents/DesigningoutWaste_EDC.pdf> (June 3, 2017).

Mossman, A. (2009). “Why Isn't the UK Construction Industry Going Lean with Gusto?.” *Lean Construction Journal,* 5(1) 24-36.

Ogunbiyi, O. (2014). “Implementation of the Lean Approach in Sustainable Construction : A Conceptual Framework”, *PhD Diss.*, University of Cental Lancashire, Lancashire, UK.

Okere, G. O. (2017). “Barriers and enablers of effective knowledge management: A case in the construction sector.” *Electronic Journal of Knowledge Management*, *15*(2), 85.

Porter, M. (1985). *Competitive Advantage.* The Free Press, New York, NY.

Salem, O., Solomon, J., Genaidy, A. and Minkarah, I. (2006). “Lean construction: from theory to implementation.” *Journal of Management in Engineering*, 22(4), 168-175.

Sarhan S., and Fox, A.(2013). “Barriers to Implementing Lean Construction in the UK Construction Industry.” *Built Hum. Environ. Rev.*, 6, 1–17.

Steinmann, H., and Schreyögg, G. (2006). Management: Grundlagen der Unternehmensführung. 6th edition, Wiesbaden.

Sundar, R., Balaji, A. N., and Kumar, R. S. (2014). “A review on lean manufacturing implementation techniques.” *Procedia Engineering,* 97, 1875-1885.

Wandahl, S. (2014). Lean construction with or without lean–challenges of implementing lean construction. In *Proceedings of the 22nd Annual Conference of the International Group for Lean Construction* (97-108). Oslo, Norway.

Womack, J. P., Womack, J. P., Jones, D. T., and Roos, D. (1990). *Machine that changed the world.* Simon and Schuster Inc., New York, NY.

Womack, J. P., and Jones, D. T. (1996). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Simon & Schuster Inc., New York, NY.

Hackler, C., Byse, E., Alves, T.C.L., and Reed, D. (2019). "Building a Lean Culture: Engaging the Value Stream." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 169–178. DOI: https://doi.org/10.24928/2019/0169. Available at: <www.iglc.net>.

BUILDING A LEAN CULTURE: ENGAGING THE VALUE STREAM

Cory Hackler[1], Erika Byse[2], Thais da C. L. Alves[3], and Dean Reed[4]

ABSTRACT

This paper presents an analysis of a Lean Leadership (LL) training program initiated by the company about three years ago. The program's main goal is to disseminate Lean throughout the company, which has been using Lean principles in its projects for about twenty years. So far, the LL program has reached over four hundred participants. Over the last year, the program included participants from the company's extended value stream. Participants include project teams and the company's strategic partners for prefabrication, equipment rental, and VDC/Project Controls support services. As part of the program, authors one and two visited participants to understand how they are applying lean leadership principles. This paper, the third in the series of building a Lean culture, shares success stories on how organizations in the company's value stream applied LL knowledge to their business including value stream mapping, Plan-Do-Check-Act (PDCA), go and see, and effective meetings. It also presents how these teams will continue their LL training to further build a Lean culture which the company can learn from its strategic partners while driving home a common purpose.

KEYWORDS

Lean leadership, training, lean journey, change.

INTRODUCTION

A value stream can be defined as the combination of all value adding, non-value adding, and supporting activities necessary to deliver a product or service (Rother and Shook 1998). These activities are performed by multiple organizations, with different attributions, cultures, and values, in geographically dispersed supply chains. Faced with this reality, general contractors constantly work to align their project partners towards delivering value to clients. However, while project partnering sessions, design charrettes, and collaborative contracts, to name a few, support this endeavour, little is done to imprint long lasting changes on the way extended value streams work to deliver construction projects.

This paper presents an analysis of a current effort by a construction company to align its personnel regarding the use of Lean through the development of a Lean Leadership training

[1] DPR Construction, 1450 Veterans Boulevard, Redwood City, CA. CoryHa@dpr.com

[2] DPR Construction, 222 N. 44th Street, Phoenix, Arizona 85034, ErikaB@dpr.com

[3] Associate Professor, J.R. Filanc Construction Engineering and Management Program, Dept. of Civil, Constr., and Env. Engineering, San Diego State University, USA, talves@sdsu.edu

[4] DPR Construction, 1450 Veterans Boulevard, Redwood City, CA. DeanR@dpr.com

program. The program was first discussed in a previous IGLC paper (Hackler et al. 2017), which explained the initial steps the company took in their journey to develop Lean leaders. The second paper focuses mainly on some lessons learned from the program, what participants seem to value in the training program, what can be improved in the future (Hackler et al. 2018). This paper focuses on extending the program to the value stream and the conclusion will address how to accelerate and measure the success including whole life integration.

LEAN THINKING AND VALUE STREAMS

The discussion about integrating construction supply chains and their related value streams took place in Lean Construction literature during the early 2000s with great intensity. Ballard and Howell (2003) outlined the different stages of the Lean Project Delivery System (LPDS) and highlighted the need to have them intersect with their immediate link; for instance, project definition decisions should intersect with the design process, which should overlap with the supply effort, which in turn should intersect with assembly, and that with the use phase. Along these lines, Tommelein et al. (2003) studied different supply chains and used value stream mapping to outline how construction supply chains work and how they can be made more efficient to deliver value.

Vrijhoef and Koskela (2000) defined the four roles of supply chain management in construction considering the following relationships between projects and their value streams: 1. Focus on the interface between the project and the supply chain; 2. Focus exclusively on the supply chain; 3. Transfer site activities to the supply chain (e.g., through prefabrication); and 4. Focus on the integrated relationship between the project and its supply chain.

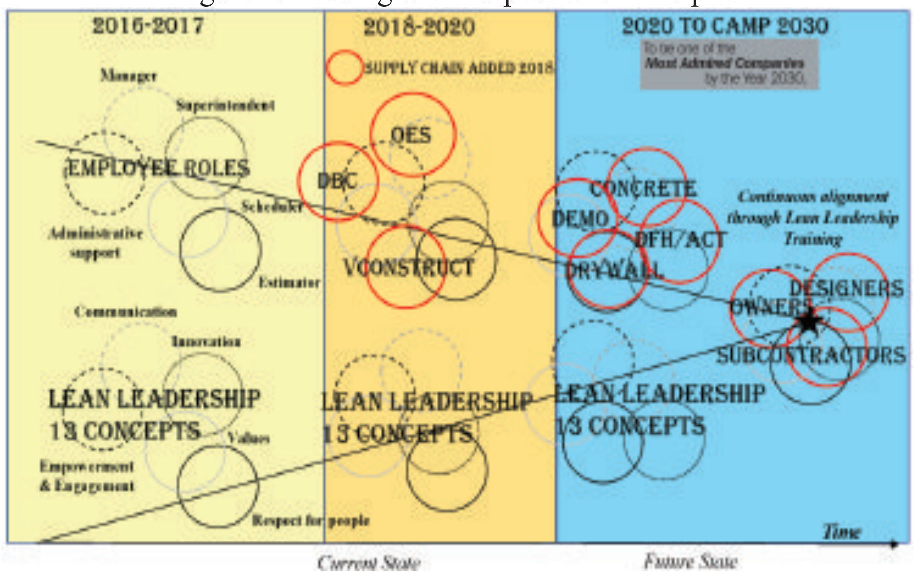
Alongside what is documented in the literature, the company is currently working to align its immediate project partners (Role 2) by using Lean principles and concepts outlined in the LPDS framework and supporting its partners to learn Lean and develop their own mapping and investigation efforts to better deliver value to its clients and stakeholders. The LL training supports these efforts, but it is not the only one currently being deployed at the company. Another concrete example, the company has been using to align its partners, focuses on delivering quality products by clearly defining a common language regarding what is expected from its value stream partners via Distinguishing Features of Work (DFOW), aligning the teams, agreeing on measurable criteria of acceptance, and verifying that the deliverables match the defined criteria (Spencley et al. 2018).

CURRENT STATE OF THE LEAN LEADERSHIP TRAINING

The cases presented in this paper are related to companies which are part of a California-based, top 50 United States-ranked general contractor's (GC) value stream. The GC currently has 26 offices in the United States, and three overseas. The GC started offering the LL training three years ago to its own personnel, and in the most recent edition in 2018, the course's ninety available seats filled up within twenty minutes, leaving an additional two hundred people on a wait list, and other business units are offering their own training, including the company's value stream partners. This demand serves as an indication of the

value of the LL training, and the need to align a rapidly growing company with its ever-growing network of partners. While the program started with the intention to train employees within the company to better manage their work, it has evolved into one of the most important steps in aligning the company's extended value stream. This is the background of the cases presented and how they are related to the GC's value stream.
The diagram shown in figure 1 introduced by the authors (Hackler et al. 2018), illustrates the idea that stakeholders, who continue to learn and are exposed to the company's shared goals, values, and beliefs, become more aligned and begin to improve performance, as well as meet customer goals. This idea is now being applied by the company, through involving its strategic partners in the LL program, with the intention of developing and sharing common team goals throughout their value streams.

Figure 1: Leading with Purpose and Principles



This paper presents four examples of value stream partners and their ability to apply LL concepts after taking the LL training. The stories address the journeys of the following:

1. A prefabrication company of exterior and interior walls that is less than four years old.
2. A Virtual Design and Construction (VDC) and Project Controls service company that has doubled their size in the last two years.
3. An equipment rental/supply company that has doubled their growth in the last three years.
4. A large IPD project in the Bay Area whose extended team took the LL training

RESEARCH APPROACH

The method used to gather data was to "go and see" the locations of the affiliated value stream and have lean leaders at each company visited show authors 1 and 2 what they implemented based on their lean leadership training. Others in the organization were also interviewed to see if the lean leadership behaviour changes were trickling throughout the organization.

The data collection happened longitudinally through interviews, observations, and conversations with leaders of the companies visited, in addition to pictures taken to document the practices/examples encountered. Common threads/questions during the interviews were related to: how the partner/s took the training, what they implemented from the training, and the results achieved. The observations of each case, in each of the four value stream partners described in this paper, are described in the following section drawing the reader's attention to important lessons learned from implementing concepts introduced during the LL Program, challenges faced, and specific examples captured during the visits.

FOUR STORIES OF THE VALUE STREAM PARTNERS

STORY 1: DIGITAL FABRICATION

A prefabrication company, which started in 2016, uses digital designs to prefabricate panelized structures and exterior and interior wall panels. They have recently added finished exterior wall assemblies and Mechanical Electrical and Plumbing (MEP) rough-in to prefabbed wall panels. The company, which has grown to over one hundred twenty people, is now providing panels to projects across the United States.

The rapid growth of this company fostered a community of learning with effective knowledge transfer and team collaboration, which led to a plant-wide training focused on Lean principles. In addition to the plant-wide training, the company's leadership group enrolled in an LL course to continue to strengthen their Lean culture. A recent graduate mentioned how the courses reset the effectiveness of company meetings by specifically focusing teams on action-oriented items. Another student, who works on the shop floor, observed how "go and see" helps create an organic interaction between the design team and fabrication staff.

During the site visit, attended by authors one and two, a discussion ensued between the Lean Integrator and students where students shared what Lean principles and tools were in place and what future Lean goals they had. They indicated the following:

- Weekly Lean learning takes place and future Lean leadership will take place.
- Visual management is in place throughout the shop including the tracking of defects and production as shown below. Soon, they expect that a new system will be on-line to provide daily production feedback for real-time adjustments. Figure 2a illustrates boards that the foreman uses to review visual metrics with their line workers each week to learn and improve.

Figure 2: (a) Visual management of production and defects; (b) Visual management of wall framing steps.

- Shop workers use a program called SmartSheet to see their workflow and production rates, which gives them real-time feedback. These activities originated from the plan developed in the scheduling software Primavera. The shop is now overlaying multiple projects in their schedule to see workflow stacking to level out production. The schedule is resource-loaded to manage *mura* (un-unevenness) and *muri* (overburden) in regards to the multiple projects fabricated in the shop.
- Fabrication lines are arranged for the best flow of material, including the panels to complete and those to be loaded onto a truck. Lines are also arranged by wall or floor type.

This rapidly growing company is using Lean principles to solve challenges they are facing, including:

- Accept the current state as bad as it may be. For example, the model often needs more work to digitally fabricate from. The company is educating its customers that the earlier they start with the model, the smoother the process will go.
- Aligning project team schedule adjustments with the fab shop to avoid double handling. A new role of Integration Manager has been added to stabilize this process.
- The Integration Manager will also help educate the preconstruction teams to understand site logistics and key installation factors to price the plan accurately.
- Truck availability and accuracy of orders delivered to site to avoid double handling. Working with key truckers and educating them is the goal.

As the Lean Integrator said, "*Everyone must understand the vision of where we are going. I think that vision is ever forward and found in Lean principles*." In addition to addressing the challenges presented above, the Integration Manager also assists with breaking down silos across all projects. For example, rethinking how teams build the project including installation methods, earlier buyout and procurement, and more upfront design and modelling to deliver a faster schedule with higher quality at the best overall cost, as it is discussed in case 4. The ability to see the entire value stream throughout projects and how one step of the process affects the next is closely related to what Ballard and Howell (2003) define as the Lean Project Delivery System (LPDS). Specifically, the ability to jointly analyze product and process options puts in practice another important piece of the LPDS: work structuring, which addresses project definition, Lean Design, Lean Supply, and Lean assembly.

STORY 2: VDC & PROJECT CONTROLS

Company leaders realized that project teams had been staffed mostly with people new to the company and that the transfer of knowledge and culture had been difficult due to their rapid growth. The leaders created the vision of a strategic partner that could help support projects from Virtual Design and Construction to Project Controls. This new company started five years ago and now has over one hundred forty people. The company is like a "Big Room" because they focus day in and day out on certain tasks and guide projects scattered across the world to use best practices and improve them. Examples of standard processes that they apply to multiple projects includes modelling, slip sheeting (i.e., updating construction documents according to the latest revisions), RFI management, submittal registers creation, and change order administration.

A few of the strategic partner employees, who participated in the LL training last year, recommended the course to others. The course is structured in a way that encourages project teams to uncover more about each other in a professional capacity and the challenges they face within their workplace. During the Leader Standard Work lesson (i.e., turning non-routine work and non-value-creating wrok into value-creating routing work, etc.), another student shared a visual on how they track time per project and task. The visuals and weekly review result in team utilization improvement by ten percent. This process thinking approach helps the teams think of new ways to track production while also making their project teams more efficient. These successes have led the company to enrolling thirty people in the LL training in 2019.

Some of the challenges that this strategic partner is currently facing includes:

- Working with GC teams to create processes to successfully guide employees, management systems, and work flow, including digital slip sheeting, RFI's, change orders, and VDC.
- Coordination and communication issues due to the remote location of the strategic team.

The common language and training that LL offers speeds up alignment, bringing about process improvements. As a result, the integration occurring between the GC team and the strategic partner creates a baseline of standard procedures that are used on multiple projects across the country. They have determined this to be the most successful model to accelerate knowledge transfer on standard procedures and improve them.

STORY 3: EQUIPMENT RENTAL AND SUPPLIES

This retail company is one of the industry leaders in providing equipment and supplies for construction job sites throughout the United States. In the last five years, they have doubled in size and now have eighteen locations throughout the United States.

A few employees new to the company recently completed the LL training in order to better integrate into the company's culture. During the value stream mapping lesson, a student decided to undertake an analysis of the invoicing process and found that half of the process

steps are waste. After the class, she re-evaluated the billing process and streamlined the steps by reducing invoicing time from three weeks to less than one week, eliminating many unnecessary steps. This also led to an increased cash flow as the cycle time was reduced from three to one.
During a site visit carried out by the first author, the students shared the progress of the Lean implementation that has taken place since the course:

- Visual management of orders that need to be filled each day. Added visual labels of all stock.
- Colour coding system ensuring equipment is ready to be procured (Figure 3).

Figure 3: Equipment Rental Quality Control

During the training, the students who were new to the company began to see improvement opportunities based on the course content; some of which were implemented immediately and others which will be implemented in 2019. Additionally, the company's goal is to have every manager complete the course; this way everyone will understand the basics of Lean principles and how they can be applied in their work environment. Moreover, the team has become even more customer focused by working with project teams to determine what improvements need to be made. The GC is working to further their relationship with the retail company by purchasing big margin products to add value. In turn, the retail company can assist the GC with order efficiency and planning.

Story 4: Large Construction Project

The GC won a project to build a multi-use research facility using IPD delivery for a repeat customer. The owner, a sophisticated Lean advocate, wanted the team aligned around Lean principles. Furthermore, the project team leader considered study action groups and the reading of *The Toyota Way* to learn about and apply Lean principles. The first author suggested that the team enroll in the LL training instead of the study action groups. This was the first time an entire project team (i.e., contractor, key trade partners, owner, design team) enrolled in the course at the same time.
The class began with an overview of traditional thinking versus Lean thinking. Over the next nine weeks, the group also discussed thirteen lean principles and closed out with how to advocate lean thinking and mitigate resistance. Once the group completed the course, they discussed how and what to implement in their own project. The team's first step was to align everyone around a mission, vision, values, and operating principles, which gave participants a reference for how to operate within the big room environment set up for the

project. Transitioning from design to construction, the team went into action using the idea of visual controls to better organize the team and problem solve. Some of the visual controls implemented included:

- A project website to share information in real-time. Project Cluster boards with team photos, goals for the week, and constraints. Eventually, these items migrated to online tools.
- BIM 360 Plan was used with the field crews to visually create and see the plan. The software also captures commitments to track Plan Percent Complete and reasons why activities were not complete. This real-time sharing of the plan and score were available for everyone to see, promoting a fly-wheel effect to propel the team to continuously improve their tasks.
- Dashboards of metrics like staff forecast and Request for Information (RFI) review time. Takt Planning for visual flow through the structure was implemented (Figure 5).

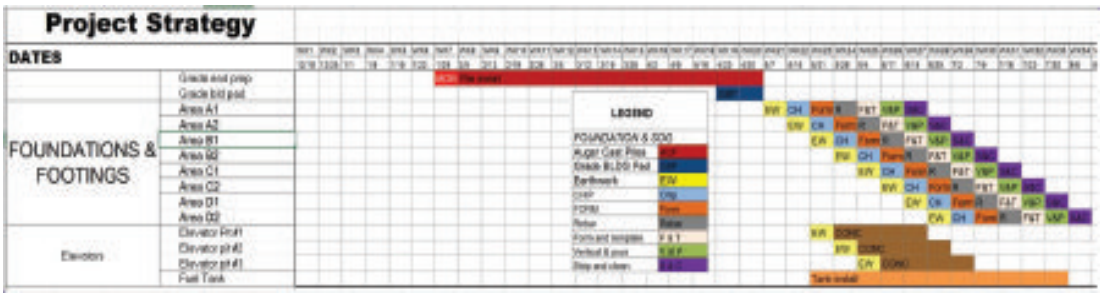


Figure 5: Takt Planning for Foundations

In addition, respect amongst employees drastically increased throughout this process. Rather than assume they knew what improvements were needed, management went directly to the field to discuss problems and possible solutions with the workers. Additionally, a scorecard was issued monthly to the extended team to allow them to grade key performance indicators (KPIs) and key behaviour indicators (KBIs). A KPI example is how often RFIs are answered on time while a KBI question is ‘are you enjoying coming to work?’ The GC often tracks KPIs but loses track of behaviours indicators in the process. When these indicators are grouped together, they address both performance and behavioural questions; the team then highlights the Lean principle ‘respect for people’. Each month, the feedback received was analysed; typically, two to three themes, issues that needed attention, would become obvious. Once a theme was identified, it was sent out to the group to become the focus for the month. With a staff of around one hundred people, this communication became vital in creating a healthy environment.

Another major change for the project team was to implement prefabrication of all interior walls. They engaged the MEP and prefabricator early in the big room to coordinate their work together months before construction in the field would begin. This forced the coordination team to think differently, as they quickly realized that what worked in the past was not going to work on this project. The team decided that the most efficient installation would be to build partial height walls with posts rather than full height walls everywhere.

This was reviewed with the design team and owner, who approved this solution, resulting in both cost and time savings.
The training inspired behaviour changes from the owner all the way to the employees in the field. For example, the design team tracked commitments and decisions that were needed to continue the value stream of design. The owner was more aware of the decisions that needed to be made and therefore, made them in a timely fashion. This enabled the project to stay on track. The KPI Scorecard allowed the team to make necessary changes, such as how to run effective meetings, and shed light on their commitment to work together to resolve issues. Tools such as KPIs encourage employees to drive changes and address the social needs of the team.

DISCUSSION AND FUTURE WORK

Since the piloting of the program in 2015, the Lean Leadership Course has continued to grow and gain momentum. After only three years, the national training gained such recognition that instructors were asked to offer a specific course to regional offices. This particular class, which began in 2018, was and is supported by management, which enables even more employees to buy in and graduate. Instructors have even noticed a drastic increase in graduation numbers within the regional course, as the national classes sometimes experience a ten to twenty percent dropout rate. Additionally, three other regional groups are starting in 2019, including one from another strategic partner. The national group check-ins are all done via web meetings, while the specific regional groups are launched and concluded with a face-to-face meeting. This allows for a better connection between instructor and students, as it encourages better conversations from the start.
The instructors recognize the importance of continuing to evolve the course to better fit the needs of their students. As a result, they recently incorporated study action teams, which allows the students to reflect and participate in more meaningful discussions about the content. The 'training and apply your learning' method gives students a common language to use when problem solving, no matter their role or experience within the company. The instructors are also using the concept of train the trainers (multipliers). This has resulted in local graduates who are now teaching the LL course to additional business units, further tailoring the course content to meet the needs of the specific region. In turn, the new instructors become much more versed in the topics of LL.
Another Lean improvement is providing all the classes with a virtual classroom to collaborate, communicate, and coordinate with one another as well as the course content in between call-ins. The instructors found that e-mails often waste time, while virtual classroom technology allows students to maintain a running dialogue; one that is read and embellished upon at a much faster rate and in a more convenient forum. This also allows students to apply the concept of 'leader standard work' and utilize check-ins to ensure their group is keeping up with assignments. In addition, the digital classroom also allows students to hold each other accountable and become responsible for their own learning, i.e. teachers as well as learners. Undoubtedly, this creates a much more powerful learning experience, as they are able to reach out to one another for questions and comments, as well as the instructors.

CONCLUSIONS

Adding the company's strategic partners to the LL training has helped people bond together around one common goal. Participants of the LL training are being given the opportunity to see the world through lean lenses. The training enables employees, in different business units, to recognize the company's shared vision and work together to achieve it. As evidenced in the stories presented, the training also provided students with the knowledge necessary to analyse, question, collaborate, and redesign their processes to improve flow of information and work through the entire value stream. These partners are writing their own story on how they are using the LL training to improve their businesses.

Moving forward, the company expects to: keep expanding opportunities for other partners in its extended value stream to participate in the LL training; align the partners and promote behaviours that can be easily replicated which improve quality, schedule, cost, and safety throughout the value stream; promote transparency by breaking down silo behaviours and sharing KPIs and KBIs to drive improvements and respect for the individual. These expectations represent additional opportunities to conduct research and identify specific KPIs and KBIs that will allow the company to evaluate how the changes are supporting its goals. Also, research on construction supply chains can be conducted to benchmark what specific actions deployed by these GC can be transferred to other construction organizations. Conclusions are limited to the value stream of this North American GC and the fact that the GC has a stake in these value stream partners.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of those who have participated in the training and helped redefine this journey. The views, comments, and opinions expressed in this paper are those of the authors and do not represent those of the company.

REFERENCES

Ballard, G. and Howell, G. (2003). Lean project management. *Building Research & Information*. 31(2), 119-133.

Hackler C., Byse E., Reed D., and Alves, T.C.L. (2017). "Building a Lean Culture" In: LC3 2017 Volume II – *Proc. of the 25th IGLC*, Heraklion, Greece, 309-316.

Hackler C., Byse E., Alves, T.C.L., Reed D., (2018). "Lean Leadership training: lessons from a learner-centered analysis" In: *Proc. of the 26th IGLC*, Chennai, India, 484-494.

Rother, M. and Shook, J. (1998). *Learning to See: Value Stream Mapping to Create Value and Eliminate Muda.* Brookline, MA: Lean Enterprise Institute. 96pp.

Spencley, R., Pfeffer, G., Gordon, E., Hain, F., Reed, D., and Marosszeky, M. (2018). "Behavior-Based Quality Closing the Knowing Doing Gap." In: *Proc. 26th IGLC*, Chennai, India. 1170-1181

Tommelein, I.D., Walsh, K.D., Hershauer, J.C. (2003). *Improving capital projects supply chain performance*. CII RR 172-11. The University of Texas at Austin, 257pp.

Vrijhoef, R. and Koskela, L. (2000). "The Four roles of supply chain management in construction." *European J. of Purchasing & Supply Mgmt.*, 6, p. 169-178.

Hamzeh, F.R, and Albanna, R.M, (2019). "Developing a Tool to Assess and Enhance the Workers' Understanding of Lean Concepts of Construction." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 179–189. DOI: https://doi.org/10.24928/2019/0241. Available at: <www.iglc.net>.

DEVELOPING A TOOL TO ASSESS WORKERS' UNDERSTANDING OF LEAN CONCEPTS IN CONSTRUCTION

Hamzeh, F.R.[1], and Albanna, R.M [2]

ABSTRACT

In order to reap the benefits of Lean Construction, construction companies should integrate, empower and enable all personnel involved in the construction process whether on or off site. As such, construction workers need to be trained on lean construction concepts and principles. The purpose of this paper is to develop a tool to assess the workers' understanding of Lean concepts in construction. In this paper, the lean construction concepts are categorized into eight main areas: planning and control, standardization, pull production, wastes, kaizen, site organization, quality and safety. A lean construction worker knowledge profile was formulated based on the aforementioned categories. This profile encompasses all the knowledge, information, and lean background that a construction worker should distinguish, utilize and harness on the construction site. This lean profile formed the basis for a survey tool conducted on different construction sites in Lebanon to test its efficacy in identification areas of weaknesses in understanding lean principles as the lever of construction workers. Out of the eight categories, the workers lacked mainly the required acquaintance in pull production and waste. As a result, training exercises and games are recommended to instill lean construction concepts in the everyday behaviour, practice and job performance of construction workers.

KEYWORDS

Lean construction, construction workers, training games.

INTRODUCTION AND LITERATURE REVIEW

Lean construction is a philosophy that is based on waste reduction and continuous improvement (Koskela, 1992). Lean culture focuses on people, teams and partners facilitating change in the way they think, behave and execute their work (Liker, 2004).

Construction workers play a significant role in the implementation of lean construction principles and methods. Lean construction mandates workers' active participation in the

---

[1] Associate Professor, Civil and Environmental Engineering Dept., University of Alberta, Canada, hamzeh@ualberta.ca

[2] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Beirut, Lebanon, rma138@mail.aub.edu

construction process stipulating new roles and responsibilities for construction workers which neccesitates being qualified in lean tools, concepts and principles, which include: first, the inclusion of workers in developing the work plan; second, reliable promises, coordination and active communication between the construction workers themselves and between the construction workers and foremen; and third, the continuous improvement through reflecting upon mistakes, finding root causes and taking preventive actions (Ballard, 2000). Unfortunately, this is not always happening. For example, while studying a large project in Brazil, one of the obstacles faced was to promote the compliance of the lean construction concepts and tools among field employees such as: foremen, crew leaders, and construction workers (Barbosa et al. 2013).

Lean implementation has has been a challenge due to many organizational and human factors related to workers, such as: weak communication and lack of transparency, poor involvement of the construction workers, inadequate preparation and training of participants and lack of role definition (Brady et al. 2011). In a recent case study addressing the implementation of Lean and Last Planner System implementation on a construction project in Beirut, Lebanon, it was confirmed that one of the main challenges was a lack of personnel training and employee resistance to change (Hamzeh et al., 2016).

Accordingly, to effectively implement lean tools, concepts and methods, Guerrero and Sire (2001) suggested training as one of the best ways to enhance, change and positively affect the workers' performance, improve their productivity, and augment the quality of the delivered work. There are many research studies that focus on teaching, providing training, workshops, and courses on lean-related topics for students, engineers and middle managers both at universities and in companies (Tsao et al. 2012). A recent study by Zanotti et al. (2017) conducted a training program targeting one aspect of lean construction which is waste identification using the A3 tool. However, there is limited research that addresses the construction understanding and application of lean concepts in construction.

Thus this paper aims to developing a tool to assess workers' insights of lean concepts in construction and include: developing a questionnaire which addresses the different lean construction categories that need to be comprehended by construction workers, testing the assessment questionnaire in Lebanon, pinpointing the areas of weaknesses construction workers have regarding lean construction concepts, and finally enumerating the training exercises that can be exploited to backfill these gaps.

METHODOLOGY

A thorough literature review was conducted to establish a holistic understanding of all lean concepts that construction workers should know. The categories were selected based on the level of understanding of the construction workers for lean concepts, their roles and responsibilities in lean construction in addition to what they should know and apply in construction sites.

The lean concepts were categorized into seven areas: standardization, pull production, waste, kaizen, site organization, quality, planning and control. Based on these eight categories, a lean worker knowledge profile was developed that included several skills and knowledge aspects. The eight areas and the lean knowledge aspects are summarized here with the literature source:

STANDARDIZATION (TEZEL 2011)

- Keep only needed tools, materials and resources in the work area
- Put everything in its place and make a place for everything (use tape, outline areas, use peg boards)
- Mark the crane spots unloading bays, areas of work and the floor to highlight the walkways and location of tools and materials such that a safe and efficient working environment is established
- Color code the places by trade, traffic and material logistics plans
- Clean the tools and working areas when done or before
- Implement a task by following a standardized procedure
- Ensure, as a construction worker that you are following the standards through periodic self-evaluation
- Make shadow boards and use them to organize and ensure the availability of the tools

PULL PRODUCTION (ARBULU ET AL 2003)

- Understand the sequence of tasks
- Realize the internal and the external customers of a process
- Provide the right products in the right place at the right time
- Make the processes transparent (Koskela 2000)
- Understand the types of flow: materials, information, crew, space,
- Understand and practice production-ordering- kanban and transport/ supplier kanban
- Know how to use kanban cards, a production leveling heijunka board, and in station quality (jidoka) via andon board (Tezel 2011)

WASTE (OHNO 1988)

- Understand and learn how to eliminate the types of wastes
- Avoid rework through using simple job aids such as checklists and standardized work plans
- Reduce unnecessary movement of workers on the construction site and unnecessary transportation of materials, equipment and tools
- Limit unnecessary processing of the work
- Understand and eliminate the making do waste which is starting a task without its standard inputs or the execution of a task is continued where one of its inputs has ceased (Koskela 2004)

- Understand and eliminate the task diminishment waste which is executing a task in a way that doesn't comply with the specifications (Patton 2013)
- Understand and eliminate the defects produced from executing a task in the wrong way
- Simplify by minimizing the number of steps to perform a certain task

KAIZEN (LIKER 2004)

- Reflect upon the root causes of a problem and take preventive measures to avoid its occurrence in the future
- Practice kaizen everyday through every work procedure done
- Make reliable promises (Hamzeh 2011)
- Suggest new ideas about how to do individual work, to improve safety, product quality, productivity or quality of work life
- Donot hide problems (i.e. lower the river to reveal the rocks)
- Ensure working as a team (Hamzeh 2011)
- Ensure viewing the process and the result, not the result alone
- Respect everyone on the construction site

SITE ORGANIZATION (TEZEL 2011)

- Ensure that flow paths of people are properly marked, unobstructed, paved, flagged, protected and empty
- Ensure a clean and organized site with signs: place for inventory, jobs, technical room, warehouse, cafeteria, floor numbers, self-explaining signs
- Dedicate clear areas with signs for materials
- Gather small parts orderly in bins and at locations close to utilization
- Use signs for the materials in the stock with their corresponding quantities for replenishment

QUALITY (LIKER 2004)

- Ensure quality right the first time even if it means to slow down or stop to enhance productivity on the long term
- Do in process-self inspection
- Ask 5 whys to understand the root causes of a problem
- Understand the regular quality control procedures for concrete, pouring ….

PLANNING AND CONTROL: (BRADY 2014)

- Organize the daily work and put a plan to execute it
- Know the weekly work schedule

- Get involved in the planning of the work and the daily huddle meetings by giving input, progress and problems while performing certain task
- Define and know the component of the product to be constructed as to content, timing, sequence, outcome, and describe the work to be done as shown in plans and specifications

To investigate the knowledge of construction workers in these categories, the authors carried out a survey. The questionnaire was pilot tested in order to evaluate the clarity of the survey questions and thus introduce corresponding adjustments. Then the survey was filled out during semi structured interviews with 73 construction workers on 7 different construction sites and with 7 different companies. The author ensured the anonymity of the respondents. The survey was printed in the local language of the construction workers for their ease of understanding and responding freely and honestly. The total number of questions of the survey was 42 distributed among the eight categories of lean construction. Respondents answered each question based on a Likert scale from 1 to 7 which expresses the degree of agreement with each statement where 1 represented "entirely disagree" and 7 represented "entirely agree".

THE SURVEY TOOL

The survey begins with a question regarding whether the respondent was a worker or a skilled worker and his/her years of experience. The respondents answered the statements based on the degree to which they agree on these statements and the degree to which they employ them in their usual daily work. The questionnaire started with an assurance regarding its confidentiality. The questions aimed to gather specific information about the way construction workers execute, and practice daily work, in addition to their indirect vision regarding lean construction concepts. As a result, the survey tried to indirectly assess the way construction workers executed their work in accordance to lean construction concepts, starting from kaizen, pull production, planning and control, waste, quality, safety, site organization, and standardization. The survey was based on the lean knowledge profile. To collect the data, a structured face-to-face interview was performed on different construction sites in Lebanon. The construction site engineers were called and the authorization to access the construction site was given. In some cases, a previous meeting was scheduled with the project manager and the general foremen to introduce them to the survey. It is worth mentioning that several companies refused to take part in this study.

When on site, the first thing was to introduce the purpose of the study. All the questions were explained in order to avoid false results. On most construction sites, the construction workers were grouped in a room or in a small circle to complete the survey.

DATA ANALYSIS AND DISCUSSIONS

Each question in the survey was related to one of the eight categories of the lean construction knowledge. First these questions were organized per the eight categories, then the average score per category for each respondent was calculated.

A boxplot was generated based on the eight categories where K represents Kaizen, PC: Planning and Control, PP: Pull Production, Q: Quality, SA: Safety, SO: Site Organization, ST: Standardization, W: Waste. The boxplot confirmed that waste and pull production scored the worst categories among the others. In addition, Pull Production, Standardization, Site Organization and Quality scored a median very close to 4. This shows that construction workers have little knowledge regarding these concepts. Kaizen scored high due to the bias in the responses of the construction workers. This type of bias is a response bias. Thus, the respondents' answers in kaizen, which refers to continuous improvement, are biased toward what they believe is socially and ethically desirable: continuously improve and develop themselves. Construction workers have general idea about the importance of using helmets, and protective equipment, but this is not enough when it comes to international safety procedures on construction sites.

The respondent averages were statistically analyzed in order to establish if the eight categories were significantly different from each other. The non-parametric test Kruskal-Wallis rank sum test was used. The null hypothesis was that there was no difference across the eight categories. The p-value obtained from the Kruskal- Wallis test is 2.895e-13 which indicates that there is enough evidence to indicate that at least one of the eight categories was different from the others.

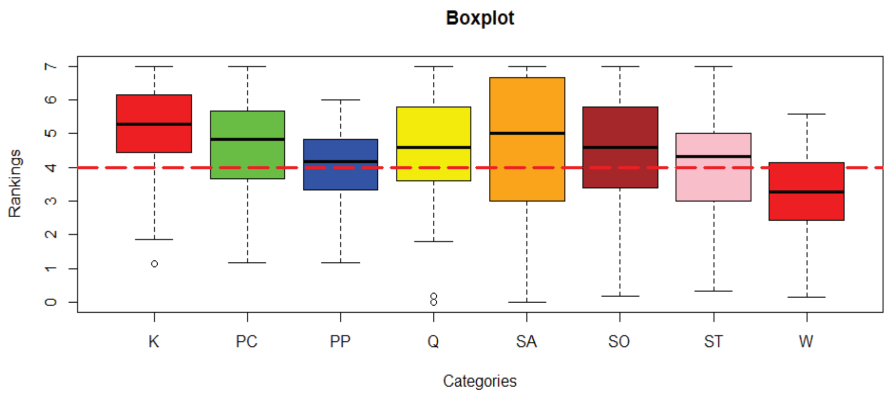


Figure 1: Boxplot for the Eight Categories of Lean Knowledge Profile

OBSERVATIONS

In this section, the authors discuss the observations encountered during the site visits. First, it was clearly observed that little-to no training is given for construction workers, where only engineers, foremen and general contractors are the center of the focus. There is a focus mainly on the training and development of engineers, project managers, and general foremen. For example: only general foremen on construction sites were trained to face safety-related procedures, such as: fire hazards, and given emergency response trainings.

Second, construction workers might have heard about safety practices, and the other lean concepts mainly from the implementation of ISO standards in certain companies. This explains the current limited knowledge regarding such practices. In addition, they might have heard of such practices from other construction sites and from the engineers on sites. But these safety standards are only the basics, for example, other safety regulations such as: working at heights and wearing high visibility jackets are being ignored.

RECOMMENDATIONS

After analyzing the results of each question and the overall categories in the survey, the following recommendations were developed:

Since construction workers showed a lack of knowledge in the areas of waste and pull production, construction workers must receive training in all categories of lean construction, with strong emphasis on those two categories. Training games demonstrate lean construction principles and concepts in action. Games allow construction workers to get involved and engaged in the learning process. Training games help construction workers implement their lean roles properly, understand the lean construction concepts, and fully integrate the lean construction knowledge profile. To develop an understanding of how lean construction games can address the seven categories mentioned in this study, the following procedure was followed:

- Different lean games that target lean manufacturing and lean construction were investigated. Out of these games, only the ones that tackle lean construction were identified and in particular, the ones that construction workers can relate to i.e. the ones, which fall into the eight categories and the lean knowledge profile.
- The lean areas that every game address were identified. Then, each area was linked to the eight categories previously mentioned before.
- The table matches the games with the areas of weaknesses found in the study.

The selected games along with their corresponding contribution to lean construction concepts are given below in table 1. They can be used by any construction project in the world to address the areas of weakness faced on the project.

Table 1: Suggested Lean games and the corresponding lean categories they address

Games	Site Organization	Waste	Kaizen	Standardization	Pull Production	Planning and Control	Qualit y
House of Cards	X	X	X		X	X	
Standard Pig Game	X	X	X	X			X
5s Numbers	X		X				
Ball Game	X		X		X		
Dollar Game			X				
Broken Squares			X			X	
Leapcon		X		X	X		
Parade Game					X		
Airplane Game			X	X	X	X	X
Maroon White Game			X			X	X
Dice Game					X	X	

Win As Much As You Can			X		X	X	
Villego			X	X	X	X	
Lebsco			X	X	X	X	
Marshmallow Simulation			X				
Deming's Red Bead Game					X	X	X
Paper Airplane Game					X		X
Helium Stick Game			X				
Pipes and Marbles			X				
Binniger's Takt Game		X			X		
InFrame		X	X		X		
Last planner Driven Game			X	X	X	X	X
Lean Apartment Simulation Game		X			X		
Lean Cups Game/ Dot Game					X		
Make a Card					X		
Kanban pizza Game					X	X	
Marshmallow TVD Game			X				
Delta Design Game			X				
Lego Game			X		X		
The Lean Lemonade Tycoon 2			X		X		

CONCLUSIONS

One of the pillars of lean construction is developing people and partners. Involving all the personnel on and off the construction site is vital for harnessing the full benefits of lean, and these personnel need to be trained on lean construction principles. Lean construction induces new roles, responsibilities and knowledge for construction workers. The authors identified eight main categories that construction workers should know, understand, and practice on the construction site, which are: pull production, planning and control, site organization, safety, quality, standardization, kaizen and waste. Based on these categories, a detailed lean construction worker knowledge profile was developed and tested. The main focus of this study was to develop a tool to assess and enhance the workers understanding of lean concepts. The assessment was made through a survey tool conducted on several construction sites in Lebanon. After analyzing the results of the questionnaire, the authors concluded that construction workers have a general lack of knowledge regarding the lean construction knowledge profile. The following results were obtained:

Construction workers have a lack of understanding and applying waste related concepts and their types, an absence of knowledge in lean pull production practices, and a general lack of understanding of site organization and standardization concepts. Construction workers are not strong believers of these concepts. They may support them but they donot strongly believe or understand the importance of applying them. These weaknesses are somehow related to the overall organization/ company's application of lean construction concepts, principles and practices.

Construction workers are not engaged in the planning and control of the construction activities on the construction site. They donot give feedback on the progress of their work. This is found when applying traditional construction methods that are still the norm on many construction sites in Lebanon.

REFERENCES

Alarcon, L. &. (1999). Playing Games: Evaluating the Impact of Lean Production Strategies on Project Cost and Schedule. Proceedings of IGLC-7 (pp. 263-274). Berkeley, CA, USA: University of California, Berkeley, CA, USA.

Arbulu, R. J., Ballard, G., and Harper, N. (2003). Kanban in construction. Proc. 11th Ann. Conf. of the Intl. Group for Lean Constr. (IGLC-11), Elsinore, Denmark.

Ballard, H. G. (2000). The last planner system of production control (Doctoral dissertation, University of Birmingham).

Barbosa, G., Andrade, F., Biotto, C., & Mota, B. (2013). Implementing lean construction effectively in a year in a construction project. In Proceedings for the 21st Annual Conference of the International Group for Lean Construction, Fortaleza, Brazil (pp. 1017-1026).

Bernstein, H. M. & Jones, S. A. (2013). Lean construction: Leveraging collaboration and advanced practices to increase project efficiency. Intelligence, McGraw Hill Construction, Bedford, MA.

Brady, D. A. (2014). Using visual management to improve transparency in planning and control in construction (Doctoral dissertation, University of Salford).

Brady, Denise Ann, Tzortzopoulos, Patricia and Rooke, John (2011). An examination of the barriers to last planner implementation. In: 19th Annual Conference for Lean Construction, 13-15th July 2011, Lima, Peru.

Guerrero, S. and Sire, B. (2001) "Motivation to train from the workers' perspective: example of French companies." International Journal of Human Resource Management, 12 (6), 998-1004.

Hamzeh, F. R. (2011). The lean journey: implementing the last planner system in construction. In Proceedings of the 19th Annual Conference of the International Group for Lean Construction, Lima, Peru, pp. 379-390.

Hamzeh, F. R. (2016). Using Forums and Simulation Exercises to Enhance Active Learning in Lean Construction Education. Ch. 6. In R. N. Nasser, & M. Romanowski, Social Justice and the Engineering Profession: Challenging Engineering Education to Move beyond the Technical (pp. 139-159). Springer, Cham.

Holt, J. (2012, April 23). Dollar Game. Retrieved 1 19, 2019, from kaizenworld: https://www.kaizenworld.com/kaizen-links/lean-games/dollar-game.html

JIT Flow Simulation AKA: The "Paper Airplane" Exercise. (n.d.). Retrieved 1 19, 2019, from Lean Australia: http://leanaust.com/wp-content/uploads/2013/04/JIT-Flow-Simulation-Paper-Airplane-Simulation-Messier-Dowty.pdf

Koskela, L. (1992). Application of the new production philosophy to construction (No. 72). Stanford, CA: Stanford University.

Koskela, L. (2000), an exploration towards a Production Theory and Its Application to Construction, VTT Technical Research Center of Finland.

Koskela, L. (2004). Making do - the eighth category of waste. In Proceedings of the 12th annual conference of the International Group for Lean Construction.

Lambrecht, M. e. (2012). Extending the Production Dice Game. International Journal of Operations & Production Management , 1460-1472.

Lean Enterprise Institute. (n.d.). Retrieved 1 19, 2019, from Lean.com: https://www.lean.org/FuseTalk/Forum/Attachments/5S%20GAME.PPT

Liker, J.K. (2004). The Toyota Way- 14 Management Principles from the World's Greatest Manufacturer. New York: McGraw Hill.

Ohio State University. (2000). Broken squares. Retrieved 1 19, 2019, from Hunter College:http://www.hunter.cuny.edu/socwork/nrcfcpp/pass/learning-circles/five/Brokensquares.pdf

Ohno, T. (1988). Toyota production system: beyond large-scale production. crc Press.

Patton, J. R. (2013) Task Diminishment: Construction Value Loss due to Sub-optimal Task Execution. A Dissertation Presented to The College of Graduate and Professional Studies, Department of Technology, Indiana State University, in Partial Fulfilment of the Requirements for the Degree Doctor of Philosophy.

Pollesch, P. R. (2017). House of Cards – a Simulation of Lean Construction Principles. Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC), (pp. 373-380). Heraklion, Greece.

Red Bead Game. (2006, 8). Retrieved 1 19, 2019, from National Quality Center: nationalqualitycenter.org/files/nqc-game-guide-chapters/01-red-bead-game/

Rhemare source center. (2010, 9 29). The Ball Game - A Creative Team Building Exercise. Retrieved 1 19, 2019, from you tube: https://www.youtube.com/watch?v=rva3wRvpS_4

Rybkowski, Z. K. (2008). Using Controlled Experiments to Calibrate Computer Models: The Airplane Game as a Lean Simulation Exercise. Proceedings 16th Annual Conference of the International Group for Lean Construction (pp. 309-319). Manchester, England: University of Salford.

Sacks, R. A. (2007). LEAPCON: Simulation of Lean Construction of High-Rise Apartment Buildings. Journal of Construction Engineering and Management, 529-539.

Shmula. (2013, 11 6). Standard Pig Game. Retrieved 1 19, 2019, from shmula.com: https://www.shmula.com/standard-pig-game/12385/

Sime, A. (2013, 9 5). Lean Games "Pipes and Marbles". Retrieved 1 19, 2019, from YouTube: https://www.youtube.com/watch?v=mYbEpJZA-Os

Smith, J. P., & Rybkowski, Z. K. (2013). The Maroon-White Game: A Simulation of Trust and Long-Term Gains and Losses. 21st Annual Conference of the International Group for Lean Construction, (pp. 987-996). Fortaleza, Brazil.

Tezel, A. (2011). Visual Management: an exploration of the concept of and its implementation in construction. PhD, University of Salford.

The Dot Game. (2009). Retrieved 1 19, 2019, from net objectives: https://www.netobjectives.com/system/files/DotGame_vas11_0.pdf

The works manager. (2011, 9 13). Helium Stick. Retrieved 1 19, 2019, from YouTube: https://www.youtube.com/watch?v=RXI-C4jQXVk

Tommelein, I. D. (1999). Parade Game: Impact of Work Flow Variability on Trade Performance. Journal of Construction Engineering and Management, 304-310.

Tsao, C. C., Alves, T., & Mitropoulos, P. (2012, July). Different perspectives on teaching lean construction. In Proc. IGLC (Vol. 20).

Villego the last planner simulation. (n.d.). Retrieved 1 19, 2019, from villego: https://www.villego.com/

Win as much as you can. (n.d.). Retrieved 1 19, 2019, from pi beta phi: https://www.pibetaphi.org/pibetaphi/uploadedFiles/Leading_with_Values/Win%20as%20Much%20as%20You%20Can.pdf

Wujec, T. (2010, 4 22). Tom Wujec: Build a tower, build a team. Retrieved 1 19, 2019, from YouTube: https://www.youtube.com/watch?v=H0_yKBitO8M

Zanotti, N.L. et al. 2017, 'Bottom-up Strategy for Lean Construction on Site Implementation' In:, 25th Annual Conference of the International Group for Lean Construction. Heraklion, Greece, 9-12 Jul 2017. pp 325-331

Muñoz, A., Laurent, J. and Dierks, C. (2019). "Team Health: A Measured Approach to Collective Learning." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 191–202 DOI: https://doi.org/10.24928/2019/0245. Available at: <www.iglc.net>.

TEAM HEALTH: A MEASURED APPROACH TO COLLECTIVE LEARNING

Anthony Muñoz[1], Jean Laurent[2], and Chris Dierks[3]

ABSTRACT

This paper addresses the problem in failing to identify, measure, and monitor the human component (i.e. participant satisfaction) in the delivery of a lean construction project. Traditional measures of lean construction fail to represent or provide insightful commentary to the lengths they measure. The authors of this paper present the *team health* assessment as a tool that DPR Construction has used to better identify and provide measurement to otherwise unquantifiable indices of a project's performance. With this tool, project teams are able to facilitate a disciplined approach to learning, learning from the team and as a team, throughout the entire life cycle of design and construction. This added awareness could then be used to better identify and optimize value from a holistic viewpoint.

KEYWORDS

Language action perspective, benefits realization, action learning, moods, collective learning.

INTRODUCTION

This industry paper is a compliment to Cleary and Muñoz (2018) *Reaping the Rewards of Production Tracking*. In that discussion, morale was identified as an unquantifiable index of a project's success. The value of morale was unable to be substantiated beyond qualitative statements as expressed by several of the subject project's participants. As it was in that case, these statements are often retrospective and do little to influence a project throughout its delivery. This lapse was later identified as an opportunity for continued research.

The body of this paper observes DPR Construction's implementation of a *team health* assessment on several of its projects to better identify and provide measurement to otherwise intangible indices of a project's performance such as participant satisfaction. As derived from the feedback of two Southern California healthcare project teams as well as from that of an Integrated Project Delivery team who recently completed campus improvements at Penn State University, the objective of this paper is to present what benefits were gained from measuring and monitoring *team health*, in addition to the more

---

1 Healthcare Project Manager, DPR Construction, San Diego, CA 92122, USA, anthonym@dpr.com
2 Project Engineer, DPR Construction, Newport Beach, CA 92660, USA, jeanl@dpr.com
3 Lean Manager, DPR Construction, Ft. Lauderdale, FL 33301, USA, chrisd@dpr.com

common lean construction measurements of productivity, in efforts to optimize value for all stakeholders.

METHODOLOGY

This industry paper is the product of its authors' experiences through observation in action learning. Through action learning, the researcher is a participant and the subject of research is change to processes in which they are involved (Westbrook 1995). Responsible subject involvement in some real and complex problem in instrumental to achieving the intended improvement (Revans 1982). This concept is based on the premise that learning emanates from reflection followed by action to solve real problems where reflection and discussion occur in small groups (McGill and Beaty 1995). An expository was additionally conducted to qualify the problem objectively through existing literature.

BACKGROUND

THE LEAN MACHINE

Drawing from Japanese manufacturing management principles, most notably that of Toyota, lean production systems are loosely defined about continuous improvement, decentralized decision-making, waste elimination, and the optimization of resource utilization (Womack et al.1990). In these systems, processes and thereby organizations are finely tuned to maximize value. This concept was foundational to Howell's response to the question, "*What is lean construction?"* as presented at the 1999 IGLC Conference holdings (Howell 1999). This discussion further provided that the defining features of lean construction include predetermined objectives to produce the greatest performance for a customer at the project level, from design to delivery, through the application of production control.

Detractors to this *new* construction philosophy criticized the western exploitation of eastern concepts, claiming the transposition of the perceived positives while altogether ignoring the inherent drawbacks. Green (1999) decried that, under the guise of this philosophy, organizations become merely machines in pursuit of predetermined objectives. Within these machines, human resources are cogs that are only necessary to achieve organizational objectives. This was neither a new nor a unique protest of lean management principles. Kamata (1982) describes how the success of Toyota as an organization was paired with significant personal deprivation of the workforce. While this process may produce the greatest value for the customer, some have argued that this value is at the expense of undue stress and exploitation of the worker (Mehri 2006).

Howell (1999) was not silent on addressing the human component of project management; however, it is considered secondary to production management. He maintains that value can be more efficiently reflected and realized by measuring the performance of the planning system. This conclusion is constrained in that it fails to consider what happens to the machine when the cog that is human resources is the root of variation.

THE PROBLEM…OR THE OPPORTUNITY

Green (1999) remarks that Japanese manufacturing organizations, in their implementation of lean philosophies, have historically wielded a great negotiation strength over workers in the threat of uprooting operations elsewhere if the workforce refuses to conform. While this is a threat on a macro level, on the micro or project level, as it is in construction, the opposite is true; worker conformance is the driver of a project's strength.

As a foundation to the Lean Project Delivery System (LPDS), a project must determine stakeholder purposes (perceptions, desires, needs and values), translate these purposes into processes, and design a system for development (Ballard and Zabelle 2000). The execution of a project is then the iterative implementation of this three-component cycle. It serves to reveal the consequences of stakeholder desires and identify the response to variation necessary throughout delivery as compared to what may have been originally conceived. LPDS utilizes "work structuring" in both qualifying and quantifying processes and systems. This planning mechanism is used to identify and create flow amongst the various activities involved through specifying how and when work is to be done within the confines of the project schedule (Ballard 1999). Ballard and Howell (2003) propose that schedules are products of work structuring that specify goals and the handoffs required to achieve those goals. Typically, these handoffs are between contractors (Howell et al. 1993). "Contractor" can be defined as the person or collective that arranges to supply materials or workers for building. It can then be theorized that the successful delivery of a lean construction project is dependent on the project team's responsiveness to the evolving perceptions, desires, needs and values of the individuals that comprise it.

A SOLUTION IN CONCEPT

Holding that project success is driven by a project team's awareness to the fluctuating perceptions of its working individuals, DPR Construction proposes a *team health* assessment to provide metrics to the qualitative indices that have been previously identified as a challenging component to objectively measure and monitor. The concept of a *team health* assessment is not novel; however, its interpretation and documented application in the design and construction industry appears to be new ground.

Agile Beginnings

The concept of a *team health* assessment is rooted in Agile methodology. The Agile approach was developed by Bernie Dimsdale, John von Neumann, Herb Jacobs, and Gerald Weinberg in the late 1950's as a method of building software that was flexible and efficient. This approach was formally reprogrammed in 2001 when a group of 17 software development professionals met to draft the Manifesto for Agile Software Development (altexsoft, 2019).

The first value of the Agile Manifesto is to prefer "Individuals and interactions over processes and tools." This Manifesto and the Agile methodology have since evolved from managing software development into becoming a more universal project management approach. For example, the *team health* assessment, also referred to as a maturity model, is a tool that has transcended across multiple industries.

Modelling Behaviour

Fowler (2014) defines the maturity model as a tool that helps people assess the current effectiveness of a person or group of people and supports figuring out what capabilities they need to acquire to improve performance. Working with these models begins with assessment to determine the current level of performance. With this measure, one is better able to identify what capabilities may be needed or require improvement. The model effectively qualifies and quantifies user perception, providing structure to what could be a more complex process. This generic model has taken many formats, often as an extension of the personality and culture of the organization employing it. One model that has seen wide acceptance for its simplicity in use is the Spotify Team Health Check.

Spotify is a digital music, podcast, and video streaming service provider. Kniberg (2014) outlines the approach to the Spotify Team Health Check. This starts with organizing a one to two-hour workshop with the *squads,* or functional teams, to hold a face-to-face conversation around the different health indicators. To facilitate this, there is a physical deck of "Awesome Cards." Each card includes one health indicator with an "Example of Awesome" and "Example of Crappy." For each question, the *squad* is asked to discuss if they are closer to "awesome" or closer to "crappy." Measures for each of the indices are then visually summarized using a colour code. Basic workshop techniques (dot voting, etc.) are used to reach consensus about which colour to choose for that indicator. The definition of the colours is loosely based around the following:

Green – no need for major improvement currently.

Yellow – flawed, but not critically important to address immediately.

Red – this "really *sucks*" and must be immediately assessed for improvement.

Summarizing responses in this way provides a visual trigger to identify areas that require greater retrospective. Between team health checks, the tallies are used as a visual management tool to promote targeted areas of improvement. **Figure 1.** is representative of this summary and provides specific examples of three of the indices used. Additional detail is being included in the **Appendices**.

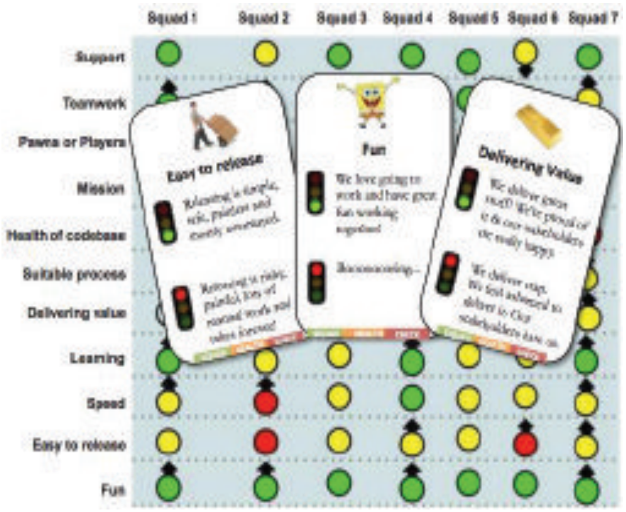


Figure 17: Spotify Squad Health Check Model Summary

AUTHORS' EXPERIENCE

A SOLUTION IN PRACTICE

DPR Construction employs an approach similar to the Spotify Team Health Check. However, while in-person discussions are preferable, a survey approach has been found to be more effective given the often satellite locations of participants on a construction project. This is done by inviting project stakeholders to participate in a regular reflection on overall project effectiveness through survey responses. The questionnaire is a collective of statements that support and measure the perceived alignment in meeting the team defined conditions of satisfaction. **Figure 2.** is representative this survey format.

KPI		HELP US IMPROVE, PROVIDE HONEST FEEDBACK Completely Anonymous	SCORE 1 to 5
COMMUNICATION	1	Information is requested and transmitted in a timely manner. Right information to the right person.	
COMMITMENT	2	The Team makes reliable commitment to each other to support the project schedule.	
PROJECT DOCUMENTS	3	The Team successfully utilizes the design documents and BIM to execute the coordinated work and communicates back to the design team.	
INNOVATION	4	I am encouraged to seek out and bring innovative ideas, solutions, and processes to the project.	
COLLABORATION	5	The team is effectively collaborating to ensure all issues are brought up as soon as they arise and dealt with quickly.	
VISUAL MANAGEMENT	6	Team successfully utilizes visual control methods-dashboards, A3's, logs, drawings, etc.	
AWARENESS	7	I fully understand the construction schedule for the project and when my response is critical to the schedule.	
QUALITY	8	The team defined clear and measurable definable features of work. Quality expectations of the projects are understood and implemented by all.	
TRUST	9	Team members demonstrate trust and respect across all levels of the team.	
LEARNING	10	The project team embraces an open, collaborative learning process and implement lessons learned.	
END USER SATISFACTION	11	The Team values End User and Member experience as a priority.	
SAFETY	12	Do you feel safety is demonstrated as a top priority?	
COST	13	Are all team members consistently integrating project budget and forecast in their daily decision making ?	
PARTICIPATION	14	Do you feel openly that you have a voice and are an important member of this project team?	
TIME MANAGEMENT	15	Are we spending time in meetings that add value?	
ENJOYMENT	16	Would you chose to work with this team again?	

17 What is the one thing you would like to see improved? (Can be anything)

18 What is the one thing the team is doing well and should continue to do? (Can be anything)

Figure 18: Example of Team Health Assessment Questionnaire

Respondents are asked to provide a quantitative response to the statements that are provided. **Figure 3**. is representative of the Likert-type scale on which these values are measured. Actual verbiage for each response scale is specific to the KPI it measures. This particular scale is as would be presented to measure KPI No. 9: Trust.

Figure 19: Team Health Assessment Likert-type Scale as Presented for KPI No. 9: Trust

Project teams have differed in the interval in which the reflections are facilitated, most commonly monthly, as well as in the delivery tool used to gather responses. However, the nature and presentation of statements have been similar and results tabulated in a normal format. **Figure 4.** illustrates the measuring wheel used to communicate the weighted response to each statement. This standard report makes future comparison over time and between projects more easily comparable. Additionally, it allows a dynamic platform to compare current response values to trending response values. This information is reviewed as regularly as the assessment is conducted. The more regular the assessment is conducted, the more live the data is. Ultimately, this trove of information can be used as a key performance indicator in a multitude of qualitative fields as determined by the assessment statements.

As is often the case in Agile methodologies, the best value of this tool comes more from the conversation that it generates than with the actual results (Kniberg 2014). As such, this section observes three project teams and their reflection on the value of the *team health* assessment as a tool – as opposed to highlighting specific survey results. However, excerpts from actual surveys and their resulting metrics have been included for reference in the **Appendices**.

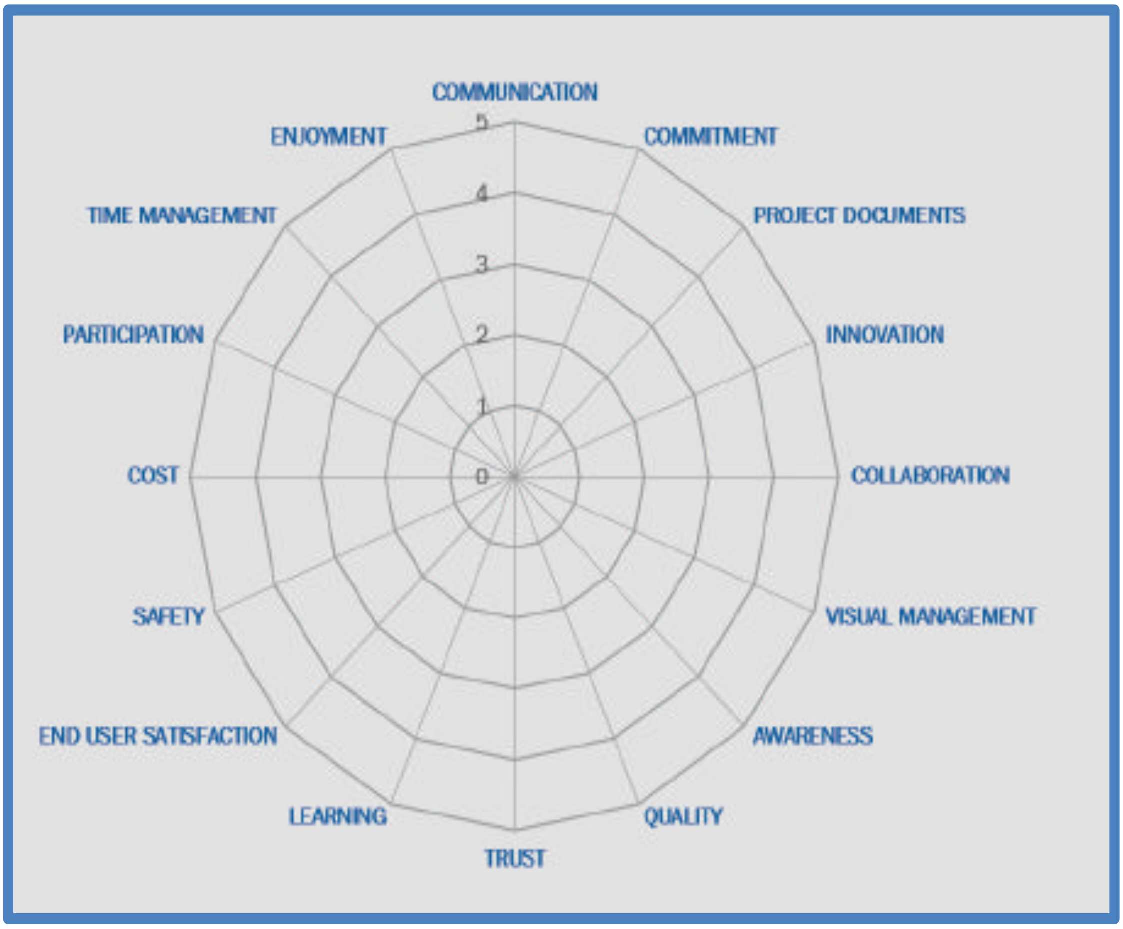


Figure 20:: Team Health Assessment Measuring Wheel

Project #1 Summary

The first of the three projects observed includes phased upgrades of an existing medical campus in Southern California. The project intent is to relocate and construct a new clinical laboratory including blood bank and part of lab administration in approximately 6,000sf of vacant space on the basement level; relocate and construct a new pathology department, including testing and administrative functions, in approximately 2,700sf of space vacated by the clinical laboratory; and expand the blood draw area into the remaining space vacated by the clinical laboratory.

The nature of this work, in and about an existing and operating healthcare campus, is predisposed to be high stress given the close quarters and life critical surroundings. To that ends, creating and executing flow to minimize disruptions is imperative.

Perceived Value

Amongst other issues that presented throughout conducting the *team health* assessments, project representatives noted that this platform helped to identify the significance of external influences on project success. More specifically, a collective of survey responses identified an underlying dissatisfaction with the timeliness of constraint identification and expectation of flexibility to resolve. Given the nature of construction within existing conditions, issues tend to first present at *the time walls are opened* if preconstruction surveys are not achievable. Moreover, construction activities such as electrical power shutdowns for equipment replacement require intensive coordination between multiple parties. In these instances, forecasting coordination meetings is challenging. While all parties had expectations of the unexpected, finding time to huddle became the source of growing stress amongst team members. The root cause was identified to be a lack of understanding of each other's project demands on top of their external commitments (outside of the project scope).

As a result, the team implemented two initiatives. The first was a shared calendar so that team members would have a better understanding of each other's overall demands on their time. The second was a Process Review Meeting to identify required deliverables by each partner to streamline these coordination efforts. These simple adjustments helped to alleviate stresses that, if had gone unchecked, could have lessened the quality and effectiveness of these constraint removal efforts by bringing alignment to demands and providing clear expectations of *success*.

Project #2 Summary

The second of the three projects observed also includes upgrades to an existing medical campus in Southern California, although in a different location than the first. The project includes tenant improvements consisting of a complete renovation of a 1-story over basement with a change of occupancy and use from vacant to ambulatory health care, including outpatient surgery and procedure suites, 39-bay pre-operative holding and post-anaesthesia recovery suites, sterile processing and complimenting support services. Additionally, the project includes improvements to site parking and patient drop-off areas.

Perceived Value

Again, the nature of working in an existing healthcare campus is predisposed to be a stressful environment. To that ends, creating and executing flow to minimize disruptions is imperative; this was facilitated using the Last Planner System. Despite acceptable PPC scores as tracked through a Weekly Work Plan report out, a collective of assessment responses identified a growing dissatisfaction with the overall management of the project plan at the early stages of execution. Through further dialogue, there was a sentiment that the Phase Pull Planning process specifically was too detailed. This extraneous effort (for this level of development) incumbered the flow of communication to crews.

This conversation led to restructuring the Last Planner sessions to place a greater reliance on Look Ahead Planning into Weekly Work Planning. This was facilitated by providing additional training to team members on the Last Planner System, focusing on required levels of flow and commitment at each stage. This index provided by the *team health* assessment provided insight to a potential constraint before it materialized in production tracking.

Project #3 Summary

The third of the three projects observed was a recently completed modernization of the Agricultural Engineering Building at Penn State University (PSU). The two major components of this 93,500 sf project include:

The modernization of the existing Charles Klauder Building. Built in 1938, the historic building required major upgrades to meet safety and energy standards, as well as end-user needs.

The demolition of a 1960's addition to the building. In its place, the project team constructed a replacement building, designed to match existing campus architecture.

The Agricultural Engineering Building houses the Department of Agricultural and Biological Engineering departments, including four multi-purpose classrooms, more than 30 comprehensive research and teaching labs, and several conference rooms and collaboration lounges. Agricultural engineering, with its broad range of study, required facilities to include complex bio-chemistry laboratories, machine shops, integrated hydrology-hydraulics laboratories and a new centralized fermentation laboratory.

This was PSU's first project using a poly-party Master Integrated Project Delivery (IPD) Agreement. The five signatory partners consisted of the Owner, General Contractor, A/E firm, Electrical Trade Partner, and a Mechanical & Plumbing Trade Partner.

Perceived Value

True to the IPD culture, the PSU IPD team sought a way to measure its performance and whether it was truly achieving the defined Conditions of Satisfaction and Value Statement. The implementation of the *team health* assessment met that objective in bringing the team members together to reflect on past performance, commit to improvements and gain consensus on the path forward. For these reasons, the PSU IPD team considered the *team health* assessment as a primary driver for project success.

Each month, throughout both design and construction, the project team allocated a minimum of one hour in one of its Big Room Meeting's agenda to reflect on the results of that month's *team health* assessment. The data was solicited, compiled and reviewed on the same day to ensure the most current information was reflected and acted upon. Intentionally, the longest part of the reflection was centred around one specific question, "What's one thing you would like to see improved? (Can be anything)". Some of the team's best innovations and efficiency improvements came from the resulting dialogue.

In one month in particular, responses strongly suggested that the MEP Cluster was not functioning as a cohesive unit. One contributing cause was identified to be that the cluster had too many attendees in its regular meetings. As such, planning sessions were constrained at a level that remained inclusive of all attendees or the discussions became too narrow for the larger group and certain partners became disengaged as a result. Either consequence resulted in inefficiencies or were otherwise detrimental to the project's wellbeing. The outcome of that month's *team health* assessment reflection provided that a sub cluster or Project Implementation Team (PIT), in this instance for the electrical partners, would address this concern and provide greater value. This PIT, consisting of four team members, would later become the highest preforming cluster on the project. Measurable outcomes for this PIT include a 4% costs savings as compared to its respective target cost. This was done through an expeditious, yet efficient design and modelling process which also yielded a 22-day schedule savings as compared to the original planned durations. This approach also supported DPR Construction's mantra, "Respect the Individual." By identifying a single individual to report up, the created additional capacity for the remaining three members of the PIT to repurpose and provide greater value in other areas of the project.

With the resulting success of creating the Electrical PIT through the re-organization of the MEP Cluster, the IPD team was inspired to observe the remaining clusters for opportunity that they too could be optimized. Three additional sub-clusters were created as a result. Given that most of the IPD team was not local, this simple change to team structure optimized and focused each individual's efforts in the right place, providing for the opportunity to offer the greatest value where and as needed. The team feels strongly that without the team health assessment and the purpose driven dialogue, it would have not recognized and benefited from these opportunities for improvement.

CONCLUSIONS

REFLECTION

Through observing the experiences of two Southern California healthcare project teams as well as the PSU IPD project team, this paper presents the value in utilizing a *team health* assessment to better identify and provide measurement to otherwise unquantifiable indices of a project's performance. Both project case studies provide credence to using this new rubric for identifying and monitoring key performance indicators not captured with traditional lean construction tools.

This holistic perspective is becoming increasingly more common in providing a more inclusive answer to the question, "*what is lean construction?*" Seed (2010) provides that lean construction is a *respect* and *relationship*-oriented production management-based approach to project delivery. Furthermore, Mossman (2018) has observed that by 2013, Howell's definition *softened* to include "An application to construction of a management philosophy defined by the *ideal* it pursues, the *principles* followed in pursuit of the *ideal*, *and* the methods used to implement the *principles*." Ultimately, by measuring not only the process, but also the people behind it, a more valuable product could be provided.

OPPORTUNITIES FOR ADDITIONAL RESEARCH

This paper introduces the *team health* assessment as a tool for measuring user satisfaction as summarised through a series of qualitative questions. The approach is still in its early stages and greater data stands to be produced. In addition to the trends that may present, additional efforts could be made to compare these trends in the *team health* indices to more traditional lean construction measures, such as PPC, productivity, safety incident rates, total project costs, etc., to identify if any significant correlation exists.

ACKNOWLEDGMENTS

Our greatest appreciation to DPR Construction in its constant support of continuous improvement - **#EVERFORWARD**.

Lessons learned provide greatest value when others could learn from them.

REFERENCES

Altexsoft. (2019). “Agile project management: Best practices and methodologies.” <https://www.altexsoft.com/whitepapers/agile-project-management-best practices- and-methodologies/>.

Ballard, G. (1999). “Work structuring.” White Paper # 5, Lean Construction Institute, Las Vegas, Nevada.

Ballard, G. and Howell, G. (2003). “An update on last planner.” Proceedings of the 11th Annual Conference of the International Group for Lean Construction. Blacksburg, VA.

Ballard, G. and Zabelle, T. (2000). “Project definition.” White Paper # 9, Lean Construction Institute.

Fowler, M. (2104). “Maturity model.”< https://martinfowler.com/bliki/MaturityModel .html>.

Green, S. (1999). “The dark side of lean construction: Exploitation and ideology” Proceedings of the 7th Annual Conference of the International Group for Lean Construction. Berkeley, CA.

Howell, G. (1999). “What is lean construction?” Proc. of the 7th Ann. Conf. of the Int’l Group for Lean Construction. Berkeley, CA.

Howell, G., Laufer, A., and Ballard, G. (1993). “Interaction between sub cycles: One key to improved methods.” *Journal of Construction Engineering and Management*, ASCE, 119(4).

Izak B., Goldstein, D. and Mead, M. (1987). “The case research strategy in studies of information systems case research.” *MIS Quarterly*, 11(3), 369–386.

Kamata, S. (1982). Japan in the passing lane: An insider’s account of life in a Japanese Auto Factory, Pantheon Books, NY.

Kniberg, H. (2104). “Squad health check model – Visualizing what to improve.” < https://labs.spotify.com/2014/09/16/squad-health-check-model/>.

McGill, I. and Beaty, L. (1995). Action learning, Kogan Page, London.

Mehri, D. (2006). "The darker side of lean: An insider's perspective on the realities of the Toyota production system." *Perspectives - Academy of Management*, 20(2), 21-42.

Mossman, A. (2018). “What is lean construction: Another look.” Proc. of the 26th Ann. Conf. of the Int’l Group for Lean Construction. Chennai, India.

Revans, R. (1982). The origins and growth of action learning, Chartrell-Bratt, Bromley.

Seed, B. (2010). Transforming design & construction: a framework for change, Lean Construction Institute, Arlington, VA.

Westbrook, R. (1995). "Action research: a new paradigm for research in production and operations management." *International Journal of Operations & Production Management*, 15(12), 6-20.

Womack, J., Jones, D. and Roos, D. (1990). The machine that changed the world, Rawson Associates, NY.

APPENDICIES (ABRIDGED)

1. Spotify Health Check Model
2. Project ABC Actuals
3. Project PSU Actuals

Ward, S. and Caklais, S. (2019). "Piloting the Deployment of ISO18404 in the Construction Sector, An Approach to Organizational Transformation." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 203–214. DOI: https://doi.org/10.24928/2019/0174. Available at: www.iglc.net.

PILOTING THE DEPLOYMENT OF ISO 18404 IN THE CONSTRUCTION SECTOR, AN APPROACH TO ORGANISATIONAL TRANSFORMATION

Steven A Ward[1] and Simon Caklais[2]

ABSTRACT

Despite significant experience with lean, the construction sector still fails to grasp the nettle and cannot keep up with other sector's rates of improvement. Ad hoc deployment of tools and techniques are common, but business transformations appear extremely rare. The research approach rests upon a focused literature review, examining the concept of Lean Construction transformation in the context of culture change, together with a single case study of the world's first business to achieve certification to the Lean ISO18404 standard. Key learning points from the case study were derived by structured interviews with construction staff directly involved and by noting similarities of the lean deployment to recommendations made in the literature. It is concluded that ISO 18404 is appropriate for the construction sector and could provide a useful roadmap to those seeking business transformation. Limitations and recommendations for further work and research are offered.

KEYWORDS

ISO18404, lean construction, organisational transformation, standardisation.

INTRODUCTION

The focus here is lean construction transformation in the context of organisation wide deployment and creation of a lean culture throughout a construction business.

The philosophy, tools and techniques of lean construction are well known. (Ansah et al. 2016) For those that apply these, the benefits are also well known. However, the industry as a whole has not adopted lean thinking and has not kept pace with the rate of improvement that other sectors have enjoyed (Barbosa et al. 2017). The existing literature is full of reasons, barriers, peculiarities of construction and excuses why this is so (Ballard & Howell 1998; Koskela 2000). Over the last twenty years many applications of lean construction have occurred, as evidenced by the significant body of literature on the subject. However, it would appear that the vast majority of attempts to apply lean in construction are of an ad

[1] Technical Director, Continuous Improvement Services, WSP, Bristol, UK +447917104399, steve.ward@wsp.com

[2] Managing Director, Gilbert & Goode, St Austell, UK +447766903418 s.caklais@gilbertandgoode.co.uk

hoc nature, mainly either on a project basis or maybe a narrowly focused process improvement basis. Ward (2015) based research around lean construction interventions because there were not enough data on transformations in construction available.

Standardisation is a theme central to lean and can be seen throughout its history and development. (Graupp & Wrona 2006). The international organisation for standardisation is an independent, non-governmental international organisation with a membership of 163 national standards bodies. (ISO 2019a) In late 2015 a new management standard was published, ISO 18404:2015, that "*defines the competencies for the attainment of specific levels of competency with regards to Six Sigma, Lean, and "Lean & Six Sigma" in individuals, e.g. Black Belt, Green Belt and Lean Practitioners and their organizations*." (ISO 2019b). The certification of individual's competencies to an international standard may interest the lean construction community, but the opportunity to gain organisational certification to a lean international standard is of particular interest because it may possibly assist with overcoming some of the barriers to more widespread adoption of Lean Construction. The usefulness of ISO18404 in construction as a transformation model is therefore explored.

REVIEW OF RELEVANT LITERATURE

ISO18404

A search using the term "ISO18404" returned nil results on the IGLC conference paper web page but a Google search using the term "ISO18404 Construction" returned a few relevant results, but all linked to the case study to be discussed here.

The question is whether this ISO standard can assist with construction company lean transformations; so, the term "transformation" was again used on the IGLC website. This time 79 papers were displayed. Two forms of transformation are discussed in these. The first is concerned with Koskela's Transformation Flow Value theory (Koskela 2000) and about process, but the second is about culture change and the industry uptake of lean. For clarity the latter is the focus of this paper.

Of the 79 papers, fifteen appeared related to the subject of transformational change in the construction sector and of these a further two were discounted after closer examination. The remaining papers were mainly concerned with organisational structure, roadmaps for lean transformation with clarifications of lean concepts, leadership and change by force.

ORGANISATIONAL STRUCTURE

According to Arbulu and Zabelle (2006), temporary organisations associated with construction projects provide an advantage when seeking transformation, which is contrary to the majority of literature on the subject of lean that, suggests temporary organisations are a barrier. Pekuri et (2014) discuss the need to create appropriate business models for lean construction transformation to take place, they examine the business model employed by the exemplar Toyota and compare this with usual construction business models. In the lean driven example provided, it appears that there is a clear *link between lean operations,* *capability and strategy*. They conclude that an appropriate business model is necessary for successful transformation.

ROADMAPS FOR LEAN AND CLARIFICATION OF CONCEPTS

A common theme across several papers discusses the perceived need for a roadmap for lean construction transformations. Naney et al. (2012) provide a useful discussion on construction-sector-wide adoption of lean. They use the Hype cycle of innovation as a tool to gauge transformational success and also link the slow uptake of lean construction, to Moore's "Crossing the Chasm," technological adoption curve. (Moore 1991) This appears similar to change curve thinking (Kübler-Ross 1969). They point out that industry wide construction sector strategies for transformation are missing, and the key "Early majority group in Moore's change adoption curve need a "*compelling case and/or a roadmap to follow*." They conclude that for castor wide uptake of lean construction, we must learn how to bridge the gap between the *early adopters and the early majority*.

The further development and adoption of a lean construction maturity model is recommended by Nesensohn et al. (2014). They are not clear on why this is needed or what benefit it might bring but Sainath et al. (2018) offer another maturity matrix for lean construction based on the perceived need to provide clarity to industry of lean concepts and also to gauge progress toward achieving these. Following Naney et al such a model might help provide the missing roadmap necessary to engage the "Early Majority" of the construction sector. Nesensohn et al. (2015) build on their earlier work concerning a maturity model and offer a more complete version, they reinforce the idea that a clearer definition of lean construction and a roadmap to follow will help transformation. Ward (2015) labours unsuccessfully over a definition of lean construction but also believes it would add significant value. Leonova et al. (2017) also call for the need for clarity regarding lean concepts, adoption and definitions.

LEADERSHIP

Lean construction in the context of organisational change caused by the adoption of the lean philosophy as opposed to the adoption of tools and techniques is discussed by Pekuri et al. (2012). They highlight 5 corner-stones necessary for success as *Leadership, Motivation, Competence, People and Trust*. Keiser (2012) is also focused on aspects of leadership, aiming to create "High Performance Teams." (Katzenback and Smith 1993) The role of leadership in transformation is discussed by Kerem et al (2013) who show how *leadership training* in lean at the coal face had a positive impact on organisational change and provide practical help on the subject of what lean leadership should look like in construction. This links with Torp et al. (2018), who compare lean transformation attempts across several linked companies within the same holding group and provide a key observation that a top down approach from senior management was essential. More guidance on business transformation using a top down and bottom up method simultaneously is provided by Kalyan et al. (2018) This model has many similarities to the case study discussed in this paper below.

CHANGE BY FORCE

Citing the first obstacle to lean construction as *"unwillingness to change until forced,"* Gehbauer et al. (2017) commendably propose transformation on a grand scale driven by focused collaborative research; they insist that culture change is the key, as the ingrained behaviours of industry must change in order for lean to flourish. They ask 34 questions that are suggested areas for focused and collaborative research to move things forward. Of these the following questions appear linked and relevant to the subject in focus here.

How can public authorities be helped to develop new regulations and new behaviour?

How can it be shown that Lean is much more than a mere collection of tools?

How can Lean be spread through education? Can a standard curriculum be developed?

How can Lean become the norm in construction worldwide?

How can Lean be developed from offering new concepts into a force that drives change in industry and society? How can drivers for change be identified?

AN OVERVIEW OF THE REQUIREMENTS OF ISO18404

The ISO18404 Standard (BSI 2015) can be broadly divided into two parts.
Firstly, it provides guidance on the knowledge and competencies that a person delivering lean improvements in an organization should be able to display. In the standard's appendices, there are three detailed tables for differing levels of expertise named Lean Practitioner, Lean Leader and Lean Expert. The competencies include a wide range of lean skills and at Practitioner level are mainly concerned with application. At Leader level, they include application, management and some training ability. At Expert level, application, management and training ability for all competencies is expected.
If an organisation has its own certified Lean Leaders or Lean Expert in place it is allowed to certify its own Lean Practitioners internally. A Lean Expert may also be an external resource if appended to the company's management system.

The second and perhaps most important part of the standard in regard to transformation describes requirements for organisational certification. To achieve certification an organisation must be able to demonstrate that:

It has the required resources in place including an appropriate level of **competent** personnel, and that this competence is maintained. (competence as defined in the appendices described above)

A clear link can be displayed between the lean deployment and company **strategy** with defined objectives.

An appropriate **architecture** needs to be in place. For example, a reporting structure, steering groups, accountabilities and support.

It can display structured **continuous improvement** with defined metrics, targets and review mechanisms.

A LEAN CONSTRUCTION TRANSFORMATION CASE STUDY UTILISING ISO18404

ABOUT THE CASE STUDY COMPANY

The company was established in 1972 and is based in Cornwall UK. They deliver a range of contracts from major projects to minor works and maintenance. In 2005 they were acquired by a registered social landlord, to expand traditional and contracting business, and also to construct the group's housing developments. They are a commercially focused contractor with a social purpose, returning any surplus profit to the parent group for re-investment for the public good.

In 2018 turnover was approximately £25mil with around 70 employees. Growth to £40mil is forecast in the next two years.

THE COMPANY'S LEAN JOURNEY

The Motivation for Lean Transformation

The managing director had experienced the benefits of lean construction whilst working as Head of Projects for a large airport authority, delivering major projects in a complex operational, logistically constrained environment.

There was a need to attack the cost base of new build housing and drive both qualitative and quantitative improvement in a structured manner. He saw the opportunity to improve productivity of the business by driving out the inherent waste in construction operations thus increasing the company's competitive advantage and delivering greater returns to the parent Group. Furthermore Cornwall, like most of the UK, suffers from a lack of skills and capacity and by working with the supply chain and offering them a platform on which they could perform and make money, more could be gained from the limited resources available and the best talent could be attracted to the company's sites. He began to encourage adoption of lean techniques within the company via knowledge transfer and in 2016 appointed a consultant to help accelerate the efforts. An initial Lean awareness workshop was held with about 20 staff. This was followed by two pilot projects predominantly using the Last Planner® System. The pilot projects yielded good results with lead time gains of around 15%. The company staff and supply chain willingly adopted collaborative planning techniques as all involved could see the benefit.

After the pilot projects the company's approach to production control using elements of the Last Planner® System was standardized and applied on every live project.

Following this initial stage, the Managing Director wanted to go further but was unsure of the best route. A number of options were investigated including pursuit of the new ISO18404 standard and this route was agreed.

Implementation of ISO 18404

No company had done this before, and the path was unclear. The company approached the Construction Industry Training Board (CITB) for help and they agreed to fund the pilot project. A plan for the deployment project was formed and work started in earnest in December 2017.

The company were already certified to other management standards such as ISO 9001, 14001 and 18001. These cover quality systems, environmental and health and safety

standards respectively. They wished to create a single integrated management system, based on lean principles using the new 18404 standard.
ISO18404 requires internal staff resources that meet the competences detailed in the standard and so key personnel received training. The MD, the Head of Development, the Head of Construction and a dedicated Project Manager to oversee initial implementation were trained to Lean Leader level. Eight other key staff covering project management, site management, sales and aftercare undertook Lean Practitioner Training.
External resources were appointed that included: a professor who chaired the committee that authored the standard to provide strategic guidance relating to this and a lean construction consultant to provide lean construction specific training and act in the capacity of certified Lean Expert under the standard.
A strategy was formed that clearly linked the lean improvement efforts back to the company's corporate strategy and metrics that could be tracked. This appears in Figure 1.

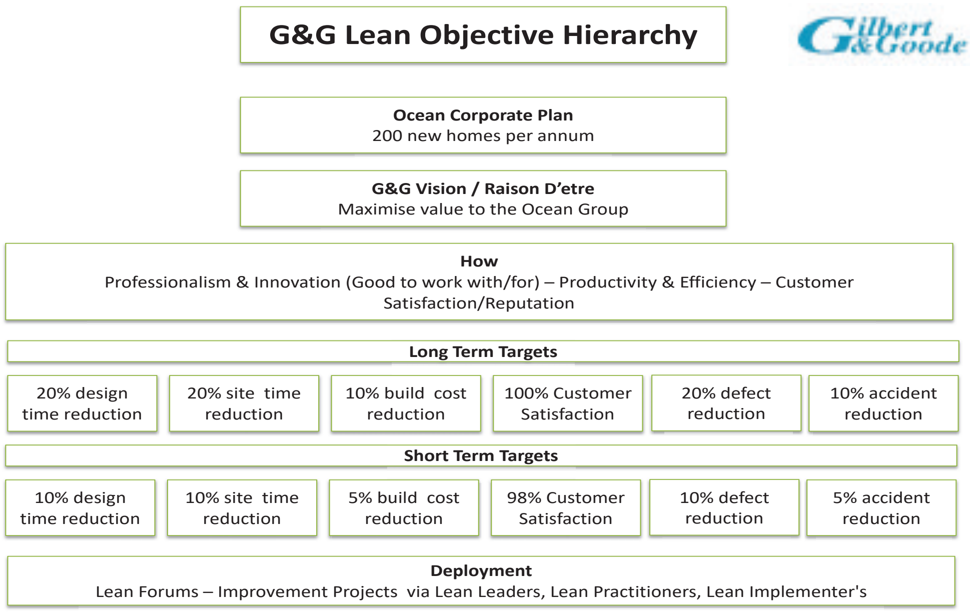


Figure 1. Lean Strategy Summary

During training a wide range of lean improvement projects were agreed covering the end to end value stream from design development and acquisition to sales and aftercare. These projects were prioritized on a single page plan and implemented according to capacity constraints, with some projects agreed but "queued". The business case for each project was weighed against its likely ability to deliver against the headline KPI's in the strategy document.
A Lean Management team, made up of the company's Lead Leaders, was created to oversee the delivery of the strategy. Six Lean improvement forums were established to support each of the KPIs and manage the improvement projects, each one being led by a Lean Practitioner and sponsored by a Lean Leader. This structure forms the basis of the company's continuous improvement architecture and is shown in Figure 2.

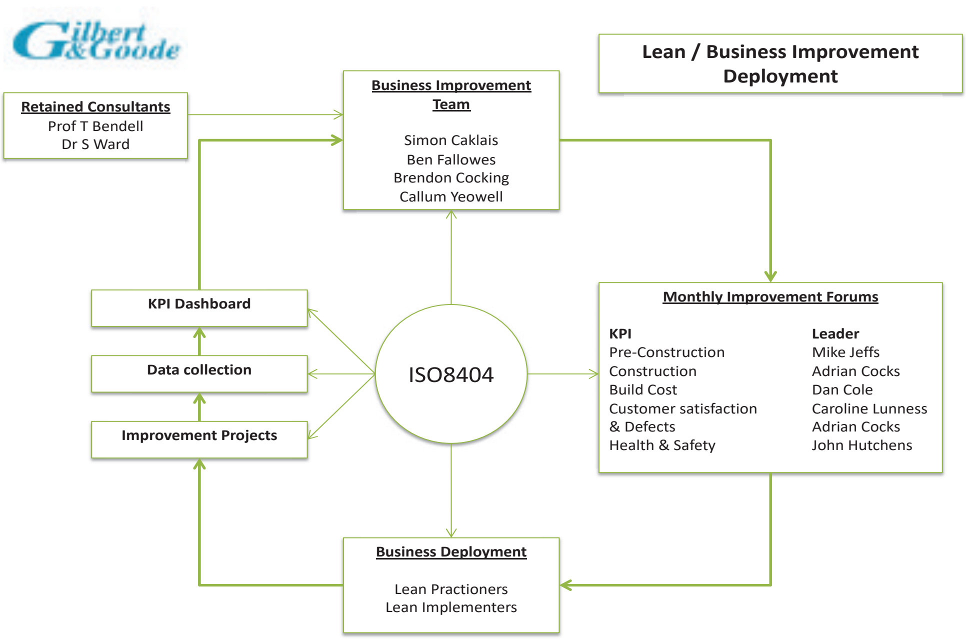


Figure 2. Architecture for Continuous Improvement

It was found that a further level of competence was required that did not exist in the standard. This level required fewer skills than Lean Practitioner, but measurable competence sought so the competencies of Lean Practitioner were cut down to a more basic level and “Lean Implementers” were trained. This served to widen the net in terms of who and how many people got directly involved in improvement efforts. A further 100 people in the business plus including key suppliers also received training at a basic level. During 2018, virtually all the company’s staff contributed to business improvements in some way.

Certification by The Royal Statistical Society and British Standards Institute

Throughout 2018 the company continued to execute the agreed plan. This was led directly by the senior leadership team with consultant support. Lean Practitioners and Lean Leaders were coached in the development of their portfolios of evidence required and were examined for competence by the Royal Statistical Society, the sector scheme owners, during October 2017. The British Standards Institute was invited to audit against the ISO Standard and carried out stage one and two audits during December 2018. The registered scope of assessment was “The management and maintenance of Lean programmes when delivering construction services.”

On the 9th of January 2019 the company received certification to the new standard, the first company worldwide to achieve this.

In terms of transformation, it is not the case that every single action or process by the company is guaranteed to be lean, or that they now perform better than any other company of their kind. (Although they may do in time) Rather it is the case that the majority of people working in the business understand the key concept of value for the customer, are supportive to continuously improving this and have a realistic methodology for doing so.

KEY LEARNING POINTS IN THE DEPLOYMENT CASE STUDY

The following learning points were formed by a combination of direct observation, participation by the authors and by content analysis of interviews conducted with the lean Leaders and Lean Practitioners after the implementation completed.

It was observed that initial motivation for the transformation appeared both internal and external. Internal derived from leadership vision and external from market conditions.

Management led from the front. The ISO18404 standard at Lean Leader level requires the leader to be able to train certain lean skills. The senior management team all took part in personally training their own staff. According to the Managing Director – this was key to getting buy-in and signalling that a new, continuous improvement culture was operating.

All staff were involved at some level and were in no doubt as to the purpose of the efforts, again supporting buy-in of the continuous improvement culture.

A clear link was created between overall strategy and lean deployment activity.

A clear path was available in terms of the guidance in the ISO 18404 standard, with the architecture and resources put in place to deliver and sustain the lean management system.

There was consensus that a tangible shift in overall culture had been achieved as a result of the implementation.

Difficulties with data capture and the ongoing management of this were a concern.

The sequence of training could have been improved with Lean Leaders beginning before Lean Practitioners and then cascading.

There was consensus that ISO18404 could help the construction sector but that each implementation must be tailored to individual organisational needs.

Practical aspects like weekly planning deployment and waste walks were seen as a significant contributor to success.

Dedicated resources for data capture & management and also helping continued administration of the system are required.

Implementation would have been extremely difficult without the external consultant expertise

THE IMPORTANCE OF DATA

As the standard title suggests "quantitative methods in process improvement", data collection and analysis are vital in supporting continuous improvement in a business. Target improvements to Key Performance Indicators (KPI's) are typically based on historic performance of the business, however the accuracy, type and format of the historic data may prove to be inadequate, especially as the focus on data capture increases within a business; meaning performance may not appear to improve on certain measures, as the data quality improves. One example in this case study was the post-handover defects reduction KPI, which appeared to get worse in the short term, as the level of detail captured increased. In addition, a number of the quality improvement projects linked to a new visual based Quality Assurance system, would take over a year to go through the project lifecycle before the improvements could be properly calculated. This also then led to a review of KPI's both based on the frequency of new data sets and also the relevance of the measures to potential changing business objectives. For example, the original time target was overall reduction in project programme time. However, as the business moved to more sales rate 'pull' delivery, the metrics for batch or cycle time had a greater relevance. In summary, the learning here is that KPIs may need to be changed or rebased as the maturity of your data increases and your understanding and application of their use evolves but the fact that measurement has become a key component of the business's continuous improvement culture, is the most important outcome.

LINKS WITH LITERATURE

In the literature review several key themes emerged and it is offered here that the case study may possibly help with the following areas.

The management system offers a "roadmap to follow" as recommended by Naney et al. as necessary to bridge the gap between the *early adopters and the early majority* on Moore's adoption curve.

Pekuri et al.'s five corner stones of Leadership, Motivation, Competence, People and Trust can be observed.

Pekuri et al's links between capability and strategy and lean operations can be observed.

Leadership training following Kerem et al. was evident.

It could be viewed that the standard provides an operational definition of lean required by Nesensohn et al. and Ward.

Many of Ward's "*Critical Success Factors for lean Construction Intervention*" (2015) are observed to have been present: e.g. Management capability, buy-in, appropriate data, collaboration with sub/c, etc.

Improvement activity was top down, and bottom up simultaneously as recommended by Kalyan et al.

Gehbauer et al. (2017) states that the industry won't change until forced. As an ISO Management, system there exists a clear capability to incorporate into procurement, thus potentially accelerating the uptake of lean principles by force. The effectiveness of business improvement using other related ISO systems was explored at length by Manders (2015) who found the best performers were internally not externally motivated as a key success factor. This does not concur with the "change by force" approach discussed by Gehbauer et al. Possibly the right answer is that both internal *and* external motivators are required.

Five of Gehbauer et al.'s thirty-four questions are listed above, and it is thought that the adoption of an international lean standard could help answer these in a positive way.

CONCLUSIONS

In 2018, the first company in the world achieved accreditation to the new international lean standard ISO18404. This company is a Main Contractor based in South West England. This suggests that it is applicable and appropriate in construction.

Following the literature review and case study, it is offered that this new standard could provide the recommended roadmap for others to follow.

The ISO18404 standard is not perfect, but in time will be reviewed and improved. This is in line with any informed approach to standardisation. There are many other certifications and competency systems and it is likely that the 18404 standards will suffer from "not invented here" syndrome. However, it is the only standard currently available in lean that is truly global with an appropriate supportive infrastructure and has the possibility of embedment in procurement systems etc.

FURTHER RESEARCH

Sustainability of the implementation should be examined. Also, after Gehbauer et al. it is recommended that the questions below become focus areas of research linked to the further deployment of ISO 18404.

How can Lean become the norm in construction worldwide?

How can Lean be developed from offering new concepts into a force that drives change in industry and society? How can drivers for change be identified?

How can public authorities be helped to develop new regulations and new behaviour?

ACKNOWLEDGMENTS

Thanks go to CITB and particularly Raquel Iredale and Nathaniel Cooke.

The Lean Leaders at Gilbert and Goode

Ben Fallowes, Brendan Cocking and Callum Yeowell

The Lean Practitioners at Gilbert and Goode

Adrian Cocks, Caroline Lunness, Craig Kendall, Mike Jeffs, Mike Pelan and Steve Luck

REFERENCES

Ansah, H.A et al. 2016 "*Lean Construction Tools"* Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, September 23-25, 2016

Arbulu, R. & Zabelle, T. 2006, 'Implementing Lean in Construction: How to Succeed' In:, *14th Annual Conference of the International Group for Lean Construction.* Santiago, Chile, 1-. pp 553-565

Ballard, G. and Howell, G. (1998). *Shielding Production: Essential Step in Production Control*. Journal of Construction Engineering and Project Management , Vol. 124(1): 11-17.

Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N. and Brown, S., 2017. Reinventing construction: a route to higher productivity. *McKinsey Global Institute*.

BS ISO 18404:2015 "*Quantitative methods in process improvement. Six Sigma. Competencies for key personnel and their organizations in relation to Six Sigma and Lean implementation"* British Standards Institute ISBN 978 0 580 81206 4

Gehbauer, F. , Ballard, G. & Leonova, M. 2017, 'How Research Can Help Transform the Construction Industry' In:, *25th Annual Conference of the International Group for Lean Construction.* Heraklion, Greece, 9-12 Jul 2017. pp 293-300

Graupp, P. and Wrona, R. (2006). *The TWI Workbook: Essential Skills for Supervisors*. Productivity Press, New York.

Kalyan, V. , Pratap, V. & Singh, S.C. 2018, 'Building a Lean Culture Into an Organization' In:, *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018. pp 1101-1110

Katzenback, J.R. and Smith, D.K., (1993). The Wisdom of Teams

Keiser, J.A. 2012, 'Leadership and Cultural Change: Necessary Components of a Lean Transformation' In:, Tommelein, I.D. & Pasquire, C.L., *20th Annual Conference of the International Group for Lean Construction.* San Diego, USA, 18-20 Jul 2012.

Kerem, C. , Barak, R. , Sacks, R. & Priven, V. 2013, 'Learning to See – Managers Working in the Gemba as Part of the Tidhar Way Training Program ' In:, Formoso, C.T. & Tzortzopoulos, P., *21th Annual Conference of the International Group for Lean Construction.* Fortaleza, Brazil, 31-2 Aug 2013. pp 957-966

Koskela, L. (2000). *An exploration towards a production theory and its application to construction* – PhD thesis Helsinki University of Technology, Helsinki.

Kübler-Ross, E. (1969) *On Death and Dying*, Routledge, ISBN 0-415-04015-9

Leonova, M. , Ballard, G. & Gehbauer, F. 2017, 'Strategies That Can Help Transform the Construction Industry' In:, *25th Annual Conference of the International Group for Lean Construction.* Heraklion, Greece, 9-12 Jul 2017. pp 333-340

Manders, B., 2015. *Implementation and Impact of ISO 9001*(No. EPS-2014-337-LIS).

Moore, G. A. (1991). *Crossing the chasm: marketing and selling technology products to mainstream customers*. [New York, N.Y.], HarperBusiness.

Naney, D. , Goser, C. & Azambuja, M. 2012, 'Accelerating the Adoption of Lean Thinking in the Construction Industry' In:, Tommelein, I.D. & Pasquire, C.L., *20th Annual Conference of the International Group for Lean Construction.* San Diego, USA, 18-20 Jul 2012.

Nesensohn, C. , Bryde, D. , Ochieng, E. , Fearon, D. & Hackett, V. 2014, 'Assessing Lean Construction Maturity' In:, Kalsaas, B.T., Koskela, L. & Saurin, T.A., *22nd Annual Conference of the International Group for Lean Construction.* Oslo, Norway, 25-27 Jun 2014. pp 1157-1168

Nesensohn, C. , Bryde, D. & Pasquire, C. 2015, 'A Measurement Model for Lean Construction Maturity' In:, Seppänen, O., González, V.A. & Arroyo, P., *23rd Annual*

Conference of the International Group for Lean Construction. Perth, Australia, 29-31 Jul 2015. pp 652-660

Pekuri, A. , Herrala, M. , Aapaoja, A. & Haapasalo, H. 2012, 'Applying Lean in Construction - Cornerstones for Implementation' In:, Tommelein, I.D. & Pasquire, C.L., *20th Annual Conference of the International Group for Lean Construction.* San Diego, USA, 18-20 Jul 2012.

Pekuri, A. , Pekuri, L. & Haapasalo, H. 2014, 'Lean as a Business Model' In:, Kalsaas, B.T., Koskela, L. & Saurin, T.A., *22nd Annual Conference of the International Group for Lean Construction.* Oslo, Norway, 25-27 Jun 2014. pp 51-60

Sainath, Y. , Varghese, K. & Raghavan, N. 2018, 'Framework for Progressive Evaluation of Lean Construction Maturity Using Multi-Dimensional Matrix' In:, *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018. pp 358-369

Torp, O. , Knudsen, J.B. & Rønneberg, I. 2018, 'Factors Affecting Implementation of Lean Construction' In:, *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018. pp 1261-1271

Vrijhoef, R. & Koskela, L. (2005), *'Revisiting the Three Peculiarities of Production in Construction'* In:, 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005. pp 19-27

Ward, S.A., 2015. *Critical Success Factors for Lean Construction* (Doctoral dissertation, The University of Dundee).

STREAM 4: LEAN CONSTRUCTION CASE STUDIES

Ryan, M., Murphy, C, and Casey J (2019). "Case Study in the Application of the Last Planner® System." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 215-226.* DOI:https://doi.org/10.24928/2019/0223. Available at: <www.iglc.net>.

CASE STUDY IN THE APPLICATION OF THE LAST PLANNER® SYSTEM

Maria Ryan[1], Christy Murphy[2], and Jason Casey[3]

ABSTRACT

The purpose of this paper is to identify the perceived benefits and challenges in the application of the Last Planner® System (LPS) in an Irish context. A case study research method was applied to one Irish case study organization. Qualitative and quantitative data was analyzed from primary and secondary data. Limitations of the study include utilisation of a single case study and the part time role of the researchers. Five key perceived benefits of LPS were identified including; Improved planning accuracy, Real time control, Proactive control, Engagement, and Design quality for construction. One key challenge identified, was a lack of time required for implementation. Insufficient training and resistance to change were not found to be issues compared to the literature review. Two different challenges were identified including lack of customization to suit different client sectors and lack of a standardized approach to deployment across projects. Further research is recommended to (a) understand these additional challenges (b) follow up of this study in the future of the case organization and (c) include additional Irish case studies.

KEYWORDS

Lean construction, last planner® system, lean, construction.

INTRODUCTION

GLOBAL AND IRISH CONTEXT

The global construction sector is experiencing positive growth (Turner and Townsend 2018). This growth is driving increased demand for skilled labour which drives prices and increases pressure on productivity (Turner and Townsend 2018). In parallel, projects are becoming more technically challenging, clients are becoming more demanding and contracts are becoming more complex (Koskela 2014). Construction Productivity increases have lagged other industries McKinsey (2017), presented in Figure 1. The Irish experience directly mirrors this with construction costs in Dublin expected to increase by 7% in 2018 (Turner and Townsend 2018). Skills shortages affecting main contractors, specialist Sub-contractors and Architects mean that prices are expected to equal 2007 boom time prices, in 2019 (Linesight 2019).

[1] Managing Director, Crystal Lean Solutions, Limerick, Ireland + 353 87 622 6899 maria.ryan@Crystalleansolutions.ie

[2] Director, Crystal Lean Solutions, Limerick, Ireland + 353 87 771 4246 christy.murphy@crystalleansolutions.ie

[3] Associate Director, Ardmac Ltd, Swords, Dublin, Ireland +353 86 855 3342 jason.casey@ardmac.com

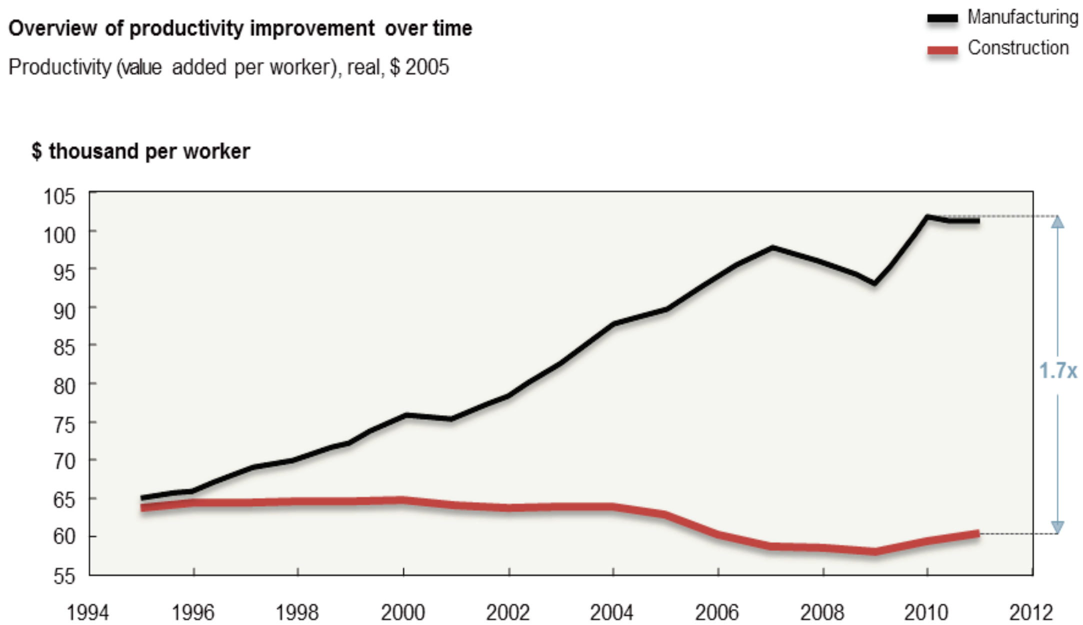


Figure 1. Construction productivity compared to manufacturing productivity 1995-2012 McKinsey (2017)

LITERATURE REVIEW

THE ORIGINS OF LEAN AND LEAN CONSTRUCTION

The term lean production was first popularised by the seminal book "The Machine that Changed the World", published by Womack, Jones and Roos (1990). The book highlighted the significantly higher levels of performance from Toyota as compared to the rest of the automotive industry. At Toyota, Taichi Ohno had already spent many years developing what became known as the Toyota Production System, drawing influences from many sources including the American Supermarket system upon which Just in Time (JIT) concept was based (Ohno 1988). The evolution of the Toyota production system mirrored that of the Total Quality Management paradigm originating in the USA, travelling to Japan and then being disseminated to the rest of the world from there. There are many detailed accounts of the origins of Lean and its subsequent transformations in the literature Holweg, (2007) Shingo, (1989), Samuel Found and Williams (2015).

Lean Construction then, is the application of the concepts of the Toyota Production System to the Construction Project context. The drivers for applying Lean in Construction have been described citing objectives such as waste elimination, process control, flexibility, value to the customer (Ross and Associates 2004). The adoption of "Lean Construction" has been cited as a potential solution in the Irish Context (Ebbs et al 2015).

To close the productivity gap, McKinsey (2017) recommend a focus in improving the project planning and execution process. Issues within the project management process have been well documented in the literature Howell and Koskela (2000) Sundararajan and Madhavi (2018). Koskela et al (2014) highlight issues with the widely used Critical Path methodology for project planning and control within the industry. LPS is often viewed as the basis for Lean Construction (Daniel et al 2015).

LAST PLANNER® SYSTEM

The Last Planner® System (LPS) focuses on the creation of predictable and reliable workflow in construction production Mossman (2018). It was developed in 1992 by Glen Ballard and Greg Howell with the following five Stages

1. Milestone Planning
2. Phase/Pull Planning
3. Make Ready/Lookahead Planning
4. Weekly Work Planning
5. Doing and Learning

The Lean Construction Institute, LCI (2015) reports that the adoption of the Last Planner® System is growing. Daniel et al (2015) found that USA and Brazil have the highest implementation of cases, 37, with 11 cases reported from Norway, UK and Finland feature from a European perspective. There were no cases reported from an Irish perspective.

Viana et al (2010) found that 95.5% of the practitioners interviewed perceived improvements as a result of LPS. To understand the benefits and challenges of the Last Planner® System, a literature review was completed across 61 cases from the USA, Asia and Brazil, Chile, United Kingdom, Finland and New Zealand. The timeframe for these cases range from 2002 to 2016.

Table 1 sumarises the benefits of the LPS from the literature review across a variety of client types. The topmost benefits include improved project delivery, more reliable planning and expansion of knowledge by the entire team.

Table 1. Perceived Benefits of the Last Planner® System

Number	Benefits	Source
1	Improve project delivery / reduce production time	Fernandez-Solis et al. 2013; Viana et al (2010); Alarcón et al (2002); Fiallo et al (2002); Mejía-Plata et al (2016)
2	More reliable planning	Fernandez-Solis et al. 2013; Johansen et al 2010, Viana et al (2010); Johnansen et al (2003);
3	Knowledge expansion and learning among project teams	Fernandez-Solis et al. 2013; Viana et al (2010); Alarcón et al (2002)
4	Improved Communication within team	Fernandez-Solis et al. 2013; Viana et al (2010)
5	Improved supply chain integration	Fernandez-Solis et al. 2013; Alarcón et al (2002)
6	Enhancement of managerial practices in construction	Fernandez-Solis et al. 2013; Viana et al (2010)
7	Improvement in quality of work practice at construction site	Fernandez-Solis et al. 2013
8	Less Firefighting or fewer day to day problems	Fernandez-Solis et al. 2013

Table 2 summarises the key challenges from the literature review. Resistance to change, lack of experience and training on the system and lack of time to implement the system are the topmost challenges cited.

Furthermore, in a similar study of the challenges, Porwal et al (2010) identified challenges including resistance to change and lack of training reported within the top three challenges presented.

Viana et al (2010) investigated the perceived benefits and challenges, in Brazil, from the perspective of three managerial levels; site engineers, foremen and crew leaders. The research found that perceived benefits were similar across all 3 levels. In terms of challenges, Engineers identified their primary challenge as lack of time for planning whereas Foremen perceiving the change of culture as the primary challenge. While a difference in perspective, both challenges feature in the top 3 challenges identified in Table 2.

Table 2 Perceived Challenges of the Last Planner® System

Number	Challenges	Source
1	Resistance to change	Fernandez-Solis et al. 2013; Mejía-Plata et al (2016); Hunt et al (2018); Alarcón et al (2002); Viana et al (2010); Koskenvesa et al (2005)
2	Lack of Experience of LPS / lack of training / Quality of information	Fernandez-Solis et al. 2013; Mejía-Plata et al (2016); Alarcón et al (2002); Viana et al (2010); Johansen et al 2010
3	Lack of time to plan / implement	Alarcón et al (2002); Viana et al (2010); Johansen et al 2010
4	Misinterpretation of PPC indicator	Fernandez-Solis et al. 2013; Alarcón et al (2002)
5	Partial or Late implementation of LPS	Fernandez-Solis et al. 2013; Hunt et al (2018)
6	Short term vision	Fernandez-Solis et al. 2013; Alarcón et al (2002)
7	Lack of stakeholder support	Fernandez-Solis et al. 2013; Mejía-Plata et al (2016)
8	Poor use of information generated during implementation	Fernandez-Solis et al. 2013; Viana et al (2010)
9	Lack of commitment/leadership to LPS implementation	Fernandez-Solis et al. 2013, Hunt et al (2018)
10	Bad team chemistry or lack of collaboration	Fernandez-Solis et al. 2013

The above literature review highlighted a dearth of cases reported from Ireland. To address this gap in the literature, the researchers focus their investigation into the benefits and challenges of Last Planner® System within an Irish context. In doing so, both from an economic and academic perspective, this research seeks to further add to the body of knowledge around the Last Planner® System. The research focuses on two additional perspectives. This first is to consider the perspective of two client segments; Pharmaceutical and Fit Out, to compare findings. The second perspective layered into the research is from the perspective of two levels within the organization; Leadership and Direct employees, building on research by Viana et al (2010).

RESEARCH METHODOGY

Case study research methodology was selected as the research instrument within one organisation (Yin 2009). The primary data came from qualitative data collection from an online survey (Fowler 2013). The secondary data was taken from analysis of a pilot project undertaken within the client company in 2015 yielding useful quantitative data. Case studies have become one of the most common ways to do qualitative research (Stake 2003) An evidence-based approach from the literature review, summaried within Table 1, Table 2 and Viana et al (2010), was utilised to provide a framework for the survey design. The survey included both open and closed questions to elicit an analysis of perceived benefits and challenges of the LPS within an Irish context.

The survey was sent to two sub groups in terms of management Levels at case organisation; Leadership and Direct Staff. Leadership include Operations Managers and Directors. Direct Staff include Site Managers, Project Managers and Staff reporting into these roles. These sub groups were designed to facilitate a comparison to Viana et al (2010) research.

Two client sectors within the case study were selected; Pharmaceutical and Fit Out. The survey design included a question to identify the client type that the participant supported. This question allowed for the comparison of the perceived benefits and challenges of the LPS between client sectors supported by the case study organisation.

Reliability of qualitative data was designed into the survey through closed questions and the survey was piloted and refined (Fowler 2013). Additional questions were included in the design to ensure validity of the qualitative data.

A critical analysis of data collected was completed by two of the researchers, who are independent External Consultants of the case study organisation. Qualitative data collected were analysed using a thematic analysis (Braun et al 2006). Secondary data was also available from a pilot project undertaken by the case study company, which is also included in this research.

LIMITATIONS

Limitations of the research is recognised by the researchers including a single case study organisation, part time nature of the researchers and a small sample size. Limitations of the research were mitigated per Hines et al. (2018).

CLIENT ORGANISATION

Ardmac is an Irish Construction company that deliver high value workspaces and technical solutions. It supports customer sectors including Pharmaceutical, Fit Out, Design and Build and Data Centres across Ireland, UK and Europe. Ardmac adopted the application of the Last Planner® System in 2015, starting with a project within the Pharmaceutical sector. Leadership fully committed to the deployment of the Last Planner® System, with all projects mandated to use this system from the start of 2018. All Employees using Last Planner® were trained on the application of the LPS.

KEY FINDINGS

RESULTS AND ANALYSIS OF BENEFITS OF THE LAST PLANNER® SYSTEM

The survey was delivered on line to 250 people, of which 49 respondents used the Last Planner® System from both Leadership and Direct Employees. Both Pharmaceutical and Fit Out client sectors were represented in the data collected.

From the analysis of the data presented in Table 3, 92% of respondents perceived the LPS is of benefit which is aligned to 95.5% of respondents from Viana et al (2010). From this study, there is a 12% difference in perception between Leadership and Direct Employees, with Leadership more positive compared to Direct Employees.

Table 3 Percentage of Participants who Perceive LPS as Beneficial

Group	LPS	Pull Plan	Constraints Log	Weekly Work Plan
All Respondents	92%	94%	98%	98%
Leaders	100%	93%	100%	100%
Employees	88%	95%	96%	98%

Reliability of the data is supported, with the perceived benefits of the individual elements of the LPS comparing favourably to the overall benefit of the LPS (94%, 98% and 98% for Pull Plan, Constraints Log and Weekly Work Plan respectively compared to 92% overall %).

The perception of participants that support Pharmaceutical and Fit Out sectors are presented in Table 4. Participants that support Pharmaceutical clients perceive the LPS to be of more benefit when managing LPS projects compared to the shorter lead time projects within the Fit Out sector. Participants from the Pharmaceutical sector are aligned with Viana et al (2010) research of 95%. Fit out projects are 17% less than Viana et al (2010) research.

Table 4 Perception of the benefits of the LPS across two client sections

Sector	% Perceive LPS beneficial
Pharmaceutical	95%
Fit Out	78%

From the thematic analysis of the perceived benefits in Table 5, five key benefits were identified; improvement in planning accuracy, improvement in real time control of a project, improved proactive control, improved engagement and improved design quality for construction. 61% of respondents identified improved planning and real time control as the top 2 benefits of the LPS. This finding is similar to the findings from Fernandes-Solis et al (2013) and the literature review summary in Table 1, where more reliable planning was considered a key benefit. It was noted in Table 5 that Leadership place more emphasis on improved planning accuracy compared to Direct Employee responses.

Other themes noted in Table 5, that align with the literature review in Table 1, include improved proactive control and less firefighting resulting from a Last Planner® System approach. Real time project control in Table 5 from the case study aligns with improved communication from the literature review and improved communication in Table 1.

Table 5 Benefits of the Last Planner® System

Benefits of Last Planner® System	All Responses	Employee Responses	Leader Responses
Improved Planning Accuracy	40%	24%	55%
Improved Real-Time Control	21%	33%	9%
Improved Proactive Control	19%	19%	18%
Improved Engagement	14%	14%	14%
Improve Design Quality for Construction	7%	10%	5%

When comparing the improvement in quality, it was noted that while the case study findings were similar with respondents perceiving an improvement in quality, what was different was the focus in improvement. The focus for the case study highlighted that there was an improvement in Design quality from Table 5. From the literature, Fernandes et al (2013) within Table 1, presented the focus on an improvement in quality of work practices at the construction site.

RESULTS AND ANALYSIS OF CHALLENGES OF THE LAST PLANNER® SYSTEM

From the thematic analysis of perceived challenges, five key themes are summarised in Table 6 as follows; lack of full engagement, lack of customisation to suit client type, lack of time to implement, person versus process focus with PPC indicator and lack of standardisation across projects.

Table 6 Perceived Challenges with Last Planner® System

Challenges of Last Planner® System	All Responses	Employee Responses	Leader Responses
Lack of Full Engagement	31%	18%	40%
Lack of Customisation to suit client type	23%	55%	0%
Lack of Time to Implement	19%	9%	27%
Other	12%	0%	20%
Person versus Process Focus when using PPC indicator	8%	9%	7%
Lack of Standardisation across projects	8%	9%	7%

When compared to the literature review, the case study findings in Table 6 align with the challenges outlined in Table 2 and cite lack of time to implement the LPS (19%) in the top 3 challenges. Lack of full engagement represents 31% of the key themes identified in Table 2, which aligns with resistance to change from the literature in Table 2.

In contrast, the case study organization highlights a number of different challenges with the Last Planner® System. While lack of training features in the literature in Table 2, it was absent from the case study challenges. It is noted that 100% of participants in the case study company have all received LPS training. This may provide an insight into why training was not identified as a challenge at the case study organization.

Table 6 identifies a second difference to the literature review in Table 2. The case study identifies lack of customisation across projects as a challenge, which is not evident in the literature. This lack of customisation may explain the 17% difference in perception between client sectors reported in Table 4. The case study organization operates in different client sectors, with the data indicating that customisation of the system may be required to meet different client sector types. A third difference identified in Table 6 was a lack of standardisation across projects compared with the findings in Table 2.

ANALYSIS OF SECONDARY DATA

Table 7 summarises the quantitative benefits for the first Last Planner® System project completed in 2015 (Lean Construction Ireland Book of Cases 2018). From the data presented, there are significant quantified results present in the areas of Safety, Quality and Labour ratio.

Table: 7 Benefits from the Implementation of the Last Planner® System (LCI Book of Case Studies 2018)

Metric	Improvement
Safety	Zero first aids / near misses
Quality	Reduced no of defects at client walkdown from 9 to 3.4
Labour Ratio	10% reduction in Labour to budget ratio

CONCLUSIONS AND RECCOMMENDATIONS

With the global and Irish construction sector experiencing growth, the adoption of the Last Planner® System is also growing. A literature review was completed, and both the perceived benefits and challenges of the System were identified. Case study research was completed within one case study organization and the perceived benefits and challenges were compared to the literature review. 95.5% of cases analysed by Viana et al (2010) compared to 95% of the case study research agree that the Last Planner® System is of benefit. Key benefits identified from the literature and the case study were aligned with improved project delivery, more reliable planning and improved engagement cited in both. Secondary data presented the benefits from one project, with improvements in safety and quality cited. Time to implement was identified as a common challenge between the literature and case study. The case study presented different challenges including lack of customization to suit a client sector and lack of standardization. The limitations of the study are acknowledged, including part time researchers and application to one case study organization. Further research is recommended both from an Irish context and also to investigate further how to overcome the challenges identified from the case study.

REFERENCES

Alarcon, LF, Diethelmand, S, and Rojo, O (2002) Collaborative implementation of Lean Planning systems in Chilean construction companies. Paper presented at the 11*th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil, xx-xx July 2002

Braun, V. and Clark, V., (2006) “Using thematic analysis in psychology” Qualitive Research in Psychology, 3 (2) pp. 77 – 101.

Daniel E.I, Pasquire, C., and Dickens, G., (2015), “Exploring the Implementation of the Last Planner® System through IGLC Community: Twenty-One Years of Experience”, In: Proc. 23rd Ann. Conf. of the Int’l. Group for Lean Construction. Perth, Australia, Ebbs P, Sexton P, Greensmith DG, Clare BG, Gibson V and Turner (2015) "Lean Construction Theory and Practice: An Irish Perspective" In Proc 23rd annual Conference of the International Group for Lean Construction

Fernandez-Solis J, Porwal V, Lavy S, Shafaat A, Rybkowski,Z, Son K,and Lagoo N, (2013) "Survey of Motivations, Benefits, and Implementation Challenges of Last Planner® System Users" Journal of Construction Engineering and Management

Fiallo, M and Revelo, VH (2002) Applying the Last Planner® control system to a construction project:A case study in Quito, Ecuador. Paper presented at the 11*th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil, xx-xx July 2002.

Fowler, F.J. Jr (2006) "Survey Research Methods, 5th Edition" Centre for Survey Research, University of Massachusetts Boston, USA

Hines, P. Taylor, D. & Walsh, A. (2018): The Lean Journey: Have we got it wrong?, Total Quality Management & Business Excellence

Holweg, M. (2007) The genealogy of Lean production. Journal of Operations Management.

Howell and Koskela (2000), "Reforming project management: The role of Lean construction" In 8th annual Conference of the international group for Lean Construction

Hunt, R.J, and Gonzalez, V.A. (2018)" Innovation in the New Zealand Construction Industry – Diffusion of the Last Planner® System"

Irish Government (2018), "National development plan 2018-2017" Online https://www.per.gov.ie/en/national-development-plan-2018-2027/

Johansen, Eric and Porter, Geoff (2003) "An experience of introducing last Planner® into a UK construction project". In: The 11th annual conference of the International Group for Lean Construction, 22 - 24 July 2003, Blacksburg, Virginia, USA.

Koskela L (1992), Application of the new production philosophy to Construction, CIFE Technical report #72

Koskela L, Howell G, Pikas E & Dave B (2014), "if CPM is so bad, why have we been using it so Long?" in Proc. 26th Annual Conference of the International Group for Lean Construction

Koskenvesa, A and Koskela, LJ 2005, *Introducing last Planner® - Finnish experiences*, in: 11th Joint CIB International Symposium - Combining Forces., 13– 16 June 2005, Helsinki, Finland.

Lean Construction Institute, (2015). The Last Planner®. [Online] http://www.leanconstruction.org/training/the-last-Planner®

Linesight (2018) Ireland Market Review -Section Updated 2018, *https://www.linesight.com/knowledge/2018/ireland/ireland-market-review*

McKinsey (2017) "Reinventing Construction: A route to higher productivity", Mckinsey Global Institute

Mejía-Plata et al (2016) "A Route Map for Implementing Last Planner® System in Bogotá, Colombia, 24th Ann. Conf. of the Int'l. Group for Lean Construction, At Boston, MA, USA

Mossman, A., (2018) "What is Lean Construction: Another Look- 2018" In 26th annual Conference of the International Group for Lean Construction

Ohno T. (1988) The Toyota Production System: Beyond Large Scale Production. Cambridge, MA: Productivity Press.

Porwal, V., (2010). Last Planner® System – Areas of Application and Implementation Challenges. M.Sc. Thesis in Construction Management Submitted to the School of Graduate Studies. A&M University: Texas

Ross and Associates (2004) Findings and Recommendations on Lean Production and Environmental Management Systems in the shipbuilding and ship repair sector, EPA contract No 68-W-03-028, US Environmental Protection Agency, available at https://archive.epa.gov/sectors/web/pdf/leanems_report-2.pdf

Samuel, D,. Found, P., & Williams, S. (2015) How did the publication of the book the machine that changed the world change management thinking? Exploring 25 tears of Lean literature. International Journal of Operations and Production Management.

Shingo, S. (1989) A study of the Toyota Production System from an Industrial viewpoint. (A.P. Dillon, Trans) Portland OR.: Productivity Press

Stake, R.E., (2003) Case Studies PDF accessed online https://www.sfu.ca/~palys/Stake2003-CaseStudies.pdf

Sundararajan S and Madhavi T (2018). "Last Planner® implementation in Building Projects," in Proc. 26th Annual Conference of the International Group for Lean Construction

Turner and Townsend (2018) International Construction Market Survey 2018, Online *https://www.turnerandtownsend.com/en/insights/international-construction-market-survey-2018/*

Viana D, Mota B, Formoso C, Echweste M, Peixoto M, Rodrigues C, (2010) " A survey on the Last Planner® System: Impacts and difficulties for implementation in Brazilian companies." in Proc. 18th Annual Conference of the International Group for Lean Construction

Womack J.P, Jones, D.T, and Roos, D. (1990) The Machine that changed the world. New York: Rawson Associates.

Yin, R.K. (2009), "Case Study Research – Design and Methods", Applied Social Research Methods Series Vol. 5, 5th Edition, Sage, Newbury Park,

McHugh, K., Dave, B, and Ray C (2019). "Integrated Lean and BIM Processes for Modularized Construction – A Case Study" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 227–238. DOI: https://doi.org/10.24928/2019/0252. Available at: <www.iglc.net>.

INTEGRATED LEAN AND BIM PROCESSES FOR MODULARISED CONSTRUCTION – A CASE STUDY

Kevin McHugh[1], Bhargav Dave[2] and Craig Ray[3]

ABSTRACT

Integrated lean and BIM practices have a proven track record of improving the efficiency of the construction project lifecycle as demonstrated by several case studies and research projects. Lean and BIM synergies range from design coordination to pre-construction, production management and eventually handover and operations. Similarly, offsite manufacturing and modularisation also has a proven track record of improving the efficiencies of the production phase and there are significant synergies between lean and offsite. Although lean construction is increasingly being applied on construction projects, applications that support its implementation on construction site remain limited. Production is significantly managed through manual processes and disparate systems. Previous case studies have proven that the use of BIM with lean practices during the construction phase improves the efficiency of planning.

One of the major aspects of lean and BIM implementations is the support of the Last Planner System and tracking of production status to ensure production runs smoothly. While 4D planning has been used to support pre-construction planning and first run studies, it has had limited success with tracking real-time production status and supporting the Last Planner System.

This paper provides an insight into an integrated lean and BIM implementation project supporting a highly modular and offsite production process on a data centre project. The case study highlights how lean and BIM can help the team to visualise the production plans, control the production in the field, report accurate production status and support the continuous improvement process.

KEYWORDS

Lean construction, BIM, Offsite Manufacturing, Digitisation, Lean and BIM.

INTRODUCTION

Production management in construction is directly linked to successful completion of construction projects, and yet an area that remains relatively ad-hoc and dependent on

[1] Associate Director, Mace Group, Kevin.McHugh@macegroup.com
[2] CEO, VisiLean Oy, Kirkkokatu A12, Helsinki, 00170, bhargav@visilean.com
[3] Project Director, Mace Group, Clonee, Ray.Craig@macegroup.com

manual processes (Zhang 2005). In terms of productivity, a meta-analysis of wasted time in construction by (Horman and Kenley 2005) reported that over the last 30 years, almost 49.6% of time was wasted during construction in non-value adding activities. Similarly, a research carried out in Sweden showed that only 15-20 % of the workers time is spent in direct work (i.e. carrying out the planned activity) (Jongeling and Olofsson 2007). There are similar studies around the world, which have reported sub-optimal performance of construction projects in terms of productivity and efficiency (Ramaswamy and Kalidindi 2009; Teicholz et al. 2001). These observations can be directly linked to sub-optimal performance of the production management systems in construction.

A production management system can be defined as a set of tools and processes that are put together to tackle the construction process on a given project. It is a complex system that encompasses a wide range of sub-systems including (but not limited to) planning and scheduling, procurement, production control, design management, subcontract (or human resource) management and various other support systems such as safety, and quality management. All these sub systems have to be effectively managed in order for the production management to perform efficiently.

On a higher level, it can be said that production management tackles two main types of information flows, i.e. product flow and process flow (Sacks et al. 2010). The product flow deals with design related knowledge, i.e. what is to be built/constructed; whereas the process related flows deal with the process of construction itself, i.e. how, when, where and who of the construction process. Production management in construction is also information intensive in nature, where systems at various operational levels including office and site based organisations have to be in constant interaction with each other.

One of the biggest factors that causes waste on construction projects is variability. It has been long argued that offsite manufacturing can reduce variability and improve flow on construction projects. Offsite manufacturing or modular construction also improves aspects such as safety and quality as production happens in a controlled environment. From this perspective, offsite manufacturing helps achieve many lean principles.

This paper explores a hypothesis that integrated lean and BIM practices can support modular construction and help improve production efficiencies. The paper begins with an introduction to the subject area followed by a brief literature review on integrated lean and BIM practices. A case study is presented where an integrated lean and BIM system was implemented to support modular/off-site production on a data centre project in Dublin, Ireland. This is followed by discussion and conclusions.

LEAN BIM AND DIGITAL – A STATE OF THE ART REVIEW

Recently, an increasing number of researchers have discussed the potential synergies between Lean Construction and Building Information Modelling (BIM) (Oskouie et al. 2012; Sacks et al. 2010; Shou et al. 2014). Simultaneous implementation of BIM and lean in the field has also shown promise as exemplified by recent case studies (Eastman et al. 2011). While the lean construction concept addresses the problems inherent to the construction process, BIM overcomes the hurdles that the 2D Computer Aided Design

(CAD) technology presents and offers solutions to efficiently handle the product model (of the construction project).

Some key aspects that emerge strongly support the notion that the synergy of Lean Construction and BIM spans the entire lifecycle of the project and not just design activities. In the original study on identifying lean and BIM synergy (Sacks et al. 2010) it was found that three lean principles had the most interactions with BIM functions (i.e. they are best supported by BIM): i) reduction of waste by getting the quality right first time (through a better designed product, reducing the product variability, i.e. changes during the later stages of design); ii) improving flow and reducing production uncertainty which eventually leads to; iii) reduction in overall construction time.

It can be deduced that simultaneous implementation of Lean and BIM can lead to a successful project delivery. Several initiatives in the past have addressed the synergistic potential of these two aspects in construction.

CURRENT STATE OF THE ART IN LEAN AND BIM INTEGRATION

In an effort to evaluate the impact of what was termed 'Computer Advanced Visualisation Tools' (CAVT), (Rischmoller et al. 2006) used a set of lean principles as the theoretical framework. Based on the case studies conducted over a four year period, it was concluded that application of CAVT results in waste reduction, improved flow and better customer value, indicating a strong synergy between the lean construction principles and CAVT. Here, the authors use the term CAVT in place of BIM.

In another attempt to integrate lean construction processes with BIM, (Khanzode et al. 2006) attempted to provide a conceptual framework to link Virtual Design & Construction (VDC) with the Lean Project Delivery Process (LPDS). The authors claim that the "VDC approach allows a practitioner to build a symbolic model of the product, organization and process (P-O-P) early before a large commitment of time or money has been made to the project". (Gilligan and Kunz 2007) reported that the use of VDC in an earlier project was considered to contribute directly to the implementation of lean construction methods

(Sacks and Barak 2008) discussed the potential contributions of BIM to visualisation of the product and process aspects of construction projects in terms of lean construction principles. They provided examples that illustrate the use of BIM and related technologies to enable a "pull flow" mechanism to reduce variability within the construction process. (Sacks et al. 2010) have developed a research framework and prototype called KanBIM. The main goal of KanBIM research is to propose, develop and test a BIM-enabled system to support production planning and day-to-day production control on construction sites.

(Dave et al. 2011; Dave 2013) proposed VisiLean that aimed to integrate the Last Planner workflow with BIM. VisiLean was developed to support the lean production management workflow on the job site and to support the production crew/site teams collaborate effectively (i.e. the Last Planners). From this perspective, the proposed system primarily addresses two major strands of the production system: i) production management process representation; ii) product representation and visualisation. Additionally, there are further requirements to support the i) communication between operatives and; ii) delivery of accurate reports to facilitate better decision-making.

While previous research and certain case studies proved the successful synergy between lean and BIM in construction, commercial software to support these interactions were not present until now. Also, majority of commercial software provided pointwise solutions, i.e. either BIM, top-down project management or bottom-up sticky note type isolated planning software that prevented an integrated approach to production management with lean and BIM. Commercialisation of VisiLean concept aimed to bridge this particular gap within the construction management domain.

CASE STUDY

PROJECT BACKGROUND

Undertaken by Mace Ireland, Project CLN, is a commercial development consisting of three single-storey data centres, split into three phases, to be powered by a purpose built 220kV Substation (also part of the campus), on a 95 hectacre (Ha) greenfield site in Clonee, Co Meath, Ireland. The data centre buildings include roof top mechanical equipment and measure up to 8.6m to the roof eaves, with a parapet wall up to 9.1m and a roof mounted plant screen wall around roof mechanical equipment up to 15.9m. The site infrastructure includes access roads, car parking, internal roads, entrance security hut, landscaping and a 220kV substation.

The 3rd phase of the project required the construction of a third single storey data centre building containing 4 data halls with a gross floor area of 25,400m2 and a data capacity of 36MW and in addition, an ancillary administration and office building of 4,360m2 and associated parking.

MODULARISATION

Prior to the modularisation, the assembly process for the fit-out of data halls featured a "stick built" method of assembling the support grid, which includes all of the high-level services. Later, the current state mapping highlights many challenges; Each component had to be assembled at height which brought with its obvious safety and programme risks. It's also a very time-consuming process, tying up large work areas at any one time and preventing multiple contractors from being able to work concurrently. As such it forces linear working methods, where each activity is dependent on one another, elongating lead-times.

The team took a system thinking approach to the problem and looked holistically at the product, the process along with the management system. The Mace DfSMA (Design for Safety, Manufacturing and Assembly) approach was used in conjunction with Lean process analysis and improvement methods to identify a Modular solution along with a future state process.

The team designed and developed a pre-fabricated frame, which could be constructed at ground level to reduce the work at height. A purpose-built temporary factory facility was set up on site to accommodate the efficient assembly of the modules and minimise transportation time / distance into the data hall for fitting.

Considering the installed pre-fabricated frame with all the fit-outs as a final production unit or "Module", the entire production system required to be formulated for hundreds of modules up to micro details considering logistics, production pace, resource availably, and process constrains.

Figure 21. Different trade contractors are discussing their upcoming activities, contains and issues in the weekly planning meeting.

Entire process involved different organisations with dedicated teams doing numbers of internal handovers. Slight delay in these handovers can pose a considerable impact to the production flow and subsequently the overall production as knock-on effects would impact the forward tasks. Additionally, the monitoring and tracking of micro-level production plan is burdensome yet crucial to be proactive in production control and management. On top of that, the necessity of having elaborated execution planning takes significant administrative work. The team made use of a highly sophisticated collaborative digital room for such coordination meeting as can be seen in Figure 21.

Managing and coordinating such production system requires significant efforts on a daily basis. In such instances, management team's major focus gets directed to the coordination and work administration rather than addressing the issues and providing better working environment for the execution. Therefore, an inevitable demand for highly-functional management system which can deal with the detail and dynamic complexities posed by mentioned production system was gradually increasing.

The team had been using the Last Planner System to better manage lookahead and weekly work plans and commitments using the traditional sticky notes approach. However, the lean champion felt the need to improve the process with an electronic last planner tool that would help with not just micro level planning but integrate it with the overall plan and the building information model in order to improve predictability and tracking. The team identified VisiLean as a potential system that would replace the traditional sticky notes with a systematic planning and execution system.

LEAN AND BIM IMPLEMENTATION

For the communication ease, entire data centre is divided into four zones namely Zone-A, Zone-B, Zone-C, Zone-D. Each zone has specific number of modules to be installed. Accordingly, the schedule was developed with respect to the zones.

During the phase planning, this zone level schedule was further elaborated by the project team to the module level. By using digital tickets, collaborative planning meetings were successfully Implemented keeping 3D model as a reference for interactive discussions rather than flowing through dozens of 2D drawings. Figure 22 illustrates the setup for collaborative meetings comprising 4D planning in cognizance with the relevant information.

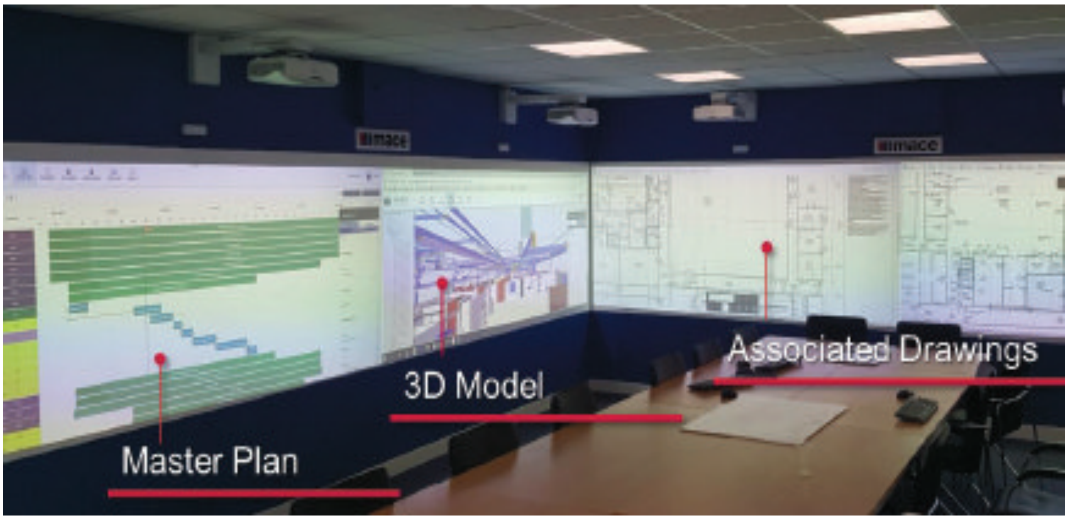


Figure 22. picture of digital display room setup, having plan and 3D model side by side along with the associated drawings

Now for detailing out the production process and the sequence, look ahead meetings were held where micro level planning was conducted. VisiLean dynamically linked lookahead planning and production control to the 3D model, transforming BIM into a visual planning tool enabling anyone to see at a glance the current build status. With the help of Visilean, the team tracked assigned responsibilities and the make-ready process. Lookahead planning was no longer confined to sticky notes and hidden in a room but integrated into a complete planning system where previously generated tickets can be used as a base for elaborated construction planning.

Here the challenge was to assign all the makeready details not only to the modules but also to the subprocesses in the module production. It takes a significant amount of efforts to carryout makeready process for each task in the micro-schedule. However, unlike using sticky notes, the project team was easily able to attach all the necessary details with the ticket itself. After the look ahead meeting each ticket (microlevel task) of the construction schedule would able to provide details like Makeready date, location, priority, important documents, qualities, plan constraints, notes etc. During the meeting, the tasks were assigned to the relevant organization member, who would then be able to provide status information using the mobile app. Figure 23 and Figure 24 show the lookahead planning along with allocation of tasks to workers using the VisiLean system.

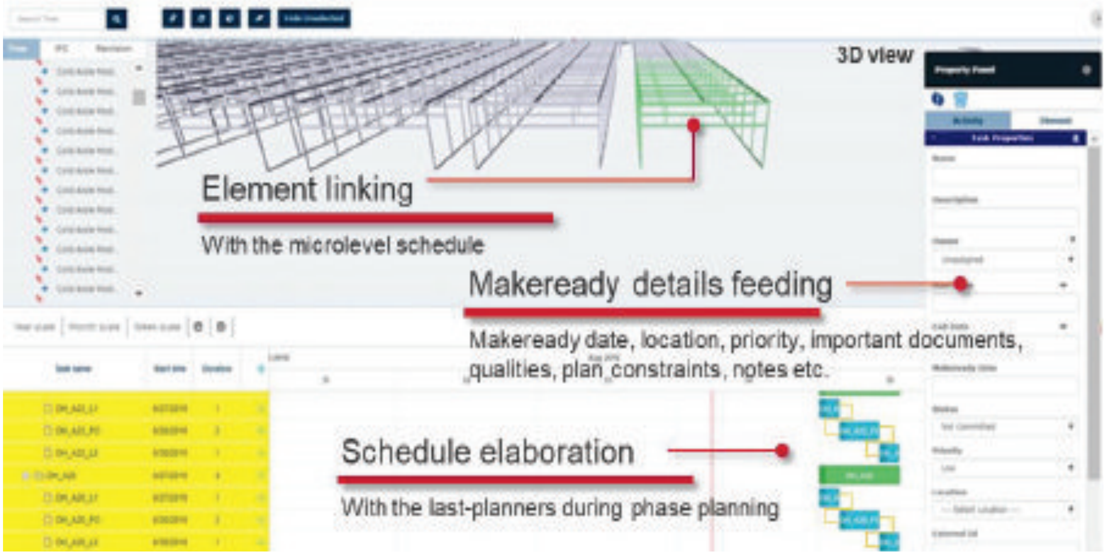


Figure 23 Creating elaborated schedules with makeready details in the Visilean.

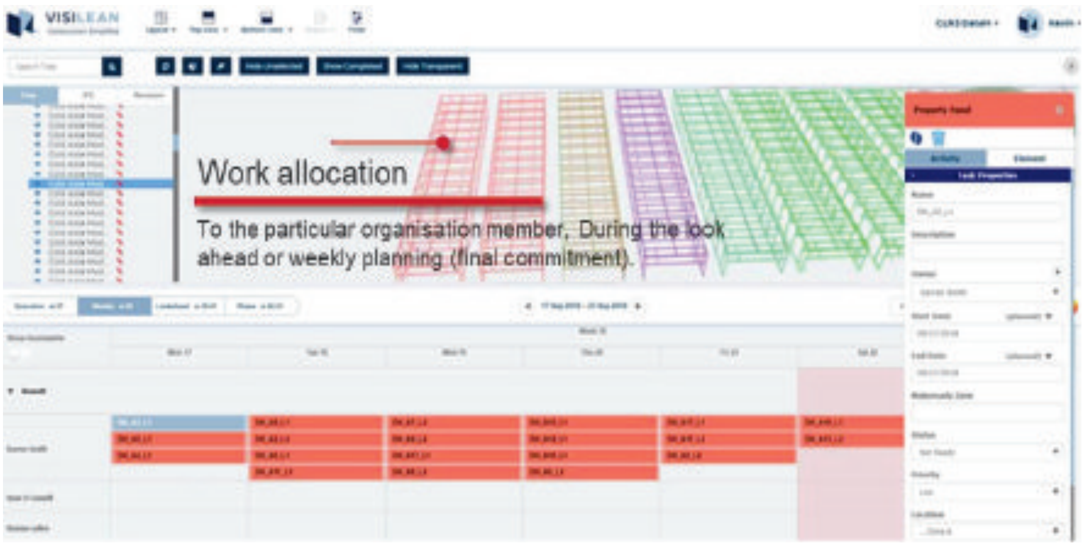


Figure 24 work allocation though commitments for the modules

Whilst conducting weekly planning, project team would primarily focus on the issues that has been raised during the make ready process. preliminary constrains or clashes for workspace, material, equipment, manpower, design were identified during this process. Later, the prominent issues are discussed and sorted out in the weekly meetings, and the final commitments for upcoming week scheduled were being made.

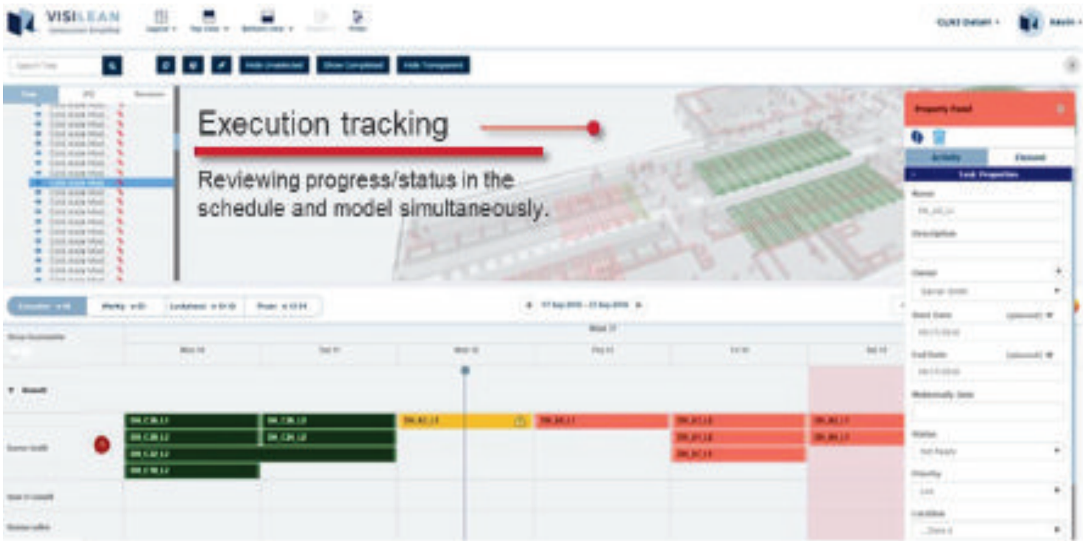


Figure 25 Visilean interface showing module progress tracking using colour coding in schedule as well as 3D model.

Asking for commitment for dynamic schedule was really challenging for the project team. Here, the Kanban style ticket approach to the execution was used to overcome this challenge, where the handovers to the different gangs has been achieved through push notification.

One of the critical issues earlier had been tracking progress and making reliable handovers within the team. In this context, the supervisors used Visilean mobile apps to update their work status directly using their smartphones/tablets which enabled smooth handovers as it prompted the subsequent task managers in real-time. Moreover, the task associated stopage or breakdown data was helpful in analyzing the planning efficiency and continuous improvement. As soon as a task finished, a notification to quality-supervisor was sent for checking the work. During execution, the system enabled supervisors to confirm task status in real-time out on site and triggered immediate notifications to follow on trades, enabling efficient and effective baton exchanges. Figure 26 shows the stoppage and warning tasks within VisiLean using "Andon" style colour coding for monitoring the work.

Figure 26 Issue/stoppage and warning alert in the Visilean.

Figure 27 Integrated production plan with BIM in VisiLean.

The project team had a federated model available to them at LOD 450 level which could help them track work progress if it was connected with VisiLean. The VisiLean team helped integrate the BIM model with lookahead and weekly plan level. This enabled a unique "lean 4D" view within VisiLean that would visually show past, current and future plans with corresponding model elements in a colour coordinated fashion. Figure 27 shows the "lean 4D" view with the model on top and a weekly plan at the bottom to show the status of the current execution and work statuses. The bottom section shows the plan, with the top section dynamically linked to the model. With one glance the production and management teams can clearly see what modules are still to be completed and when this is planned to be done (indicated in red). In case of any problems, the management team could take proactive action to help streamline production.

DISCUSSION

While previous lean and BIM projects were achieved through manual intervention of internal and external consultants and integration of various different systems, scaling their implementation on larger more complex projects has been challenging. Sustainment of the integrated lean and BIM effort in this case was achieved through the adoption of the management systems deployed (VisiLean and Last Planner), coupled with a dedicated team and a collaborative culture supported by the Project Director. A regimented process that was developed in collaboration with supply chain members that ensured discipline in the planning, scheduling and control processes alongside digital solutions such as VisiLean made sure that on-field process clashes were avoided and learning was improved.

The management of trade handovers was improved using 4D tools to track the activities. As a task flowed through various statuses, the team could follow this visually and take proactive action whenever necessary. The collaborative planning system allowed greater communication between trades and identified opportunities to improve the workflow in each area.

Using the data provided by VisiLean, opportunities for improving the installation process were identified. By using the data collected by VisiLean, the production process was continually improved as there was a rich source of live information. Bottlenecks were identified, material management, lobour allocations and potential safety issues were identified. This allowed the teams to collectively improve their productivity and streamline the installation process. This resulted in a 30% time improvement from the first data hall installation to the fourth data hall.

Without the management system integrated into the solution, the module design alone would not have delivered the actual benefits realised from deploying a complete construction system. Such a solution would not have been possible without a fully committed leadership team that can spread an infectious appetite for change, continual learning and a clear passion to exceed the expectations of the customer.

CONCLUSIONS

This project attempted to set the standard for data centres across the globe and is seen in the eyes of the customer as the benchmark site for construction excellence. The project aimed to use leading edge innovation as it tried to encapsulate a construction solution going beyond design, to include, product, process and performance management. It is a systematic solution that achieved significant benefits through collaboration and active engagement of the entire supply chain. It is one of the first projects of its kind (in terms of size and complexity) globally to implement a cloud based production planning and tracking system that integrates the Lean processes with BIM in form of VisiLean. Ultimately the solution has delivered a project safer, quicker and to a higher quality, whilst creating a better working environment. Some of the benefits measured as part of the implementation were; i) 75% reduction in working at height, ii) 60% reduction in defects, iii) 43% improvement in program efficiency, iv) 45% reduction in labour spend. Additionally, the team was able to reduce transport and congestion on site and improve real-time project transparency. The use of an electronic tool rather than physical sticky notes reduced the meeting preparation and reporting time and data integrity. Finally, the consistent data collected at the work face helped with continual improvement processes.

While the team recognises many improvements over traditional last planner implementation, there are future improvements that can be achieved to further enhance the production management efficiency. The time and effort needed to connect the plan activities to the model can be reduced by introducing an automated linking process between the model and the plan. Managing resources at the ground level is crucial and the electronic last planner system such as VisiLean can be further enhanced by introducing bottom-up resource management where labour, material, equipment and other resources can be planned and tracked in various production stages.

REFERENCES

Dave, B. A. (2013). “Developing a construction management system based on lean construction and building information modelling.” University of Salford.

Dave, B., Boddy, S., and Koskela, L. (2011). "Visilean: Designing a Production Management System With Lean and Bim." *19th Annual Conference of the International Group for Lean Construction*, J. Rooke and B. Dave, eds., Lima.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons, Hoboken, NJ.

Gilligan, B., and Kunz, J. (2007). "VDC use in 2007: significant value, dramatic growth, and apparent business opportunity." *TR171*, 36.

Horman, M., and Kenley, R. (2005). "Quantifying Levels of Wasted Time in Construction with Meta-Analysis." *Journal of Construction Engineering and Management*, 131(1), 52–61.

Jongeling, R., and Olofsson, T. (2007). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD." *Automation in Construction*, 16(2), 189–198.

Khanzode, A., Fischer, M., Reed, D., and Ballard, G. (2006). "A guide to applying the principles of virtual design & construction (VDC) to the lean project delivery process." *CIFE, Stanford University, Palo Alto, CA*.

Oskouie, P., Gerber, D. J., Alves, T., and Becerik-Gerber, B. (2012). "EXTENDING THE INTERACTION OF BUILDING INFORMATION MODELING AND LEAN CONSTRUCTION." *Proceedings for the 20th Annual Conference of the International Group for Lean Construction*.

Ramaswamy, K. P., and Kalidindi, S. N. (2009). "Waste in Indian Building Construction Projects." 3–14.

Rischmoller, L., Alarcón, L. F., and Koskela, L. (2006). "Improving value generation in the design process of industrial projects using CAVT." *Journal of management in engineering*, 22(2), 52–60.

Sacks, R., and Barak, R. (2008). "Impact of three-dimensional parametric modeling of buildings on productivity in structural engineering practice." *Automation in Construction*, 17(4), 439–449.

Sacks, R., Radosavljevic, M., and Barak, R. (2010). "Requirements for building information modeling based lean production management systems for construction." *Automation in construction*, 19(5), 641–655.

Shou, W., Wang, X., Wang, J., Hou, L., and Truijens, M. (2014). "Integration of BIM and Lean Concepts to Improve Maintenance Efficiency: A Case Study." *Computing in Civil and Building Engineering (2014)*, ASCE, 373–380.

Teicholz, P., Goodrum, P., and Haas, C. (2001). "U.S. Construction Labor Productivity Trends, 1970–1998." *Journal of Construction Engineering and Management*, 127(5), 427–429.

Zhang, X. (2005). "Critical Success Factors for Public–Private Partnerships in Infrastructure Development." *Journal of Construction Engineering and Management*, 131(1), 3–14.

McHugh, K., Dave, B, and Ray C (2019). “Integrated Lean and BIM Processes for Modularized Construction – A Case Study” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 227–238. DOI: https://doi.org/10.24928/2019/0252. Available at: <www.iglc.net>.

Hamerski, D.C., Formoso, C.T., Isatto, E.L., and Cevallos, C.A. (2019). “Combining Lean and Agile Project Management in A Multi-Project Environment: Case Study in a Retail Company.” In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 239–250. DOI: https://doi.org/10.24928/2019/0217. Available at: <www.iglc.net>.

COMBINING LEAN AND AGILE PROJECT MANAGEMENT IN A MULTI-PROJECT ENVIRONMENT: CASE STUDY IN A RETAIL COMPANY

Douglas C. Hamerski [1], Carlos T. Formoso[2], Eduardo L. Isatto [3], and Cristian A. Cevallos [4]

ABSTRACT

Both the Last Planner System (LPS) and Scrum have been suggested as suitable planning and control methods for dealing with complex project environments. However, most previous studies have investigated the use of those methods for planning and control in single projects, in general managed separately from other projects. This paper reports the results of an investigation which aims to propose a planning and control model for managing construction projects in a multi-project environment. Using Design Science Research (DSR) as a methodological approach, an empirical study has been carried out in a fashion retailer company from Brazil. The model has been built by using a research strategy similar to Action Research. These are the main findings so far: (a) the nature of the project management activities demand a different planning and control approach, compared to what is normally found in relation to planning and control design or construction; and (b) there are challenges on the systematic use of performance measures to support learning and decision-making. These initial conclusions will serve as a basis for incorporating improvements in the model.

KEYWORDS

Lean construction, agile project management, planning and control, project management, construction projects.

INTRODUCTION

The starting point of this investigation was a practical problem identified by a fashion retailer company from Brazil, which has a portfolio of over 60 projects a year. Those

[1] M. Sc. Student, School of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, douglas_hamerski@hotmail.com

[2] Professor, School of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, formoso@ufrgs.br

[3] Associate Professor, School of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, isatto@ufrgs.br

[4] M. Sc. Student, School of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, cristiancevallosj@hotmail.com

projects are built in different parts of the country, and in other Latin American countries. The company has a Department of Architecture and Engineering (DAE), which is in charge of managing the design and construction stages. DAE coordinates the work of several types of suppliers, including designers, construction management companies, general contractors, and furniture suppliers, which are directly responsible for the design and delivery of the projects. In the department routine, multiple projects are developed simultaneously, with relatively short lead-time (typically within a year). Some of them are refurbishment or retrofit projects. The individual characteristics of each project and the fact that there is some degree of interdependence between projects, due to shared resources, make this project management environment highly complex. Before the beginning of this study, the company had been adopting a very traditional project management approach, strongly based on the Project Management Body of Knowledge (PMBOK), produced by the Project Management Institute (PMI): Critical Path Method (CPM) as a planning and control tool, emphasis on the control of deliverables, performance measurement focused on results, etc. Based on an assessment of the company's project deliverable system, one of the main improvement opportunities identified was to change the planning and control process, which included both design and construction stages at a project management level. In fact, the company had been faced several problems related to additional costs, project delays and lack of quality.

The underlying assumptions of project management have evolved over time in an attempt to improve managers' ability to cope with different circumstances (Laufer et al. 1996). Although management styles have evolved over time, companies from different industries continue to face problems and obtain failed results (Atkinson 1999). Several causes have been pointed out for those problems. Shenhar and Dvir (1996) and Turner (1999) pointed out the lack of an explicit theory for the area. Koskela and Howell (2002) argue that the underlying theoretical foundation of project management as espoused in the PMBOK is the most applied in practice. Based on a comparison of the PMBOK implicit theories with alternative theories, those authors argue that this foundation is obsolete and has to be replaced by a broader and more powerful theoretical foundation. In fact, previous studies indicate that the poor performance of construction projects can be related to the fact that the traditional project management approach is used in isolation from other managerial approaches (Laufer et al. 2015).

One of the main criticisms related to the traditional project management approach is the fact that it ignores some of the attributes of complexity and its effects (Williams 2002), mostly due to the limitations of its implicit theories (Koskela and Howell 2002). The importance of understanding complexity (from a management point of view) is related to the need to adjust the managerial processes in such a way as to help in reducing the problems that can be generated from their attributes (Bosch-ekveldt et al. 2011). Looking specifically at the construction industry, Telem, Laufer, and Shapira (2006) argue that the industry, in general, is increasingly complex, both in technical and organizational aspects.

Researchers have widely argued that complex environments require appropriate actions, methods, techniques, and tools to be successfully managed (Baccarini 1996). In this context, Lean Construction (LC) and Agile Project Management (APM) concepts and methods have been gradually accepted and implemented in the construction industry, having the advantage of considering to a certain extent the concept of complexity and its effects (Chen et al. 2007).

Focusing specifically on planning and control systems, both LC and APM managerial approaches have well-established planning and control methods: Last Planner System (LPS) (Ballard and Howell 1998) and Scrum (Schwaber and Beedle 2002). It has been argued that those two methods overcome to a certain extent the theoretical limitations of the traditional project management approaches, pointed out by Koskela and Howell (2002) and have been used successfully in the management of complex projects (Ballard and Howell 1998; Schwaber and Beedle 2002).

However, the context in which each of these methods has been applied is not the same. The majority of LPS implementations have been in the construction industry, in design and construction stages and for the management of prefabricated building systems (Ballard and Howell 1994; Ballard and Howell 1998; Ballard 2000; Castillo et al. 2018). By contrast, Scrum has been mostly used in the software industry (Rising and Janoff 2000; Schwaber and Beedle 2002; Conboy 2009; Dingsøyr et al. 2012; Perkusich et al. 2017).

These two methods have focused on the planning and control of projects, sometimes complex, but managed individually. In the LC context, it is worth mentioning that most research and implementations have been carried out within the conceptual limit of a single project (Sacks 2004). Only recently some studies have paid attention to portfolio management, however, focused on the management of subcontractors to improve production flows in the industry (Sacks 2016). Also, related to LC, there is an isolated attempt reported in the literature on planning and control in multi-project environments, in which LPS was adapted for the planning and control of the design process of prefabricated engineer-to-order systems (ETO) (Wesz et al. 2018). Regarding APM, Stettina and Hörz (2014) have suggested that the success of applying Scrum to the projects (managed in an isolated manner) indicates that it should be extended to the practice of portfolio management.

It is important to emphasize that there are some attempts to combine LC and APM (Naim et al. 1999; Cristopher and Towill 2000; Court et al. 2006; Owen et al. 2006). However, it can be argued that these efforts have in most cases focused on theoretical discussions or initiatives on supply chain management (Naim et al. 1999; Cristopher and Towill 2000; Owen et al. 2006; Owen and Koskela 2006; Court et al. 2006; Virmani et al. 2017), rather than on combining LC and APM for proposing a planning and control approach. Furthermore, most studies that have attempted to combine elements of LC and APM are concerned with design or construction management, rather than at the project management level.

The aim of this research study is to propose a planning and control model for managing construction projects in a multi-project environment that combines theoretical elements from LC and APM. This research is relevant due to the need to make the portfolio management in this environment more reliable, by improving the effectiveness of project planning and control. The model has been devised as a combination of elements from LPS and from Scrum. This paper presents some initial results of this investigation.

RESEARCH METHOD

Design Science Research (DSR) is the methodological approach adopted in this investigation. This type of research typically involves the proposition of an artefact that aims to solve classes of practical problems, while at the same time it produces scientific knowledge (Holmström et al. 2009). The main artefact that is being devised is a planning and control model for managing construction projects in a multi-project environment.

This research process has been carried out in close collaboration and engagement of the professionals from the fashion retail company's DAE. Thus, the research process is adopting a research strategy similar to Action Research. As suggested by Järvinen (2007), this type of action research fits well the DSR approach.

The organization in question is one of the largest retailers in Brazil, with more than 20.000 employees. DAE - specific department under study, has 58 construction projects being developed in 2019, including the development of new stores and the renovation of existing ones. In addition, the department has several other special projects: development and implementation of new technologies or information systems, changes in process and in the organizational structure, among others. This study is focused on construction projects, and specifically on the development of new stores.

Figure 1 presents an outline of the research design. From the definition of the scope and the context of the research, two major stages were defined.

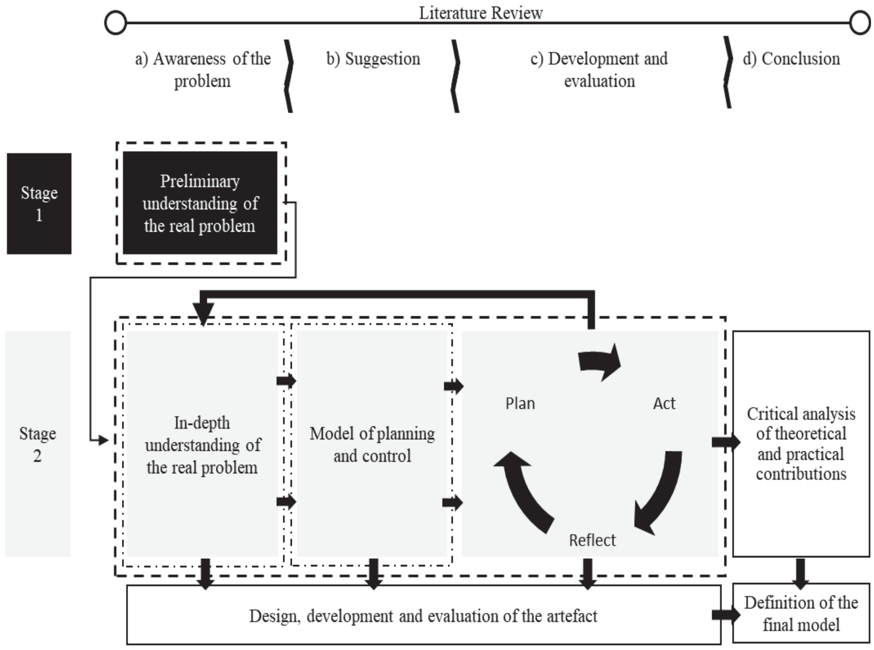


Figure 4: Outline of the research design

The purpose of the first stage was to have an initial understanding of the real problem in a preliminary, looking at the project delivery process as a whole. This stage was carried out between September 2017 and January 2018. The second stage consists of designing, developing and evaluating the artefact to be devised in this research study. The development of the artefact is based on the literature review and on the understanding of the real problem (stage 1). This stage began in January 2018 and it is expected to be finished by May 2019 (the initial idea was to complete this step in March 2019, however, the implementation process faced some difficulties which delayed its completion).

Figure 1 indicates that the model is being devised after several learning cycles. Throughout the development of this research study, the artefact is being assessed against criteria, as suggested by March and Smith (1995). The evaluation of the model is being carried out based on a set of criteria jointly established by the authors and the company's participants, based on two constructs: utility and applicability (at this moment, the data obtained with all the implementation process are being analysed and the final evaluation of the artefact is being carried out).

Different sources of evidence have been used in this research work: semi-structured interviews, open interviews, participant observation, primary data collection, document analysis, among others. The purpose of the multiple sources of evidence is to create a corroborative style of research (triangulation), as suggested by Yin (2003).

As mentioned before, the starting point of this investigation was a practical problem identified by a fashion retailer company from Brazil. As it is typical of DSR, the artefact has been designed, developed, and evaluated (through learning cycles) in collaboration with professionals of this organization. As this whole process requires considerable time and dedication from the researcher, a single empirical study has been carried out in this research. Therefore, the artefact has been highly influenced by the context of the company involved in this investigation, which represents a limitation of this study. Further work is necessary to refine the artefact and test its applicability to other contexts.

RESULTS

GENERAL DESCRIPTION OF DAE

The organization's product development process (PDP) for the development of new stores can be divided into the following stages: (a) Pre-project; (b) Design; (c) Construction; and, (d) Post-completion. This process was formalized in a process protocol (Cevallos 2018), which was an adaptation of principles used by Kagioglou et al. (2000) to develop construction project process protocols. This protocol was developed as a guide that provides an overview of everything that is necessary to know for the development of new stores of the organization. It includes the tasks carried out by DAE in the management of the design and construction stages, and also by other departments of the organization.

DAE consists of five teams: Planning and Control, Architecture, Visual Merchandising, Engineering, and Maintenance. The main focus of this study is on the Architecture and Engineering teams, which are mainly responsible for the design and construction stages, respectively. The Architecture and Engineering teams have four professionals each and are led by their managers. On average, each DAE architect/engineer manages simultaneously four construction projects (not counting special projects).

Regarding the short lead-times, the development of new stores in shopping centres, for example, the design stage lasts 75 days on average, while the construction stage lasts 100 days on average. In some projects, there is a need to overlap some activities, which, together with the number of projects being developed simultaneously and other factors, such as uncertainty in downstream processes, increases the complexity of the management processes.

The managerial processes carried out by DAE has been strongly based on a long-term plan, which has a fine level of detail. There has been no other formal levels of planning. It is assumed, therefore, that the plan generated at the beginning can be executed. In addition, weekly meetings are held in which architects/engineers report the status of their projects based on the long-term plan, but little is done to increase compliance with deadlines. It is possible to identify the use of a predominantly reactive style, which seeks to solve problems after they have happened. These problems are strongly related to the fact that a traditional project management approach has been adopted.

OVERVIEW OF THE PROPOSED MODEL

Figure 2 presents an overview of the planning and control model that has been developed. It has the purpose of managing multiple projects at a project management level, focusing on the conduct of design and construction stages (after the definition of the portfolio). The model is divided into three hierarchical levels - long-term planning, stage planning (defined by hard gates) and short-term planning, and, in two different perspectives – single project view and multi-project view. The model is based on a process protocol previously developed in the organization and on some key elements of LPS and Scrum.

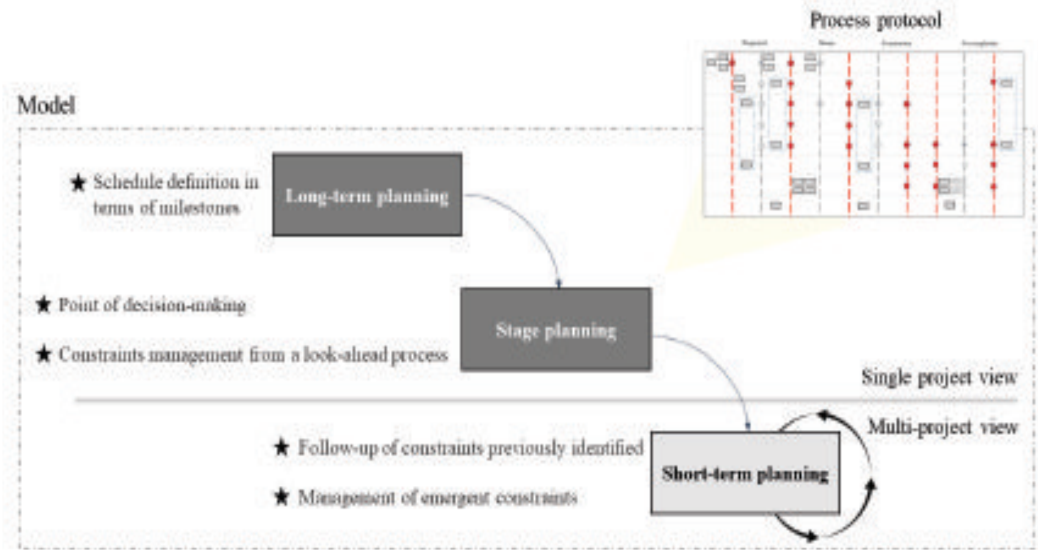


Figure 5: Overview of the planning and control model being developed

Level 1 is related to long-term planning (master plan) and is carried out "by project". This plan is developed by the architect and engineer in charge of the project, in which milestones used as a reference for control are established. This plan is based on the store opening date from the portfolio definition (which is related to the organization's strategic objectives).

Level 2 refers to the stage planning that occurs throughout the development of the project and is also performed "by project". These meetings are connected to the hard gates of the existing process protocol. Different stakeholders participate in these meetings, including the architect (design managers) and engineers (construction project managers), representatives from other sectors of the organization and sometimes suppliers. These meetings are divided into two main stages: (a) point of decision-making - based on a verification of documents and information available and analysis of long-term plans; and, (b) constraints management considering a look-ahead horizon. At these meetings, the look-ahead process is at least one stage ahead of the next meeting (next hard gate). The purpose of this is to ensure that two subsequent planning horizons overlap. The average time between one meeting and another at this level of planning is 30 days.

Level 3, in turn, is related to short-term planning (commitment planning) and is carried out weekly, considering a multi-project environment, ie, several projects are discussed in the same meeting. In these meeting, all architects (in the design management meeting) and all engineers (in the construction project management meeting) and their respective managers participate. It is worth mentioning that the main role of these meetings is coordination, and are carried out separately for the design management and for the construction project management teams. These meetings are also divided into two main stages: (a) follow-up of the constraints identified during stage planning meetings; and (b) management of emerging constraints.

RESULTS FROM THE IMPLEMENTATION PROCESS

A partial implementation of the model has been carried out. Most advances were made at the short-term planning level, and these are highlighted in the paper. Some improvements implemented at the other levels of planning are only briefly presented in this paper. As mentioned before, this investigation has not been fully concluded, as the evaluation of the artefact is being carried out.

Regarding the development of the long term plan, a major change was use the project process protocol as a reference for the definition of activities and deliverables. Moreover, some visual devices have been used to increase process transparency: an integrated panel for visualizing the long-term planning of all projects was produced.

The demands of the management system that the company had been using before the beginning of this study (strongly based on the PMBOK) was very time consuming for design and construction project managers. For that reason, a set of procedures was developed for stage planning with the purpose of giving agility and focus in planning meetings. One of the points addressed by these procedures was the management of constraints: some of the constraints were pre-established (as they typically repeat for the same type of project - example: new store development), and some of them were considered to be emerging events (which had to be identified during the meeting).

Short-term planning level

The short-term planning meetings usually starts by doing an overall analysis of on-going projects (usually 16 per team), by projecting some data on a screen. One-by-one, each project is analysed, under the coordination of the team leader. For each project, some questions are asked to the architect or engineer in charge. The same questions asked in the daily Scrum meeting, but adapted to a weekly time horizon: what was done last week? What will be done this week? Is there any kind of constraint that blocks what should be done?) (Schwaber and Beedle 2002). Based on that a brief understanding of the status of each project is obtained. It is expected that with the answers (explanation) of the architect or engineer it is possible to capture some emergent constraints of the project. This process of capturing emerging constraints is supported by the diversity of perspectives from all meeting participants. Based on emerging constraints or remaining constraints from stage planning meetings, assignments are negotiated between the parts (team leader and architect or engineer in charge). The negotiated assignments, which are typically related to constraint removal, are then included in the short-term plan. This plan is in a "cloud" file that can be easily accessed by everyone. At the end of the short-term planning cycle, a general evaluation of the effectiveness of this level of planning is performed, using an indicator similar to Percent Plan Complete (PPC) proposed by Ballard and Howell (1998). This indicator is calculated by the ratio between the number of assignments concluded and the number of assignments scheduled, with the particularity that, in this case, assignments have the function of removing constraints. It was chosen the name PPC, because the frequency of analysis is weekly, as it typically is in conventional LPS implementations.

During the implementation process, some difficulties emerged, most of them related to the nature of the activities carried out by project managers in this specific context. The activities of DAE architects and engineers are of a different nature from what we usually find in the literature related to design processes (Reinertsen 2009) and to construction processes (Koskela 2000). In fact, the nature of the activities found is in line with the characteristics presented by Mintzberg (1973) to describe the operations performed by CEOs, but which are often cited as common characteristics to operations performed by managers in general. These characteristics are brevity, variety, and fragmentation (Mintzberg 1973).

This was observed during the participation of research team members in the existing managerial routines and confirmed during the implementation of the model at the short-term planning level. Most of the assignments negotiated during the meetings, which actually aim to remove previously identified or emerging constraints, typically start with expressions such as: "*check, call, confirm, communicate, align, request,* etc." In fact, the plan at this level comprises a large number of small activities, but which does not take up a whole week, as usually happens in the weekly work planning of planning and control systems focused on design or construction processes. This large number of activities can also be explained by the fact that this level of planning is being implemented in a multi-project environment.

Figure 3 presents the PPC obtained at the short-term planning meetings during two months of implementation in the Architecture and Engineering teams. The PPC variability showed below can be derived from different sources. On one hand, because short-term planning consists of a large number of small activities but does not take up a whole week, as explained earlier, in some cases, the goal of 100% is reached, something unusual when implementing LPS to the design or construction processes (Moura and Formoso 2010). On the other hand, due to the lack of available time/commitment of architects/engineers due to the demands of the management system that the company had been adopting until the beginning of this study (which has a high level of complexity due to the fact that it is strongly based on PMI), sometimes, planning effectiveness is low. As an example of the complexity of the existing management system, there are more than 210 documents that need to be managed in the development of new stores.

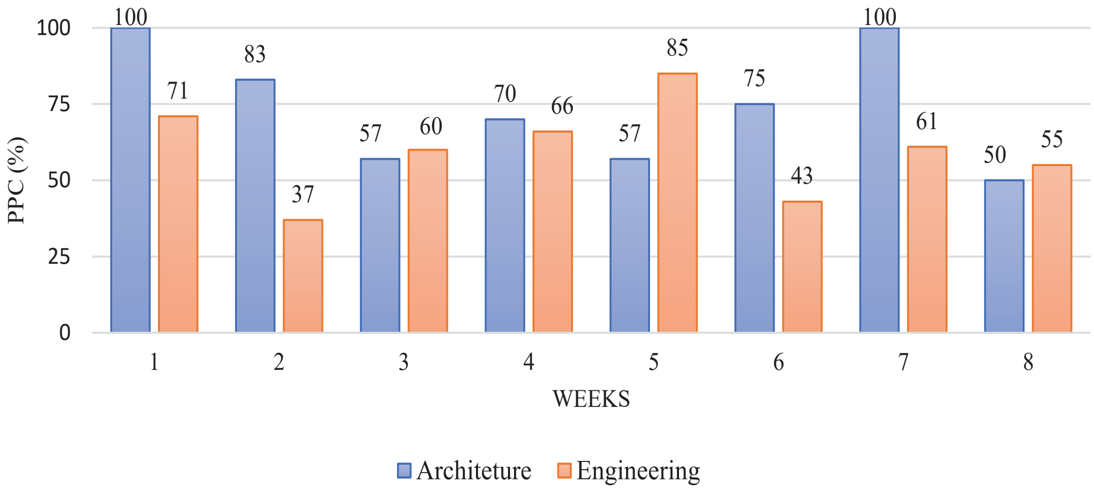


Figure 6: PPC obtained at the short-term planning during two months of implementation

This PPC variability is in line with the general difficulty of using metrics in this context, which has been discussed in the project management literature. Mintzberg (1973) has identified, for example, that managers work verbally with fresh information, rather than analytically with systematic information. In fact, Sproull (1984) found that managers spend 80% of their time talking with people. This is in line with Jönsson's (1998) statement that "*managers work with words*". Despite the importance of communication, the research team believes that the benefits from this practice could be increased through the systematic support and use of a performance measurement system, as suggested by Neely, Gregory, and Platts (1995).

As "*managers work with words*", they usually have great communication skills, which also happens in this case. DAE professionals consider themselves as highly qualified. As the professionals have PMI training, there has been a strong resistance to change. This issue seems to affect in parts, the process of negotiating the assignments, for example. Architects and engineers are not always enthusiastic about this process, sometimes facing it as a kind of change imposed by the team leaders. In this case, team leaders have to deal with some of the challenges present in this type of human resources, as argued by Kotter (1982), to criticize (suggest assignments/discuss) and at the same time motivate their subordinates.

Along the implementation process of the short-term planning level, some improvements have been observed, such as the separation of one part of the weekly meeting (which was initially less orderly) to do planning and control. Further improvements are expected, such as: improve the preparation of the architects/engineers for the meeting, improve the assignment negotiation process and also the commitment of the professionals to the weekly goals, among others.

CONCLUSIONS

This paper discusses the initial results of a research project under development which aims to propose a planning and control model for managing construction projects in a multi-project environment, having as a theoretical foundation LC and APM. This investigation has been developed in partnership with a fashion retailer company from Brazil, more specifically, with the sector in charge of managing of construction projects. At the beginning of this investigation, the existing managerial system was strongly based on the traditional project management approach.

The proposed model has been partially implemented and tested in this. These are the main findings so far: (a) the nature of the project management activities demand a different planning and control approach, compared to what is normally found in relation to planning and control design or construction; and, (b) there are challenges on the systematic use of performance measures to support learning and decision-making.

One of the limitations of this study is the fact that the proposed planning and control model has been developed to the project management level. The connections to the managerial processes carried out in the design and construction stages have not been fully explored. Therefore, further work will extend the proposed planning and control model to suppliers, i.e. designers, construction management companies and general contractors.

REFERENCES

Aken, J. E. V. (2004). “Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules.” *Journal of management studies*, *41*(2), 219-246.

Atkinson, R. (1999). “Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria.” *International journal of project management*, *17*(6), 337-342.

Baccarini, D. (1996). “The concept of project complexity—a review.” *International journal of project management*, *14*(4), 201-204.

Ballard, H. G. (2000). *The last planner system of production control.* (Doctoral dissertation, University of Birmingham).

Ballard, G., and Howell, G. (1994). “Implementing lean construction: stabilizing work flow.” *Lean construction*, 101-110.

Ballard, G., and Howell, G. (1998). “Shielding production: essential step in production control.” *Journal of Construction Engineering and management*, *124*(1), 11-17.

Bosch-Rekveldt, M., et al. (2011). “Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework.” *International Journal of Project Management*, *29*(6), 728-739.

Castillo, T., et al. (2017). “Effects of Last Planner System Practices on Social Networks and the Performance of Construction Projects.” *Journal of Construction Engineering and Management*, *144*(3), 04017120.

Cevallos, C.A. (2018). *Diretrizes para a gestão de empreendimentos de construção complexos do tipo comercial do mercado varejista com base nas abordagens Lean e Agile.* (Masters dissertation, Universidade Federal do Rio Grande do Sul).

Chen, Q., et al. (2007). Interface management—A facilitator of lean construction and agile project management. In *Proceedings of the 15th Annual Conference of the International Group for Lean Construction (pp.* 57-66).

Conboy, K. (2009). "Agility from first principles: Reconstructing the concept of agility in information systems development." *Information Systems Research*, *20*(3), 329-354.

Court, P., Pasquire, C., Gibb, A. & Bower, D. (2006). Design of a Lean and Agile Construction System for a Large and Complex Mechanical and Electrical Project. In *Proceedings of the 14th Annual Conference of the International Group for Lean Construction (pp. 1-).*

Christopher, M., & Towill, D. R. (2000). Supply chain migration from lean and functional to agile and customised. *Supply Chain Management: An International Journal*, *5*(4), 206-213.

Dingsøyr, T., et al. (2012). "A decade of agile methodologies: Towards explaining agile software development." *Journal of systems and software,* 85(6), 1213-1221.

Holmström, J., Ketokivi, M., and Hameri, A.-P. (2009). "Bridging Practice and Theory: A Design Science Approach." *Decision Science*, 40(1), 65–87.

Järvinen, P. (2007). "Action research is similar to design science." *Quality & Quantity*, *41*(1), 37-54.

Jönsson, S. (1998). "Relate management accounting research to managerial work!" *Accounting, Organizations and Society*, *23*(4), 411-434.

Kagioglou, M., et al. (2000). "Rethinking construction: the generic design and construction process protocol." *Engineering, construction and architectural management*, *7*(2), 141-153.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*. VTT Technical Research Centre of Finland.

Koskela, L. J., and Howell, G. (2002). The underlying theory of project management is obsolete. In *Proceedings of the PMI Research Conference* (pp. 293-302). PMI.

Kotter, J. P. (1982). *The General Managers*. New York: The Free Press.

Kurke, L. B., and Aldrich, H. E. (1983). "Note—Mintzberg was right!: A replication and extension of the nature of managerial work." *Management science*, *29*(8), 975-984.

Laufer, A., et al. (1996). "Simultaneous management: the key to excellence in capital projects." *International Journal of Project Management*, *14*(4), 189-199.

Laufer, A., et al. (2015). "What successful project managers do." *MIT Sloan management review*, *56*(3), 43.

March, S. T., and Smith, G. F. (1995). "Design and natural science research on information technology." *Decision support systems*, *15*(4), 251-266.

Mintzberg, H. (1973). *The nature of managerial work.*

Moura, C. B., and Formoso, C. T. (2010). "Análise quantitativa de indicadores de planejamento e controle da produção: impactos do Sistema Last Planner e fatores que afetam a sua eficácia." *Ambiente construído: revista da Associação Nacional de Tecnologia do Ambiente Construído. Porto Alegre, RS. Vol. 9, n. 3 (jul./set. 2009), p. 57-74.*

Naim, M. M., Naylor, B., & Barlow, J. (1999). Developing Lean and Agile Supply Chains in the UK House Building Industry. In *Proceedings of the 7th Annual Conference of the International Group for Lean Construction* (pp. 26-28).

Neely, A., Gregory, M., and Platts, K. (1995). “Performance measurement system design: a literature review and research agenda.” *International journal of operations & production management*, *15*(4), 80-116.

Owen, R., Koskela, L. J., Henrich, G., & Codinhoto, R. (2006). Is agile project management applicable to construction?. In *Proceedings of the 14th Annual Conference of the International Group for Lean Construction* (pp. 51-66).

Owen, R., & Koskela, L. (2006, May). An agile step forward in project management. In *2nd Specialty Conference on Leadership and Management in Construction and Engineering* (pp. 216-224).

Perkusich, M., et al. (2017). “Assisting the continuous improvement of scrum projects using metrics and bayesian networks.” *Journal of Software: Evolution and Process*, *29*(6), e1835.

Reinertsen, D. G. (2009). *The principles of product development flow: second generation lean product development* (Vol. 62). Redondo Beach: Celeritas.

Rising, L., and Janoff, N. S. (2000). “The Scrum software development process for small teams.” *IEEE software*, *17*(4), 26-32.

Sacks, R. (2004). “Towards a lean understanding of resource allocation in a multi-project sub-contracting environment.” In *Proceedings of the 12th Annual Conference of the IGLC*.

Sacks, R. (2016). “What constitutes good production flow in construction?” *Construction management and economics*, *34*(9), 641-656.

Schwaber, K., and Beedle, M. (2002). *Agile software development with Scrum* (Vol. 1). Upper Saddle River: Prentice Hall.

Shenhar, A. J., and Dvir, D. (1996). “Toward a typological theory of project management.” *Research policy*, *25*(4), 607-632.

Sproull, L. S. (1984). “The nature of managerial attention.” *Advances in information processing in organizations*, *1*, 9-27.

Stettina, C. J., and Hörz, J. (2015). “Agile portfolio management: An empirical perspective on the practice in use.” *International Journal of Project Management*, *33*(1), 140-152.

Telem, D., Laufer, A., and Shapira, A. (2006). “Only dynamics can absorb dynamics.” *Journal of construction engineering and management*, *132*(11), 1167-1177.

Turner, J. R. (1999). “Project management: a profession based on knowledge or faith?” *International Journal of Project Management*, *17*(6), 329-330.

Virmani, N., Saha, R., & Sahai, R. (2017). Evaluation of leagile criteria using DEMATEL approach. *Information Technology*, *16*, 19.

Wesz, J. G. B., et al. (2018). “Planning and controlling design in engineered-to-order prefabricated building systems.” *Engineering, Construction and Architectural Management*, *25*(2), 134-152.

Williams, T. (2002). *Modelling complex projects*.

Yin, R. K. (2003). Case study research: Design and methods (applied social research methods). *London and Singapore: Sage*

Simonsen, S.H.F., Skoglund, M.H., Engebø, A., Varegg, B.E., and Lædre, O. (2019). "Effects of IPD in Norway – A Case Study of the Tønsberg Project." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 251–262 DOI: https://doi.org/10.24928/2019/0157. Available at: <www.iglc.net>.

EFFECTS OF IPD IN NORWAY – A CASE STUDY OF THE TØNSBERG PROJECT

Sarah Hermine Fossum Simonsen[1], Maren Holte Skoglund[2], Atle Engebø[3], Bjørn Edmund Varegg[4] and Ola Lædre[5]

ABSTRACT

The study aims to identify the effects of implemented elements of Integrated Project Delivery (IPD) on the production phase, and the effect on team, individual and task needs. The paper advances research on IPD in practice and facilitates better transition to IPD to resolve challenges in the construction industry. The research includes a single case study of the Tønsberg Project in Norway, combined with a literature review. The case study consists of a document study and semi-structured interviews with key informants from the contractor. The research established that too many elements were attempted implemented at once, causing a tendency to fall back on traditional ways of doing things when the process lagged. Even so, the interviewees saw great potential in IPD, with more education and training. Furthermore, the experienced effects in the Tønsberg Project fulfilled team needs to a greater extent than individual and task needs. This reflects the IPD idea of the owner, contractor and designer working together as a unit and shows the value of leaders using IPD. The research is limited by a single case study and the contractor's perspective. Further work might study different projects or increase the differentiation in roles and data collection.

KEYWORDS

Integrated Project Delivery (IPD), collaboration, team model, commitment, effects.

INTRODUCTION

In traditional project delivery, projects often suffer because participant success and project success are not necessarily related. Integrated Project Delivery (IPD) is a project delivery method that integrates people, systems, organisations and practices into a single

1 M.Sc. student, Department of Civil and Environmental Engineering, NTNU – Norwegian University of Science and Technology, Trondheim, Norway, +47 90807120, shsimons@stud.ntnu.no

2 M.Sc. student, Department of Civil and Environmental Engineering, NTNU, Trondheim, Norway, +47 98899555, marenhs@stud.ntnu.no

3 PhD Candidate, Department of Civil and Environmental Engineering, NTNU, Trondheim, Norway, atle.engebo@ntnu.no

4 Deputy Director and Lead Contract and Procurement, Vestfold Hospital Trust, Norway, +47 90911917, bjorn.varegg@tonsbergprosjektet.no

5 Associate Professor, dr.ing, Department of Civil and Environmental Engineering, NTNU, Trondheim, Norway, +47 73594739, ola.ladre@ntnu.no

collaborative process that seeks to optimize results and value to the owner, reduce waste and maximize efficiency through all phases of the project (AIA 2007). In other words, IPD aims to make projects more successful through solving current construction industry problems, such as adversarial relationships and slow increases in productivity. Hospitals are particularly complex construction projects, considering size, technology and the variation in stakeholders. It is therefore natural that hospital projects experience conflicts and productivity challenges to a higher degree.

The number of research articles on IPD is generally increasing yearly (Kahvandi et al. 2017). However, there is a lack of focus on the effects of IPD in projects. In a Norwegian context, IPD is a new delivery method, and there is therefore little research on this nationally. However, IPD is becoming more relevant as interest for relational contracts increases. This paper studies the effects of implementing IPD in a Norwegian hospital project as a single case study.

Specifically, this paper seeks to identify the effects of IPD on the production phase through an analysis of the implemented contractual, technological and processual and cultural IPD elements. It therefore provides a broader perspective on IPD than earlier studies. Furthermore, the analysis provides a perspective on how IPD affects team, individual and task needs to support effective management in project organisations.

The research is limited to a single case study, as there is only one ongoing IPD project in Norway. Additionally, interviews have focused on the contractor's perspective and the production phase, but with varying roles within this stakeholder.

METHOD

This paper is based on qualitative research, including a literature review and a case study of the ongoing Tønsberg project. Firstly, the Tønsberg project is the first Norwegian project to implement the IPD delivery method. Secondly, as a large hospital project, it is worth studying the success of IPD in a complex project. The project consists of a psychiatric building and a somatic building with a total area of 44,500 m^2 and cost of 335 million USD. Planned completion is March 2019 for the psychiatric building and March 2021 for the somatic building (Vestfold Hospital Trust 2016). The IPD agreement is between the owner, designers and main contractor. Additionally, three technical subcontractors participate in the shared risk and reward pool.

Following the selection of the case project, a single-case research approach was chosen. A qualitative case study approach is suitable for "how" and "why" type of research questions (Yin 2017). Thus, this approach was perceived as valid for this topic. A case study allows for researching a single phenomenon in-depth but limits the ability to generalise the results beyond the single case studied. Still, this paper documents the Norwegian construction industry's first experiences with IPD in the production phase. This case study consists of a document study and three pilot interviews.

A literature review was conducted to map and understand the various elements of IPD. Relevant literature was found through electronic searches in internationally acknowledged, peer-reviewed, multidisciplinary databases. The systematic searches in each database used identical keywords and similar filters to ensure reproducibility of the search. The bibliometric search results were followed by a qualitative evaluation of credibility, objectivity, accuracy, and relevance for each source.

The data collection was initiated by a document study. The study covered the preliminary project report and the IPD agreement for the Tønsberg project. As described by Bowen (2009), the document study provides background information and context to the case study. The document study reveals the implementation plan for the IPD project. However, it did not generate sufficient insight into the execution or effects of IPD. Therefore, the research was supplemented with data collected from interviews.

Interviews represent a suitable data collection method within the case study approach. Three interviewees were recruited from the contractor's part of the IPD organisation. They were chosen based both on their experience in the industry, ranging from 10 to 30 years, and their roles in the project, namely one project executive and two site engineers involved in construction and BIM. The in-depth, semi-structured interviews were conducted onsite the project in November 2018. An interview guide was developed and used during interviews to allow for preparation and to clarify any uncertainties. The interviews were audio-recorded and transcribed. The transcripts were analysed using a stepwise deductive inductive approach as described by Tjora (2012).

The literature study, document study and interviews all provide a basis for data triangulation. Triangulation strengthened the research by providing a mean for checking the data against each other (Yin 2017), and to gain satisfactory validity. The data is considered reliable, but somewhat limited due to few interviews. This effect is attempted minimised by quality control of the findings by the Tønsberg project's Deputy Director and Lead Contract and Procurement.

THEORETICAL FRAMEWORK

DEFINITION AND ORIGIN OF IPD

IPD is by the American Institute of Architects (AIA) defined as a "delivery approach that integrates people, systems, business structures and practices" (AIA 2007). IPD was created as a reaction to problems arising in traditional delivery models, and therefore aim to solve the problems to improve project feasibility. **Error! Reference source not found.** shows Matthews and Howell's (2005) four major systematic problems with traditional contractual approaches, and how IPD solves them.

The largest challenges related to IPD are market risk and fear of change. Closely following are lack of knowledge and attention to the delivery model, as well as a missing suitable legal framework (Ghassemi and Becerik-Gerber 2011).

IPD ELEMENTS

The definition of IPD by the AIA is broad, and the requirements for an IPD project must therefore be specified. Literature shows disagreement in which elements are required to categorise a project as IPD. **Error! Reference source not found.** is a summary of common elements listed in various literature. In this paper, all the listed IPD elements are assumed relevant.

Table 10 – Problems with traditional delivery models (Matthews & Howell, 2005)

Problem	Result of problem	Solution using IPD
Good ideas are held back	Loss of time and opportunity for innovation later in the process.	Shared risk and reward Increased innovation
Contracting limits cooperation and innovation	Minimal (if any) innovation and collaboration across stakeholders.	Multiparty contracts Encourage collaboration and innovation
Inability to coordinate	Unexpected clashes between the stakeholders	Holistic coordination
Pressure for local optimisation	Focus on companies' own interests, while neglecting the project's interests.	Commonly defined goals Global optimisation

Table 11 – IPD elements in various literature, adapted from Aslesen et al. (2018)

IPD elements	(AIA 2007)	(Kenig et al. 2010)	(Ghassemi and Becerik-Gerber 2011)	(Lee et al. 2014)	(Pishdad-Bozorgi and Beliveau 2016)
Contract					
Multiparty contract		X	X	X	X
Shared risk and reward	X	X	X	X	X
Early involvement of key participants	X	X	X	X	X
Intensified planning	X	X			X
Collaborative decision making	X	X	X	X	X
Collaborative goal definition	X	X	X		X
Liability waivers		X	X	X	X
Financial transparency				X	X
Technology and processes					
Lean				X	X
BIM				X	X
Integrated information	X			X	X
Culture					
Mutual respect and trust	X	X		X	X
Willingness to collaborate				X	
Open communication	X	X		X	X
Co-location					X

Project teams in construction projects

An essential aspect of project delivery is the construction team that delivers the project. As described by Fischer et al. (2017), teams are the primary operational elements of the IPD organisation, and making the team work effectively together is therefore vital for the project outcome. However, the best structuring and management of IPD teams is not well researched.

The process of building project teams consist of a set of logical steps, such as recruiting team members, establishing a meeting structure, creating team identity and a shared sense of purpose, and designing conflict resolution mechanisms, all the while orchestrating decision-making (Larson et al. 2014). The literature on the psychology of teams and leadership agree that all teams:

Develop their own culture and personality

Respond to leadership

Are motivated according to criteria usually applied to individuals

While literature explicitly states the need for teamwork in order to tackle complex projects, no universal theory on how to achieve the required level of teamwork exist. Adair (1986) sought to explain teamwork by linking it to leadership. His team model focuses on leadership as combining the generic needs of the task, team, and individuals, as shown in **Error! Reference source not found.**. The task is the project purpose, and the team is the group of people put together to achieve the task (Oakland and Marosszeky 2017). Individual members within the team have their own set of needs. The team model establishes that for any group to function optimally, needs of the task, the team, and the individuals must be fulfilled. These needs are assumed to be valid for all projects.

Figure 28 – Team model of leadership needs (Adair 1986)

The overlapping areas in **Error! Reference source not found.** illustrate the importance for leaders to combine and balance the task, team, and individual needs to achieve optimal teamwork and results. If the leader's focus is unbalanced and, for example, only fulfil the task needs, the team members might lose motivation and make less of an effort. This impairs individual needs and the overall result of the task or project (Oakland and Marosszeky 2017).

In literature on Lean construction, leadership is gaining more attention. Howell et al. (2004) stated that work management in Lean project delivery is understood as "making and keeping commitments", meaning that the nature and focus of leadership must be considered. Concerning the discussion of waste, Macomber and Howell (2004) stated that while organisations and projects manipulate material, they are better characterised by actions such as coordinating, learning, and innovating. Furthermore, these actions are tightly coupled with leadership and were not at that time discussed as a potential source for waste. Thus, leadership should be centred around producing trust through getting people to participate in a network of commitments, see each other as reliable performers, and learn to align and connect their interests with each other's interests and with those of the project (Howell et al. 2004).

Moreover, Seed (2014) proposed that the traditionally trained Project Manager is not equipped to deal with the relationship-based nature of IPD projects. Hill et al. (2007) suggested using 'Study Action Teams' to achieve the organisational transformation required for the implementation of Lean project delivery practices. In sum, the literature review provides an overview of the various elements of IPD and the vital role of the project team, set in the context of lean construction and lean project delivery.

FINDINGS AND DISCUSSION

CONTRACT

The owner, contractors, and designers in the Tønsberg project jointly adapted the Hanson Bridgett's Standard Multiparty agreement to Norwegian conditions. The signed **multiparty contract**, the IPD agreement, formalised collaboration and use of various Lean tools and IPD elements. The interviewees did not see direct effects of the multiparty contract itself. However, the study shows that the multiparty contract is necessary to enable implementation of other IPD elements, such as early involvement of key participants. It was also used to build an IPD culture through enforcing collaboration, with collaboration tools such as workshops and BigRoom meetings. A multiparty contract should promote clear responsibilities, but this effect was not present throughout the project. Therefore, the element fulfils neither task nor individual needs. Team needs were fulfilled because the multiparty contract resulted in a common identity for the stakeholders involved.

The owner, designers, main contractor and technical subcontractors practice **shared risk and reward** through pooling their profits. This pool is eaten into by cost overruns but increases with cost savings. In the final settlement, it is divided up proportionally to the entry amount of each participant. The element provided a better understanding of the other stakeholders' choices and created a 'give and take' culture at the top levels of the organisation, although this effect was not present throughout the project organisation. One possible explanation is that cost and profit information do not traverse downward through the organisation. An observed issue related to the implementation of the element was that there seemed to be an imbalance between the stakeholders' share of risks and costs compared to their respective decision-making authority. Nevertheless, the element improved the feeling of a common identity between interdependent stakeholders, and therefore fulfilled the team needs. The effect of shared risk and reward did not sufficiently meet task nor individual needs.

The interviewees considered **early involvement of key participants** as an element with great potential and believed that it would result in a more efficient and less time-consuming production. However, early involvement was not implemented correctly in the early stage of the project since users and the best suited people were not involved. The interviewees believed the project would benefit from early involvement in the production of the second building, because the right participants are already involved in the project and are present before the production phase starts. At this particular time, the effect from early involvement of key participants did not positively affect neither task, team nor individual needs, but it is reasonable to believe that all will be fulfilled in the second production phase.

In the Tønsberg project, **intensified planning** was applied to the design process, but the buffer between the design deadline and the production start was too short. The lack of buffer was a result of external circumstances that pushed the production start before the detailed design was ready. The production start imposed additional challenges on the design team, which led to frustration. The interviewees thought that lack of commitment to deadlines contributed to overdue design plans. Intensified planning fulfils all three types of needs as the element emphasises task needs such as achieving targets and standards, team needs such as growth and development as a unit, and individual needs through enabling team members to contribute and therefore feel valued.

A decision-making body named IPD principals (IPD-P) implements the **collaborative decision-making** element. The IPD-P consist of one representative each from the owner, designer and main contractor. The intention was to include the entire risk and reward team in collaborative decision making. However, due to the concurrent development of the IPD agreement and preliminary project report, this was not put into practice. The interviewees stated that collaborative decision-making worked once established. However, some concern was aired regarding the members' equal voting rights, because of varying expertise on the problems at hand. Day-to-day operations in the organisation experiences some indecision, attributed to the lack of role definitions, too many workers at the same organisational level, and little commitment to tasks and deadlines. Nevertheless, collaborative decision-making contributed to a supportive climate and development of the team as a unit. The team members were able to contribute, but lack of responsibility led to missed targets. Hence, both team and individual needs were fulfilled, whereas task needs were not.

A sixth element within the contract category is **collaborative goal definition**. The literature review revealed consensus regarding the designer and contractor developing goals together, but discord on whether the owner should include the other stakeholders in developing overarching goals. In this project, the owner chose the goals for the entire project, without designer and contractor participation in establishing specific goals for the project. The interviewees felt little affiliation towards the goals and believed this to be a factor in the project team missing particular short and long-term aims. Lack of collaborative goals allowed the participants to act in the firms' best interest instead of the project's interests, contrary to the IPD philosophy. Therefore, in this particular project, the element did not fulfil neither task, team nor individual needs.

The shared risk and reward stakeholders signed **liability waivers**. The interviewees experienced more efficient problem-solving, fewer conflicts and fewer resources wasted on placing guilt. Another effect of the liability waivers was a better work environment due to the absence of blaming and 'finger pointing'. However, the study found that liability waivers could lead to a lack of commitment if wrongly implemented. An example was liability waivers being used as a shield against holding each other accountable for not delivering on time. Another explanation for this is the lack of role definition and the flat organisation structure. The liability waivers resulted in a supportive climate within the project and the growth of the team as a unit, therefore it fulfilled the needs of a team. Additionally, individual needs were fulfilled through the team members' feelings of acceptance and being valued by their peers and leaders.

Within the IPD-P and at the top levels in the project organisation there was **financial transparency**, which resulted in an increased understanding of costs compared to a traditional project. Regardless, further down in the project organisation there were still uncertainties about the progress of the project related to costs. Financial transparency in lower parts of the organisation aided coordination of work tasks and in avoiding misunderstandings. The financial transparency helped achieve targets and standards through a mutual understanding and acceptance of cost-based priorities and thus fulfilled task needs. Developing the team as a unit met team needs. Individual needs were not fulfilled.

TECHNOLOGY AND PROCESSES

The project implemented **Lean tools** such as the Last Planner System (LPS), and Target Value Delivery (TVD). The effect was regarded as positive in production, where weekly planning meetings and the digital program *Touchplan* were extensively used. The interviewees' perception of better cooperation onsite and higher efficiency in building indicate the success of this IPD element. However, LPS was discontinued in the design phase because the participants preferred traditional planning and control systems. Late deliveries suggest that successful implementation of LPS could have led to a better feeling of ownership of the various tasks and a realistic plan. However, this requires enthusiasm and commitment, which takes time to build in an organisation.

Overall, contract clauses and early planning reveal an aim to use several more Lean tools. However, most of these were new to the project team. Change resistance, time pressure and lack of training were reasons for not implementing the planned tools. However, all interviewees had a positive attitude and thought there was great potential for collaboration, economic savings and better quality through the use of Lean. In this case, Lean tools fulfilled task needs and individual needs in production, although it was not successful in design. Team needs were not met with the current implementation of Lean tools.

Building information modelling (BIM) was planned to use in 7D but is currently not used in 4D and 5D. Positive results of the BIM model are more paperless work onsite, more accessible communications in multidisciplinary meetings and ease of information onsite with BIM kiosks. However, there were also challenges such as compiling fragmented working models into one fully integrated model, and a lack of knowledge in building a BIM model. Overall, the interviewees see the positive effects of BIM in the form of multidisciplinary cooperation and communication but understand the need for more training and leadership. BIM can, therefore, be said to fulfil some task needs in the systematic approach it offers in design but did not meet team or individual needs.

Integrated information was partly successful with the implementation of common platforms, such as email domain and web hotel. Nevertheless, this process included some confusion due to consultants working on different platforms, and participants using both project-specific platforms and employers' platforms. The interviews revealed that the concept of integrated information seemed to be perceived as somewhat abstract, where interviewees focused on different aspects and had limited experiences with how integrated information affected project execution. There was evidence of awareness of the potential benefits, such as timesaving and improved collaboration, but the concept did not reach its full potential. This element, therefore, does not fulfil any needs in the team model.

CULTURE

Mutual trust and respect were seen as one of the most significant changes in attitude in connection with IPD. This is shown through the lack of the 'us and them' attitude in the Tønsberg project, compared to other projects where the interviewees have worked. For example, the owner showed trust in the contractor's actions and gave praise both to outside parties and within the project organisation. Both mutual trust and respect were seen as vital for project success by the interviewees. It can both be argued that trust and respect are effects of particular elements and that it is part of a circular cause and effect relationship. In the team model context, mutual trust and respect fulfil some team and several individual needs through a focus on making a supportive climate, sense of achievement and accept and value the individuals in the organisation. From that perspective, trust and respect are essential to ensure a balanced leadership and project success but are not directly fulfilling task needs.

Willingness to collaborate seemed to be varying across the organisation. There seemed to be some 'growing pains' in accepting an owner who is active in every project phase, and in getting used to dividing work between parties working with different billing methods. For example, team members on a fixed salary tended to finish work for people with hourly billing when the latter had surpassed the budgeted number of hours assigned to that particular task. This shows that the IPD mindset is adapted to a varying degree for different members of the project organisation. However, another effect of willingness to collaborate was a positive working environment where, typically, everyone makes the best of the situation. There was also a significant degree of willingness to collaborate within the production team, which shows that this element fulfils team needs in the team model. A more mature IPD organisation might find that willingness to collaborate can meet task and individual needs as well, although these were not fulfilled at this time in the Tønsberg project.

Open communication seemed to be present between horizontally related parties in the project organisation, for example between subcontractors. However, in early phases, there was a lack of clear role definitions and communication vertically in the organisation, resulting in indecisiveness and delays. While the interviewees saw open communication as a necessity for successful IPD, there is evidence that this takes time or needs training to develop throughout the organisation. As for this project, open communication fulfilled individual needs, through for example constructive criticism and continuous feedback. However, this element is not prevalent enough throughout the Tønsberg project to satisfy team or individual needs.

Co-location was seen as one of the most positive elements and was mentioned in several contexts. The owner, designers, and contractors were all located in a single office building on the site during the design phase and at the beginning of the production phase. However, due to cost and time concerns of the commute to the particular location, co-location has been discontinued onsite, and designers are currently in offices in the capital city. Advantages of co-location were that people got to know each other on a personal level and therefore were more inclined to give and accept constructive criticism and feedback. Additionally, communication went faster and more directly, using richer communication channels than for example emails. The project used a so-called *BigRoom* as a working space. However, the room design was not ideal, as many perceived it as noisy and unfit for 70 people to work in. This contributed to the limited use of co-location in the project today. In the team model, co-location gave a systematic approach in daily work with *BigRoom* meetings and fostered a supportive climate where the difference of opinion was welcome, as well as a common workplace for employees of different companies. Therefore, co-location fulfilled task and team needs, but not individual needs.

CONCLUSIONS

This paper aimed to identify the effects of implemented elements of IPD on the production phase, and the effect on team, individual and task needs.

It is a challenge for both individuals and organisations to implement new elements to replace established practices. In this case, not only were new elements implemented, but an entirely new delivery model, in a Norwegian context, was also put into practice. The findings show that, on an operational level, there exists a tendency to fall back on the traditional way of doing things when the process is lagging or obstacles occur. This explains why the effects of some elements in this particular project deviated from the theoretical framework. Executives within the different organisations understand the IPD framework, but the case study shows that this knowledge has not been appropriately conveyed throughout the organisations. The IPD framework consists of many new elements which all need time to be learned and practiced. It is a maturing process of tools and ways of working within the operative units of the organisations. If the project had not introduced so many new elements without sufficient prior training of the individuals and organisations, they might have worked better than they did.

Leadership also plays a significant part in the successful implementation of new elements, and for a project as a whole. Adair’s team model indicates that if leadership is balanced between task, team and individual needs, then the likelihood of success increases (Adair 1986). **Error! Reference source not found.** is a summary of how task, team and individual needs are fulfilled by the IPD elements in the Tønsberg project. The table is sorted by the needs fulfilled by the most elements, while the elements follow the organisation in **Error! Reference source not found.**.

Table: 12 – Summary of task, team and individual needs in the Tønsberg project

	Contract								Technology and processes			Culture			
Fulfilled needs	Multiparty contract	Shared risk and reward	Early involvement of key participants	Intensified planning	Collaborative decision making	Collaborative goal definition	Liability waivers	Financial transparency	Lean	BIM	Integrated information	Mutual trust and respect	Willingness to collaborate	Open communication	Co-location
Team	X	X		X	X		X	X				X	X		X
Individual				X	X		X		X			X		X	
Task				X				X	X	X					X

It is evident that team needs are fulfilled to a greater degree than task or individual needs. This reflects the IPD aim of greater collaboration between stakeholders and seeing the project team as a unit. Contrary to traditional delivery models IPD emphasises the necessity of developing a project culture to achieve a successful project. **Error! Reference source not found.** reflects this philosophy as the elements within the culture category fulfils several needs and thereby shows that IPD supports effective leadership. The implementation of IPD in the case study is not ideal, and this is reflected in the fulfilled needs. With more successful implementation and training, one effect could be that more of the elements contribute to fulfil needs in the team model.

Further research is encouraged to increase the validity of the case study, for example through interviews with various roles representing different stakeholders. Additionally, a study after project completion can investigate quantitative data such as overall duration, cost, productivity, and quality.

REFERENCES

Adair, J.E. (1986). *Effective teambuilding*. Gower, Aldershot, UK.

AIA. (2007). *Integrated Project Delivery: A Guide.* The American Institute of Architects. <https://www.aia.org/resources/64146-integrated-project-delivery-a-guide> (27 Feb 2019).

Aslesen, A. R., Nordheim, R., Varegg, B., and Lædre, O. (2018). "IPD in Norway." In: *Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC), González, V.A. (ed.)*, Chennai, India, 18-20 Jul 2018. pp 326-336.

Bowen, G. A. (2009). "Document Analysis as a Qualitative Research Method." *Qualitative Research Journal*, 9(2), pp. 27-40.

Fischer, M., Ashcraft, H. W., Reed, D., and Khanzode, A. (2017). *Integrating Project Delivery*. Wiley, Hoboken, New Jersey, USA.

Ghassemi, R., and Becerik-Gerber, B. (2011). "Transitioning to Integrated Project Delivery: Potential barriers and lessons learned." *Lean Construction Journal*, pp. 32-52.

Hill, K., Silvon, C., and Draper, J. (2007). "Another Approach to Transforming Project Delivery: Creating a Shared Mind." In: *Proc. 15th Annual Conference of the International Group for Lean Construction (IGLC), Pasquire, C.L. and Tzortzopoulos, P. (ed.)*, East Lansing, Michigan, USA, 18-20 Jul 2007. pp. 417-422.

Howell, G. A., Macomber, H., Koskela, L., and Draper, J. (2004). "Leadership and Project Management: Time for a Shift from Fayol to Flores." In: *Proc. 12th Annual Conference of the International Group for Lean Construction (IGLC), Bertelsen, S. and Forsmo, C.T. (ed.)*, Helsingør, Denmark, 3-5 Aug 2004.

Kahvandi, Z., Saghatforoush, E., Alinezhad, M., and Noghli, F. (2017). "Integrated Project Delivery (IPD) Research Trends." *Journal of Engineering, Project, and Production Management*, 7(2), pp. 99-114.

Kenig, M., Allison, M., Black, B., Burdi, L., Colella, C., Davis, H., Elsperman, D., Frey, J., Katherman, R., Lambert, M., Lynch, J., Maibach, D., and McKimmey, M. (2010). *Integrated Project Delivery For Public and Private Owners*. NASFA, COAA, APPA, AGC of America and AIA. <https://www.agc.org/integrated-project-delivery> (27 Feb 2019).

Larson, E.W., Honig, B., Gray, C.F., Dantin, U., and Baccarini, D. (2014). *Project management: The Managerial Process*. McGraw-Hill education, North Ryde, New South Wales, Australia.

Lee, H.W., Anderson, S.M., Kim, Y.W., and Ballard, G. (2014). "Advancing Impact of Education, Training, and Professional Experience on Integrated Project Delivery." *Practice Periodical on Structural Design and Construction*, 19(1), pp. 8-14.

Macomber, H., and Howell, G. (2004). "The Two Great Wastes in Organizations." In: *Proc. 12th Annual Conference of the International Group for Lean Construction (IGLC), Bertelsen, S. and Forsmo, C.T. (ed.)*, Helsingør, Denmark, 3-5 Aug 2004.

Matthews, O., and Howell, G. (2005). "Integrated Project Delivery An Example of Relational Contracting." *Lean Construction Journal, 2(1), pp. 46-61*.

Oakland, J., and Marosszeky, M. (2017). *Total Construction Management: Lean Quality in Construction Project Delivery*. Routledge, Abington, UK.

Pishdad-Bozorgi, P., and Beliveau, Y. J. (2016). "Symbiotic Relationships between Integrated Project Delivery (IPD) and Trust." *International Journal of Construction Education and Research*, 12(3), pp. 179-192.

Seed, W. R. (2014). "Integrated Project Delivery Requires a New Project Manager." In: *Proc. 22nd Annual Conference of the International Group for Lean Construction (IGLC), Kalsaas, B.T, Koskela, L. and Saurin, T.A. (ed.)*, Oslo, Norway, 25-27 Jun 2014. pp. 3-14.

Tjora, A. (2012). *Kvalitative forskningsmetoder i praksis*. Gyldendal, Oslo, Norway.

Vestfold Hospital Trust. (2016). *Tønsbergprosjektet Forprosjektrapport.* Tønsberg: Tønsbergprosjektet. <http://tonsbergprosjektet.no> (20 Feb 2019).

Yin, R. K. (2017). *Case Study Research and Applications: Design and Methods*. SAGE Publications, Los Angeles, California, USA.

Simonsen, S.H.F., Skoglund, M.H., Engebø, A., Varegg, B.E., and Lædre, O. (2019). "Effects of IPD in Norway – A Case Study of the Tønsberg Project." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 251–262 DOI: https://doi.org/10.24928/2019/0157. Available at: <www.iglc.net>.

Berg, P., and Reed D. (2019). “Capability-Building Competition in Construction: Case Study Reinterpretation.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 265–274. DOI: https://doi.org/10.24928/2019/0219. Available at: <www.iglc.net>.

CAPABILITY-BUILDING COMPETITION IN CONSTRUCTION: CASE STUDY REINTERPRETATION

Peter Berg[1], and Dean Reed[2]

ABSTRACT

This industry paper is applied research with the purpose of answering whether Takahiro Fujimoto’s theory of capability-building competition in the automobile industry can be applied to the construction industry. This study begins with an empirical account of the work a series of project teams did to prefabricate and install exterior wall (X-wall) panels on six different buildings. The authors then explain relevant aspects of Fujimoto theory. Finally, the authors create a framework for evaluating the work in light of this theory and do so. The authors find that Fujimoto’s theory is relevant to construction. This paper is limited because the construction data set is relatively small and the evaluation of the competitiveness of routines and learning is based on the assessment of the first author, who initiated and directly managed the work on two projects and was engaged in its development on later projects. The paper is relevant for industry professionals because Lean management and process capability is required to make value flow to customers. Lean Construction theory can advance by understanding the elements of capability-building in the auto industry and how they can be applied to design and construction.

KEYWORDS

Theory, transformation, flexible manufacturing, evolutionary, emergence

INTRODUCTION

The authors observation, based on many years of practice, is that the construction industry lacks a language, and therefore theory to methodically improve and develop new capability that would provide greater value. This paper seeks to address the question of whether Takahiro Fujimoto’s theory of capability-building competition in the automobile industry can be applied to construction, in contrast to placing Fujimoto in a system view of Lean Construction (Picchi 2001). The method is to describe capability-building on a series of building projects, then introduce and use Fujimoto’s theory to reinterpret the development of onsite pre-fabrication and assembly of exterior wall (X-wall) panels on a series of buildings.

1 Project Executive, DPR Construction, 222 N. 44th Street, Phoenix, AZ 85034, USA, peterb@dpr.com

2 Lean/Integration Advocate, DPR Construction, 1450 Veterans Boulevard, Redwood City, CA 94063, USA, deanr@dpr.com

CASE STUDY: EXTERIOR WALL PRE-FABRICATION

THE HSEB EXPERIMENT: THE IDEA & TEAM BUY-IN

Traditional exterior building wall (X-wall) installation involves "stick building", or installing individual metal studs atop scaffold, then applying gypsum sheathing, water vapor barrier, z-girts, insulation, hat channel and finally copper rain screen. Working atop scaffold is very dangerous due to possible collapse, falling objects and cramped work space; it is also difficult for craftspeople to install work around bracing. Site and exterior wall work, that could otherwise progress, cannot be completed until scaffold is removed. And finally, scaffold is a temporary structure that is removed from the project, adding little value while costing a great amount in terms of safety, quality and money.

In 2010, the General Contractor Project Executive (PX) working on a new 6-story 270,000 square foot medical school building asked his project team if there was a way to install X-wall without scaffold by prefabricating modules on the ground and hoisting them onto the building. The project team responded by noting a number of barriers that would make installation without scaffold very difficult, if not impossible. After a back and forth discussion and no progress, the PX asked the team if trying a pre-fabrication approach on a single elevation would help by minimizing the risk that failed implementation would adversely impact the project.[3] The PX also committed to the team that he would accept sole responsibility and any resulting consequences for failure on behalf of the team. The team deliberated, then agreed that attempting pre-fabrication for the first time on a single elevation was a tolerable level of risk and committed to the approach. The North X-wall elevation was selected because of its geometric simplicity compared to the other elevations; it was essentially a vertically flat plane from a panel perspective.

DESIGNING THE PROCESS

Once the team committed, they had to learn what information, resources and steps were required to complete the North elevation using pre-fabrication. They started by mapping the work: create fabrication drawings; build the fabrication shop; order materials; create the fabrication schedule; fabricate and install panels. As the team thought about and pursued each step, they encountered many questions, problems and things that were not initially anticipated. Each step represented a new capability that the team had never performed before.

Fabrication drawings were typically not produced for walls framed in place (stick-built) built standing on a scaffold, so the team had to create a process to design them. Prefabricating panels required the project team to understand 3-dimensional tolerance variations across the complete north elevation; if the slab edge was inside or outside of the designed location they needed to know in advance because that would cause the panel structural connection and wall to be in the incorrect location. Additionally, if the slab edge was low or high, panels would be located incorrectly for the same reason. Once existing tolerances were understood, a flexible panel attachment could be designed to compensate

[3] Arguments for and against X-Wall Pre-fabrication are listed in Table 4 in the Appendix, available on request to the authors.

for out-of-tolerance existing conditions. The team blended laser-scanning technology with surveying and 3-D drafting to develop an as-built scanning process to deliver accurate useful information that could be incorporated into the fabrication drawings and overlaid onto the 3-D building design model, enabling flexible panel attachment design. Fabrication drawing capability necessitated as-built scanning capability.

Fabrication Shop

Off-site and on-site panel fabrication shop locations were analyzed. With all factors included: cost, schedule, site logistics, transportation, accessibility, rigging, hoisting, work environment, quality installation, inspections, and not having an existing fabrication space, the team decided to move forward with constructing the panels onsite. Shop size was determined by calculating the panel production rate required by the project schedule. The team concluded all panels could be fabricated at the needed production rate on two field fabricated jig tables utilizing minimal space. A multi-trade step-by-step workflow was mapped out by the workers. A pull production schedule was developed to support the project schedule, materials were ordered and delivered on a weekly basis to support production, and fabrication commenced.

Rigging, Hoisting and Installation

Rigging and hoisting each of the panels was a concern. Walls are traditionally designed for static vertical loads; pre-fabrication requires rigging and hoisting the panels, which imposes x, y and z dimensional dynamic loads on the panels. Analysis by the team and cold-form steel engineer concluded that cold-formed steel cross braces fastened to the interior side of the X-wall were required to prevent possible wall frame deflection during the hoisting process. Two removable rigging eyelet connections were designed and installed at the top and at a location at either end of each panel prescribed by the structural engineer. Prior to hoisting, installers marked the precise locations of each panel to be hoisted on the top, vertical edge and bottom of the concrete slab. One half of the flexible X-wall panel structural connection was welded to a steel plate embedded into the concrete slab edge in the exact location needed to receive the panel side of the structural connection. All field dimensions were located using information from the 3-dimensional fabrication model uploaded into laser-based surveying equipment. This combination of conventional field markings, pre-installed structural connection and model-based laser surveying insured that each panel was installed and located without error. With all safety and quality measures in place, the panels were then hoisted into their respective locations on the building and permanently connected.

Scaling / Paying It Forward

The team diligently documented everything involved in this experiment of pre-fabricating a single elevation. Workers for the GC from other projects were invited at multiple points to visit the project for purposes of sharing experiences. Future projects decided to use this pre-fabrication approach due to its benefits. Each future project made improvements to the initial approach, one experience building upon another. These projects are described in Table 5 of the Appendix, available on request to the authors.

THEORY OF CAPABILITY-BUILDING COMPETION

In the book, *The Evolution of a Manufacturing System at Toyota*, Takahiro Fujimoto attempted to fill in three missing pieces in the story of how a total manufacturing system evolves: the evolutionary perspective for detailed analysis of manufacturing; the information approach to manufacturing routines at the total system level; and the three-layer framework of organizational capabilities: routinized manufacturing, routinized learning, and evolutionary learning.

The evolutionary view is the idea that systems evolve because of unanticipated events and unplanned behavior and is related to system emergence. Fujimoto uses the term “multi-path system emergence” to describe an interplay of both intended and unintended consequences for the people who create a system, when decision-makers don’t often know beforehand which path will lead to a successful outcome: deliberate planning, environmental imperatives, intuition, imitation or luck. Emergence means that a certain system trait cannot be explained by the behavior of its constituent parts alone or predicted from the previous states of the system owing to its complexity from the observer’s point of view. Fujimoto describes the three levels (or “layers”) of organizational capabilities in Table 1.

Table 1: Three Levels of Manufacturing Capability (Takahiro Fujimoto 1999)

Capability Level	Basic Nature	Influence	Characteristics
1. Routinized manufacturing capability	Static & routine	Competitive performance in stable environment	Firm-specific pattern of a steady-state information system in terms of efficiency and accuracy of repetitive information transmission
2. Routinized learning	Dynamic & routine	Changes or recoveries of competitive performance	Firm-specific ability of handling repetitive problem-solving cycles or a routinized pattern of system changes
3. Evolutionary learning	Dynamic & non-routine	Changes in patterns of routine capability	Firm-specific ability of handling system emergence or non-routine patterns of system changes in building routine capabilities

The third level of the framework is evolutionary learning capability, which is also dynamic but differs from routinized learning capability because it is related to higher order system changes that are irregular and infrequent, and are often connected with rare, episodic and unique historical events. Evolutionary learners do not even know in advance if this route is open to them. Evolutionary learning capability is a firm-specific ability to cope with a complex historical process of capability-building, multi-path system emergence, that is neither totally controllable nor predictable. Fujimoto asserts that evolutionary learners simultaneously activate two different modes of learning: intentional and opportunistic.

Figure 1 shows Fujimoto's operational definition of multi-path system development and evolutionary learning capability.

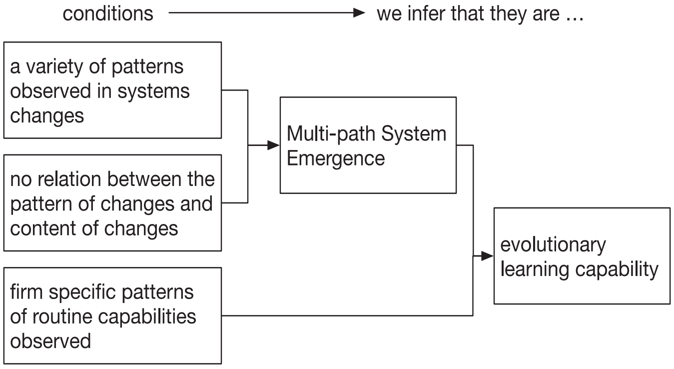


Figure 1: Operational Definitions of Multi-path System Emergence & Evolutionary Learning Capability (Takahiro Fujimoto 1999)

Fujimoto propose a dual-layer (or "level") problem-solving framework to explain the evolutionary process of system emergence, one that consists of two levels of partial or incomplete problem-solving processes, shown in Figure 2. The lower level mechanism, representing the process of system emergence generates miscellaneous solutions for various purposes, while the upper level mechanism, reflecting a certain evolutionary learning capability of the firm, absorbs the solutions and converts them to manufacturing capabilities.

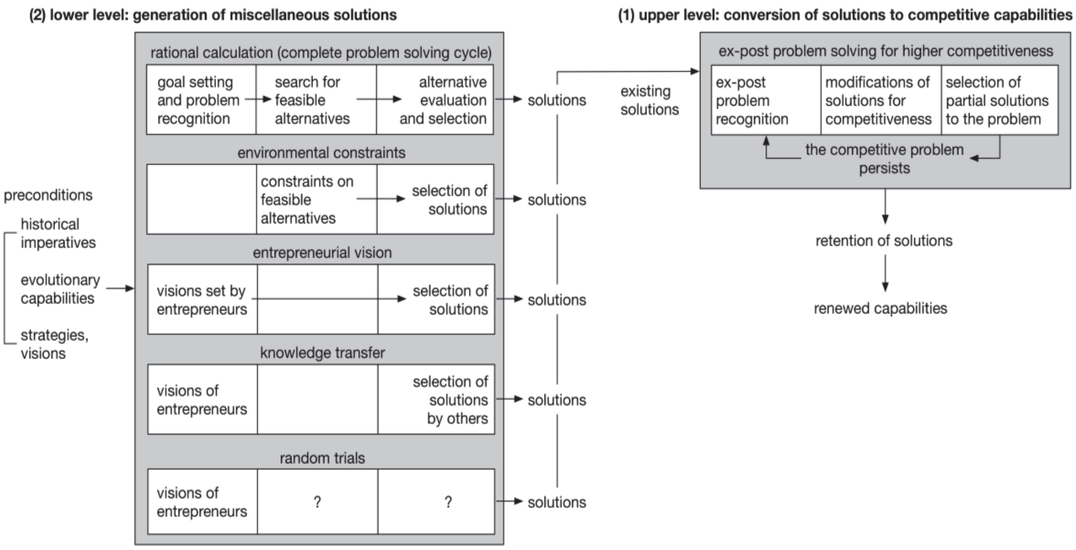


Figure 2: Dual-Layer Problem-Solving (Takahiro Fujimoto 1999)

Fujimoto believes that focusing on information offers the only way to understand the total system because it runs through the three basic components of Toyota's system: production, product development and supplier systems, and carries value beyond the boundaries of manufacturing, circulating between the producer (including its suppliers), and customer.

Fujimoto asserts that the basic unit of an information system is a combination of information and its medium - an information asset and information processing as activities that change the state of an information asset, including information content, medium, and location. Fujimoto's definition of information processing includes "not only what computers and telecommunication devices do but also human communication, knowledge creation, and even physical transformation." In addition to multi-path system emergence, Fujimoto postulates that problem-solving cycles also explain information system changes. "A problem-solving cycle refers to a series of information processing in which goals or problems (i.e., input information) are converted to solutions to the problems (i.e., output information), using regular heuristics ..." A typical cycle includes five steps (goal setting, alternative idea generation, model development, experiment, and selection) and is typically initiated by recognition of certain problems (i.e., gaps between goals and current situations). "Alternative ideas are then created or retrieved from the repertoire. Since knowledge of the causal relationship between the alternatives and their consequences is normally imperfect, the cycle typically develops simulation models and conducts experiments for various possible combinations. After the results are evaluated, an acceptable alternative may be selected or a new cycle of problem-solving may begin. As a result of a problem-solving cycle, the solution set (i.e., information content) of the firm changes."

Fujimoto explains that as "product development and production processes go on, the information becomes refined from product concepts to basic or functional product designs, finalized as detailed (structural) product designs, translated and deployed in production processes, and eventually transmitted to the products." Fujimoto argues that "production activity can also be regarded as transfers of the product design information from the production process to the product. At each station of the process, a fraction of the product design information – stored in the workers, tools, equipment, manuals, and so on – is transferred to material or work in process, which 'absorbs' the information step by step and is transformed eventually to a product." Figure 3 shows the relationship between multi-path system emergence, evolutionary learning capability, information routines for learning and manufacturing, and manufacturing performance.

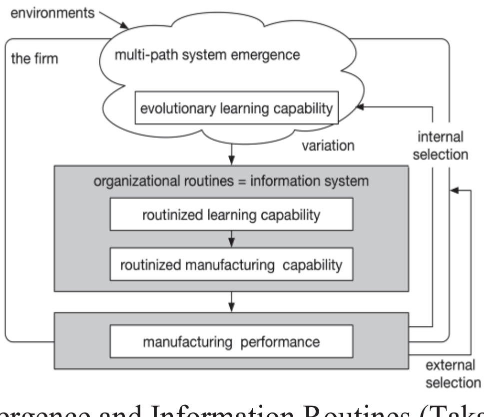


Figure 3: System Emergence and Information Routines (Takahiro Fujimoto 1999)

Fujimoto notes that the "Toyota-style production system focuses on reduction of "muda," or the time when information transmission is not happening (i.e., non-transmission time) on both the sender and receiver side." For example, in "a labor-intensive process, trained workers are the senders and works-in-process are the receivers of the value-carrying information. The system aims at low levels of non-value-adding time on the worker side (e.g., waiting time) on the one hand, and non-value-receiving time on the work-in-process side (e.g., inventory) on the other."

Fujimoto explains that once transmission errors happen, they have to be detected and proper remedies have to be implemented. "Effective automakers tend to reduce the lead time between fabrication and inspection, and thereby make information feedback cycles quick. On-the-spot inspection, in which direct workers (including team leaders) inspect what they just made before transferring it to the downstream step, is a typical example."

Continuous improvement of productivity and quality (kaizen) is often seen as a core capability of effective Japanese production systems. Fujimoto asserts that "the idea of a factory as a 'learning laboratory' applies here. The elements of both just-in-time and total quality control appear to contribute jointly to a Toyota-style capability of routinized learning (i.e., repetitive problem-solving) ..."

Fujimoto states that "the functional principle behind effective manufacturing routines is quite simple and straightforward. The structure of the manufacturing routines may be quite entangled, but their ultimate function is almost always clear – to outperform rivals in attracting and satisfying customers. Once this principle is explicitly or intuitively understood, it is not difficult to explain the competitive function or dysfunction of an existing manufacturing routine. No matter how remote the routine-holding units are from the customer interface, they are connected to customers by the information web. No matter how remote two organizational units are (e.g., a stamping shop and a dealer's showroom), they share one informational node – the customer. And all the information held by effective routines eventually flows into this node, like all the little streams that eventually join the river."

Fujimoto explains that "the concept of 'customer orientation by all employees' is crucial – not only because it is good for customers, but also because it maintains the overall integrity of manufacturing routines. Even though Toyota's employees may never call their practices an information system, they are virtually and intuitively referring to the informational nature of their system's routine capabilities when they emphasize customers (ultimate note of information),"muda" (non-information-processing state), "the downstream station is the customer" (accurate transmission of information to the next step), and so on." Fujimoto proposes that the information network is the deep structure that governs Toyota's manufacturing activities.

Fujimoto states that "Toyota-style manufacturing routines, as a total system, are complex in the sense that they were not created by any prior grand design. However, the system is also simple in the sense that the ultimate function of individual routines can be clearly explained by a simple principle of customer satisfaction, whether they were created to achieve this intentionally or unintentionally." Fujimoto asserts "this is why companies like Toyota, which have applied such a principle throughout the firm, could consistently outperform others by cumulatively building routines that turn out to create high performances through a combination of system emergence and evolutionary capability; for such companies, the system of manufacturing routines is too complex to design ex-ante, but simple enough to grasp ex-post." (Takahiro Fujimoto 1999)

CASE STUDY REINTERPRETATION

ASSESSMENT FRAMEWORK

Reinterpretation required designing a framework based on Fujimoto's theory for assessing the competitiveness of routines, multi-path system emergence and evolutionary learning capability within project teams for six consecutive projects.

Assessment: the first author of this paper served as the Project Executive for the first, third and fourth projects listed in Tables 2 and 3 below, and acted as entrepreneur, process designer and teacher / mentor. He was entirely accountable for project team performance on these projects and assisted with the others. This made him the best single source for identifying routines and assessing multi-path emergence and evolutionary learning in the absence of well-defined criteria.

Routines: ten routines, listed in Table 2, were identified for the projects.

Competitiveness: a 0 to 5 scale was chosen to assess the impact of routines on safety, quality, schedule and cost, with each contributing a maximum of 25% towards X-wall competitiveness compared to framing and sheathing wall panels in place. The total score expressed as a percentage had no top-end limit. It was and is possible to fail to improve competitiveness or succeed beyond 100% as can be seen in Table 2.

Multi-Path System Emergence: a yes/no answer was given for the presence of the five paths identified by Fujimoto shown in Figure 3 above and in Table 3 below. This determined the percentage for each path's contribution to generating solutions on all six projects.

Firm Specific Patterns of Routine Capabilities: a 0 to 5 scale was chosen to assess the degree to which ten routines, had been implemented ("routinization"). This allowed a percentage score to be calculated for each project.

Evolutionary Learning Capability: a yes/no answer was given to assess the contribution each routine made to the X-wall production system on each project. As with patterns of routine capabilities, a percentage score was calculated for each project. Table 3 shows these scores.

Table 2 shows the first author's assessment of the competitiveness of the routines impact on safety, quality, schedule and cost compared to framing and sheathing exterior walls in place, with each factor contributing from zero to a maximum of 25% to the cumulative score. Tables 6, 7, 8, 9, 10 and 11 in the Appendix, available on request to the authors, display the contribution each of the categories made to the project scores.[4]

Table 2: Competitiveness of Routines

ID	Project	1	2	3	4	5	6
	Routines & Improvement in Competitiveness						
1	As-Built Scanning	10%	20%	20%	20%	30%	30%

[4] The projects are described Table 5 in the Appendix, available on request to the authors.

2	Fabrication Drawings	10%	20%	20%	20%	30%	40%
3	Fab Shop	15%	15%	15%	25%	30%	30%
4	Pull Production Schedule	10%	20%	20%	20%	25%	30%
5	Panel Production	15%	35%	70%	70%	50%	70%
6	Quality at the Source	0%	0%	0%	0%	40%	15%
7	Rigging & Hoisting	5%	10%	10%	20%	40%	40%
8	Install	10%	20%	20%	20%	40%	60%
9	Pre-Pour Scan	0%	0%	0%	0%	15%	0%
10	Post Pour Scan	0%	0%	0%	20%	40%	15%
	Improvement in Project Competitiveness	75%	140%	175%	215%	340%	330%

Table 3 shows the first author's assessment of multi-path development, firm specific patterns of routine capabilities and evolutionary learning capability, and their contribution to capability of the X-wall production system. Tables 12, 13, 14, 15, 16 and 17 in the Appendix, available on request to the authors, show the detailed analysis.

Table 3: Multi-path System Emergence & Evolutionary Learning Capability[5]

Project	P-S	EC	EV	KT	RT	PRC	ELC
1	90%	20%	30%	0%	10%	0%	0%
2	70%	10%	0%	70%	0%	14%	10%
3	70%	10%	10%	70%	0%	28%	30%
4	80%	20%	20%	80%	0%	46%	20%
5	100%	20%	30%	80%	20%	64%	90%
6	90%	20%	20%	80%	20%	84%	80%

REINTERPRETATION OF X-WALL PRODUCTION

All of routines were either focused on creating or using accurate information for production to meet the end and intermediate customer's requirements. All of the project teams used the Last Planner System and Building Information Modelling in pursuit of project objectives for safety, quality and elimination of waste and increased production flow.

Given the newness of the evaluation framework and the lack of criteria for evaluating the effectiveness of new routines, trends rather than absolute numbers offer the best opportunity for insight. The following trends can be seen.

Competitiveness: the increase on the first project is a strong argument for taking the risk of doing something different, even when it is not clearly understood at the

[5] Paths are abbreviated as follows: P-S for Problem-Solving; EC for Environmental Constraints; EV for Entrepreneurial Vision; KT for Knowledge Transfer; and RT for Random Trials. PRC stands for Firm Specific Patterns of Routine Capabilities and ELC for Evolutionary Learning Capability.

outset. The progressive and dramatic increase across all projects is an extremely good return on investment resulting from persistence.[6]

Multi-Path System Emergence: knowledge and information came primarily from problem-solving throughout all projects. Site logistics constrained possible solutions on almost all of the projects. The first author proposed new approaches when his project teams could not see a path forward, the "entrepreneurial vision" Fujimoto describes. Knowledge was transferred to each successive project.

Firm Specific Patterns of Routine Capabilities: starting from zero on HSEB, routines for gathering and using information in production became more effective and the advantages of pre-fabrication over framing and sheathing exterior walls in place using scaffolding became greater. Learning through problem-solving on a single project was shared within the General Contractor organization and introduced into successive projects, which was only possible because practitioners could describe what they experience as a series of activities that could be repeated regardless of the specific technical challenges they faced on new projects.

Evolutionary Learning Capability: the assessment indicates that project teams became better at problem-solving and transferring knowledge, and that routines were better understood, which in turn increased their application, integration, effectiveness. An X-wall production system emerged and was optimized, especially on the last two projects.

CONCLUSION

The analysis of X-wall capability-building indicates that Fujimoto's theory can be useful and possibly the foundation for a comprehensive approach enabling companies and project teams to develop the capabilities they need fast enough to improve project delivery outcomes. Further retrospective studies coupled with proactive capability-building based on Fujimoto are needed. This can be a meaningful contribution to Lean Construction theory.

REFERENCES

Picchi, F. A. (2001). "System View of Lean Construction Application Opportunities." 9th Annual Conference of the International Group for Lean Construction, G. Ballard and D. Chua, eds., Singapore, Singapore.

Takahiro Fujimoto. (1999). The Evolution of a Manufacturing System at Toyota. Oxford University Press, Inc., 198 Madison Avenue, New York, New York, 10016.

[6] Without considering scaffold, pre-fabrication was approximately 15% less expensive. Once the cost of scaffold is subtracted, pre-fabrication was much less expensive than the traditional stick-build approach. Pre-fabrication panel and water vapor barrier quality was far superior. Safety was greatly improved by eliminating scaffold. Interestingly because scanning was required for pre-fabrication, the team found other areas of the project where scanning could add benefits in different ways; specifically, pre-concrete-pour and post-pour scanning were experimented with and developed as a consequence of the pre-fabrication experiment.

PLENARY PAPERS (2)

Christensen, R., Greenhalgh, S., and Thomassen, A. (2019). "When a Business Case is Not Enough, Motivation to Work with Lean." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC)*, Dublin, Ireland pp. 275–286. DOI: https://doi.org/10.24928/2019/0146. Available at: <www.iglc.net>.

WHEN A BUSINESS CASE IS NOT ENOUGH MOTIVATION TO WORK WITH LEAN

Randi Christensen[1], Stephen Greenhalgh[2] & Anja Thomassen[3]

ABSTRACT

Lean practitioners have always been very passionate about sharing their experiences and knowledge so others also can benefit from better processes and reduced waste. When lean practitioners get together to discuss and spread knowledge, the 'implementation of lean' is often at the core of the conversation. How do we get others to understand the nature of lean and how do we get them to implement it? Despite clearly documented, positive outcomes and strong business cases, we still encounter resistance and it can be challenging to even get our own colleagues to be engaged with lean.

This paper explores what motivates individuals with different project roles to work with lean, when some research shows that knowledge and will is not enough to change. It considers why incentive measures and a focus on time and cost savings could have a negative impact on the motivation to change for some groups. This discussion is supported with survey data and experiences from a major infrastructure project and within the organisation of the client, Highways England.

KEYWORDS

Lean construction, implementation, motivation, sense making, change

INTRODUCTION

No one ever said: "*When I lack motivation to go to work in the morning, I just remember that my team contribute to cost and time savings. By constantly optimising our own work processes I know we contribute to significant savings every day, which is documented in important trackers, spreadsheets and in case examples. This motivates me to do my best!*". (Inspired by Münster, 2017).

Implementing lean construction from the lean construction community's perspective is seen as a significant change from traditional project management and perhaps even a paradigm shift (Korb & Ballard 2018). By lean practitioners it is seen as a fundamental shift from construction's traditional transformation processes to a more production line

[1] PhD, MSc, Lean Manager, COWI working on behalf of Highways England at Lower Thames Crossing, London, Co-Founder of CollabDecisions, +44 7702 856113, rmch@cowi.com

[2] BSc, Civil Engineering, Lean Manager for East Region & Complex Infrastructure Programme for Highways England stephen.greenhalgh@highwaysengland.co.uk

[3] PhD, Cand.merch Anja O. Thomassen, Associate Professor, Department of Learning and Philosophy, Aalborg University, aot@learning.aau.dk

methodology and a systematic approach to management and continual improvement. Lean practitioners recognise that they need to support project production with a different approach and a different skill set. The lean community also seems to see a fundamental need to understand this paradigm shift in theory before practice (Howell and Koskela 2000).

As a lean practitioner, when you have recognised this shift, it can be highly challenging to work with non-lean practitioners. You ask yourself, “Why can’t they see they are wrong?”, “Why can’t they see that lean is much more beneficial?”. This is often the point where lean practitioners start looking for hard evidence of the outcomes of a lean approach. The frustrations then surface when this information does not have an impact on non-lean practitioners. It can result in lean practitioners feeling a sense of resignation when the clear evidence of the impact of lean construction is ignored or disbelieved (Korb & Ballard 2018). The mentality of people seems to be the root problem for change (Koskela et al 2003).

In this paper, we explore how best to implement lean construction by considering what motivates project team members to work with lean construction and continual improvement. More knowledge about motivating factors might support future research to explore how to most efficiently implement lean construction. Thus, the research question is: “What motivates and demotivates people to work with lean and is motivation influenced by role, discipline and hierarchical position?”.

Structure and Methodology

Firstly, we will discuss what research and literature tell us about motivation for change and sense making, and how this can be impacted by different factors in the specific context. Secondly, the theoretical discussion is supplemented by observations carried out on a specific case, the Lower Thames Crossing scheme. A lean specialist working for Highways England, a large infrastructure client and operator in UK and the lean manager working on the specific case recorded their observations using the client’s standard approach. The client had developed its approach to standardise the assessment of lean activity, strategy and culture across all of its significant infrastructure projects. We also provide an insight of how the client has set up and motivated its supply chain to adopt a lean construction approach. The observations are supported by findings from a survey sent to the full-time staff on the project asking questions on lean implementation and the motivation to work with lean.

A questionnaire was developed which consisted of 22 questions, including 6 that were focused on motivation. The questionnaire was sent to 260 recipients across the project organisation, of which 167 were fully or partly completed, giving a response rate of 60%. This response rate is considered as acceptable. The intention of sending the questionnaire to all relevant organisational levels was to provide a diverse range of opinions. However, as the number of respondents at each level was limited, this influenced the survey’s explanation power. This is taken into account in this research, as the answers are perceived as indicators and not as objective facts (Bryman 2015; De Vaus 2013).

The collaboration between the lean manager, who works full time on the project, and the client lean specialist, who visits the project approximately once a month, have ensured the reflection on practice, and an external researcher have provided critical input to the research methods and results.

WHEN DOES CHANGE MAKE SENSE?

Management literature has previously focused on how to create change and behaviour by using a few logical steps. Firstly, we need to ensure the employees have the right knowledge and secondly, we need to ensure that the receiver is convinced and wants to change. If the receiver gets the right information and understands the benefit of the change, they will start changing. (Münster 2017)

With his book "Thinking Fast Thinking Slow", Daniel Kahneman influenced a new generation of management literature, to understand that people do not act as they do due to deliberate considerations but out of habits. Two systems were proposed; System 1 is our automatic pilot that takes us through the day where thousands of decisions are taken with little effort. System 2, on the other hand, supports more deliberate changes, but this is a very resource heavy thought process and our capacity is to implement these changes is limited. Therefore, when we are under pressure, changes are unlikely to happen through these deliberate processes (Kahneman 2011). Therefore, we need to consider how to influence the more unconscious thought processes to change behaviour.

Motivation can also be divided up into intrinsic and extrinsic motivation. Intrinsic motivation refers to doing something because it is interesting or enjoyable, whereas extrinsic motivation refers to doing something because it leads to something else (Ryan and Deci 2000). For example, performance and incentivisation measures can be considered an extrinsic motivation for the project team. Extrinsic motivation leads to higher performance when the work tasks are simple and require a large portion of System 1 thinking (Pink 2007). This can be applied to refining known processes and making them more efficient and reliable. But, if the processes by which you reach your goal are unknown or highly complex, incentives have been shown to have a negative impact on performance. In other words, extrinsic motivation factors seem to undermine System 2 thinking. This is worth considering when motivating to use lean construction in highly complex work environments where creativity and problem solving form a large part of the work.

The elements that build intrinsic motivation are things like autonomy, mastery and purpose (Pink, 2007). Autonomy might include the ability to set up your own team, to manage your own time and define tasks. Mastery is the ability to develop skills and purpose to achieve something meaningful and important. A lack of motivation is the result from not valuing activity, not feeling competent to do it or not believing it will lead to a desired outcome (Ryan and Deci 2000).

In addition to motivation, Weick's notion of sense making might be helpful in understanding why people continue to behave in similar ways despite obvious facts support a change in behaviour. Weick's argument is that people implement new methods and processes if it makes real sense to the individual. For example, a project manager might tell you that it is a good idea to implement lean; however, if this does not make sense to you, it will not influence a change in behaviour. If it is received as an instruction and thereby a limitation of autonomy, it might even inhibit change. Hence, change does not occur due to good arguments and convincing results, change occurs when it makes sense to change (Weick 1995).

LEAN IMPLEMENTATION ON A MAJOR INFRASTRUCTURE PROGRAM

Lower Thames Crossing is a £5bn infrastructure project for Highways England, the government organisation responsible for the strategic road network in England. The project will connect the highway network from North East to South East of London with some 20 km of roads and what will be the world 3rd biggest tunnel of its kind under the River Thames. The project is scheduled to open in 2027 and is currently in the preliminary design phase.

CLIENT DEMAND AND EXPECTATIONS

Since the mid-2000s, Highways England has been influencing its supply chain to adopt a lean approach to construction and from 2011 has used lean maturity to determine which suppliers the company wants to continue to do business with (Drysdale, 2013). Highways England state that the more mature a company is in adopting a lean approach, the better understanding it has of lean which leads to delivery of improvements in cost, time and quality and creates a more globally competitive supply chain. Highways England developed a lean maturity assessment tool (HELMA) to encourage its "supply chain to adopt lean principles to help foster a culture of continuous improvement for mutual advantage." They suggest that the outcome of the HELMA can help organisations highlight areas for improvement, with suppliers encouraged to implement an improvement action plan to drive lean deployment across their organisation.

Once in a contractual relationship the requirements of Highways England's suppliers become more explicit. Contracts include clauses such as the use of continual improvement, based upon lean principles to generate and realise reductions in the costs. A requirement of Highways England's funding from government is that design, construction and maintenance of its network should be more efficient, hence why it also expects its supply chain to deliver and document efficiencies based on a lean approach (Highways England 2015, HM Government 2015). Efficiencies have to be documented showing a saving in either time and/or cost, or a documented delivery of value beyond expected. There is a requirement for regular forecasts and reports on progress on delivering and documenting efficiencies in relation to a specific target set by Highways England for each scheme.

These measures are expected to incentivise the its supply chain to continual deliver more value with either the same or fewer resources. Highways England also provides support to both implement lean and deliver efficiencies with its specialists, to some extent, actively engaging with projects to ensure a continual development and focus on lean and the delivery of efficiencies. Highways England also facilitate knowledge transfer through the sharing of efficiency registers, peer-to-peer lean practitioner events and smaller lessons learned meetings.

LEAN STRATEGY AND DEPLOYMENT PLAN

On the Lower Thames Crossing scheme, a Lean Strategy and Deployment Plan sets out the requirements for continual improvement and developing competencies within lean construction on the project. Furthermore, the team is responsible for delivering and documenting efficiencies, and to deliver value management and innovations. Initially the Lean Strategy and Deployment Plan was based on the requirements and incentivisation measures set by the client, Highways England. Although the strategy has been stable, the deployment plan has been updated due to:

- Changes in the scheme stages and meeting specific challenges;
- Development in project lean maturity, and;
- Resource constraints.

The changes of the deployment plan have been made in collaboration between the lean manager and client specialist lead. The lean implementation for the current stage of the project is centred around four main initiatives: Last Planner System (Collaborative Planning), Choosing by Advantages (Further described in (Schöttle et al 2018)), Visual Management and a Lean Training Program. A team of lean champions and Choosing by Advantages facilitators have been trained to support the lean implementation.

LEAN RESULTS

In addition to lean maturity assessments of the organisations delivering the scheme, the lean maturity of the project has been assessed four times since its commencement. The lean maturity (on a scale of 0 to 4) has increased from a level 1.5 in February 2017 to a level of 2.05 in November 2018. Furthermore, the project has delivered more than 300% of the required efficiencies for the current financial period, although none of these have been explicitly linked with lean initiatives.

LEAN AWARENESS SURVEY

In order to understand the breadth of lean understanding on the scheme, a lean survey of the project team was undertaken in November 2018. The respondents covered a wide range of project staff from project senior leaders to graduates, see Figure 1. As the project is in the preliminary design phase, the project team has a significant proportion of technical specialists and engineers contributing to the design.

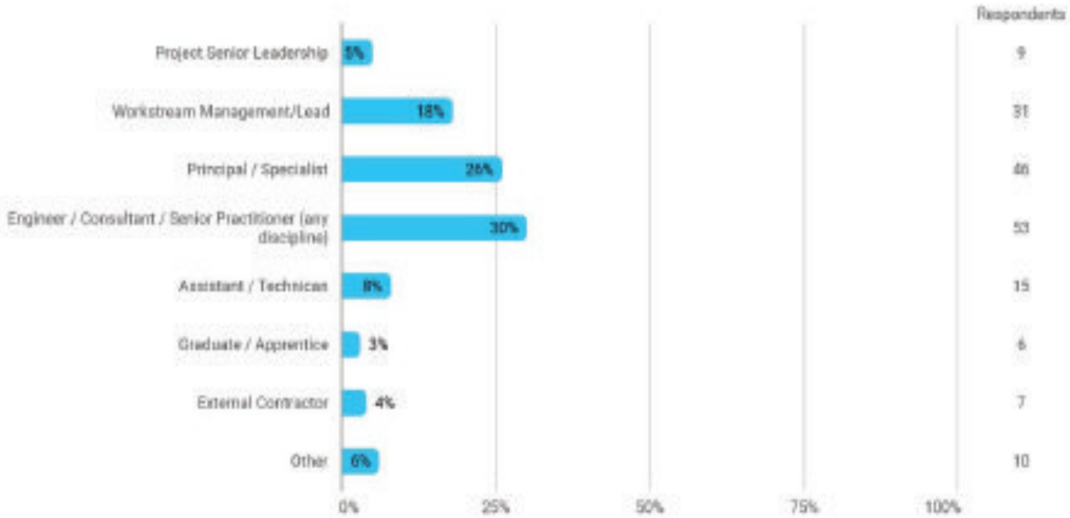


Figure 1: Roles of the respondents

As lean has been part of the scheme management approach for more than 2.5 years, the team is expected to have knowledge about lean practices and tools. Some 63% responded they understood the concept of lean and on a scale from 0-100 the respondents rated their average knowledge to 33. Around 41% responded to having had some kind of lean training (from 3 hours to 10 weeks programme). Over 60% responded that they believed lean could be further developed in their role, see Figure 2. In summary the majority of staff had an understanding of lean and it would appear that there is a positive attitude towards lean in the Lower Thames Crossing team.

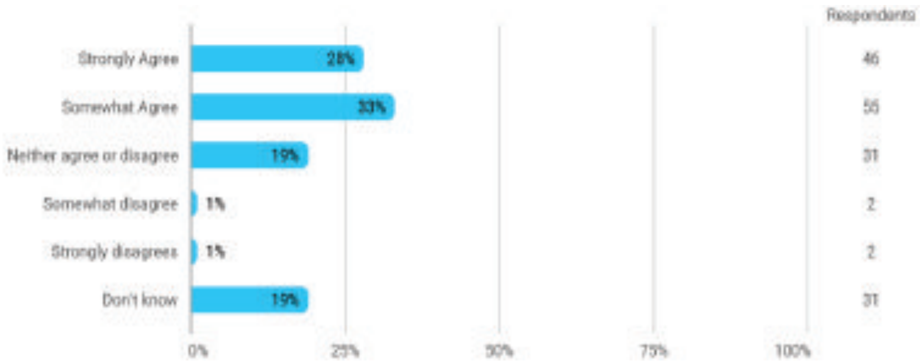


Figure 2: Responses to the question: Can Lean be further implemented in your role?

When asking what motivates the project team to work with lean, 32% responded that they were motivated by the ability to improve their own personal work processes, 22% by contributing to better quality and 15% to savings and time reductions, see Figure 3.

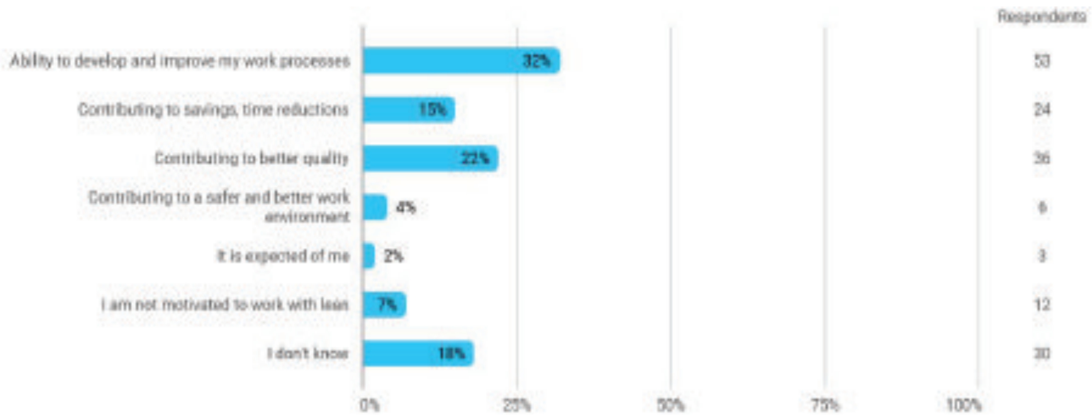


Figure 3: Responses to the question: What motivates you most to work with Lean?

Diving down in the results to see what motivates the different roles gives slightly different picture, see Figure 4.

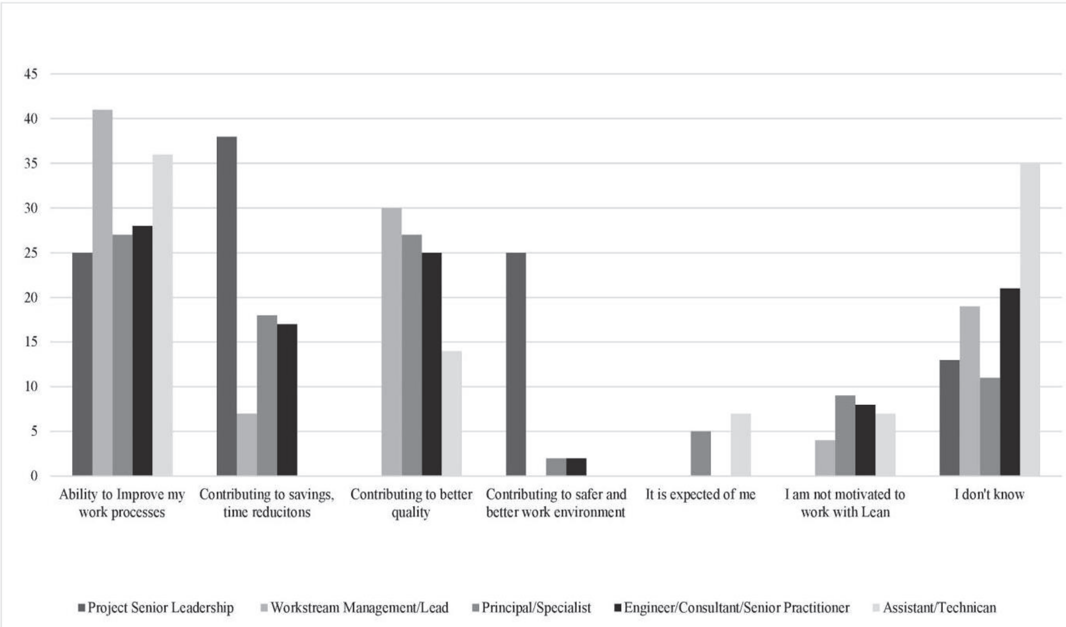


Figure 4: Responses to the question: What motivates you most to work with Lean? compared to role on project.

The senior management group are highly motivated by savings in time and cost, work stream leads are mostly motivated by improving own work processes, principals and specialists are mostly motivated by contributing to higher quality. Interestingly, the senior managers are the only group motivated by creating a safer and better work environment. Asking the opposite question on what demotivates the different groups the picture is more consistent, see figure 5.

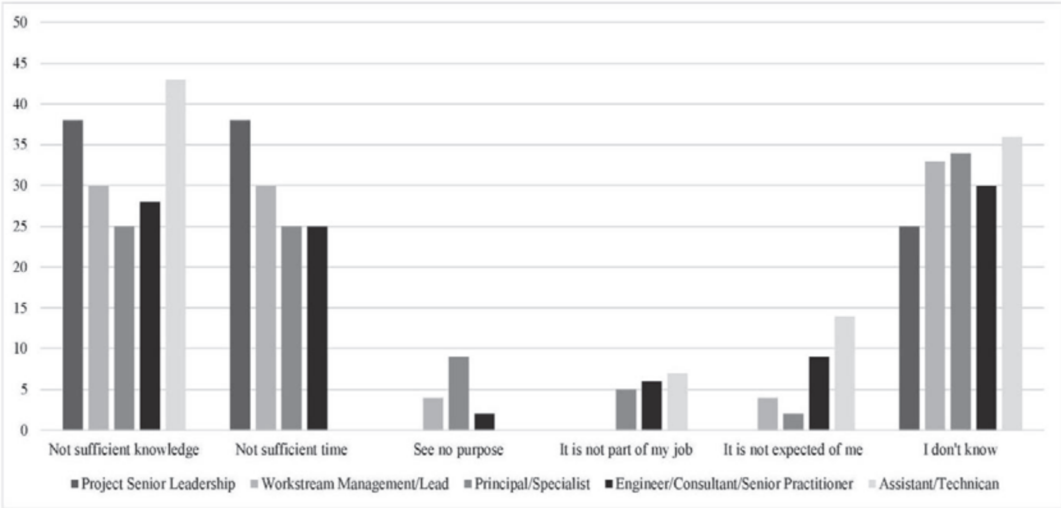


Figure 5: What demotivates you to work with Lean?

The demotivating factors across the team is that project team members do not feel they have enough time, knowledge or they do not know what demotivates them. Possibly also due to lack of knowledge of what lean entails.

DISCUSSION: WHEN DOES IT MAKE SENSE TO CHANGE?

The client, Highways England, in its strategy documents, tender and contractual requirements set out clear expectations towards the implementation of lean on the Lower Thames Crossing scheme. By setting clear expectations, Highways England has enabled lean implementation across the industry (Tezel, A. et al., 2016). The efficiency target and lean maturity assessment framework work as clear extrinsic motivation measures and enabled clear communication, with the project senior management team having bought into the need for lean implementation. This resulted in resourcing lean implementation from the early start of the project and appointing lean specialists to support the project team. In the survey the senior managers rated time and cost savings as the most motivating factor when working with lean. This is not surprising as this organisational level is measured on these parameters.

The results of lean assessments of the project organisations and on the project, itself indicates an increasing adoption of lean and an increasing use of lean on the Lower Thames Crossing scheme. In general, the project team members have a positive attitude towards Lean and support that it could be further developed within their role. 41% responded to have had some sort of Lean training and when asked to rate own knowledge the answers were also that they perceived they had some knowledge about lean. When asked about specific lean tools 53 have participated in Collaborative Planning and 45 in Choosing by Advantages. Despite this, the respondents pointed to lack of knowledge as one of the main barriers for engaging more in lean.

Another main barrier for the project team to engage more in lean is a feeling of not having enough time. The perception on the project is also that there is a significant focus on schedule and cost savings. Looking back at the motivation theory, a strong focus on extrinsic motivation factors inhibit development of productivity in highly complex production settings (Pink, 2017).

Lean practitioners know that time constraints should not be a barrier to work with lean as applying lean techniques should free up resources. So, one answer to these barriers could therefore be to provide training and developing more evidence of lean. But this would be to do more or what we already have done, at it seems not to work.

Another answer could also be to ask whether the feeling for mastery is present with a project focus on cost and time savings. As seen in the literature, change require more than knowledge and will to change. When people do not immediately change behaviour despite knowledge of the benefits, it could be due to lack of bandwidth for change inhibiting system 2 to allow for deliberate changes. (Kahneman, 2011).

Al groups also point to the motivating factor of improving own work processes and for the engineers and specialists improving quality was also a motivation factor. These are intrinsic motivations of wanting to avoid inefficient working processes from own perspective. Many engineers and specialists are very proud of their own discipline and want to contribute to heighten the quality of the project instead of looking for savings in time and cost.

So perhaps what we see is a tension between the motivation of the senior managers that focus on time and cost savings while the rest of the organisation is motivated by solving problems and creating quality? And when managers then try to motivate by setting the scene with pressure on time and cost, this actually inhibit the rest of the organisation to change and invest in development?

Why is it that the lean managers have difficulties in convincing people to put an effort in to implementing lean even though it is acknowledged that it will be advantageous and a requirement of the client? One reason might be the organisation's strong focus on efficiency and production optimization, or what Ellström defines as the logic of performance (Ellström 2006). Refining and optimisation of existing procedures becomes the organisation's main objective. When lean managers enter the room, they bring a rationale, which at first glance does not correlate with the logic of performance. Implementing lean construction can remove time and resources from what are perceived as core activities. In order to overcome the gap between the project managers' focus on performance and the lean managers' interest in implementing lean construction, the lean managers construct best practice cases outlining the many possible positive gains in applying lean construction. Thereby, they try to create a fit in rationale between the business case and the logic the managers apply in their daily practice. Despite the convergence in rationale, managers do not implement lean construction – why is that so? Is it difficult to implement lean construction because it does not make sense to the managers? Continuously, the lean managers outline all the positive aspects in lean construction; however, these are the lean construction managers' understandings. Being told that lean construction is a good idea does not imply that it makes sense to the receiver of the message. The American social psychologist Karl Weick (1996) argues that implementation and change in behavior cannot be forced upon people; it is not possible to control organizations. What change agents can do is to provide alternative stories and cues and approach implementation of lean construction as sensemaking.

We are still stuck in a culture where we control and punish for unwanted or poor performance, and do not pay enough attention to what actually motivates people to deliver. Particularly, when it comes to work tasks that have no clear and precise outcome in the beginning, is this a fault. People need to think and solve problems, and design to deliver.

We would encourage future research to test the conclusion of this paper on more cases and to explore the benefit of addressing different motivating factors for different roles and disciplines.

CONCLUSIONS

Client organisations can, with explicit requirements in delivery strategies, tender and contract requirements, encourage suppliers to adopt a continuous improvement methodology such as lean. By setting explicit expectations the senior managers can be motivated to support and resource lean adoption. The managers are, to a large extent, measured on extrinsic measures such as time and cost, and thereby their motivation to support and work with lean also lies within these areas. Engineers and specialists see their purpose as improving quality and in general the most project team members were motivated by making own work processes better.

There was a disconnect between the respondent's ability to use lean and the actual experience they had within the field. The root cause for this could be the tension between motivation factors at the different organisation levels. A strong focus on time and cost could actually inhibit creative thinking and development of new processes. Senior managers and lean managers should be aware of this fact when developing lean implementation strategies. By focusing on what motivates the different roles in a project we might be able to better influence the adoption of a lean approach. So perhaps a business case is not enough to motivate our colleagues to work with lean.

REFERENCES

Bryman, A. (2015). Social Research Methods, 5th Revised Edition. Oxford University Press.

De Vaus, D. (2013). Surveys in Social Research, 6th Edition. Taylor & Francis Ltd.

Drysdale, D. (2013). "Introducing lean improvement into the UK Highways Agency supply chain." In Proceedings of the 21th Annual Conference of the International Group for Lean Construction (IGLC), Fortaleza, Brazil.

Highways England. (2015). "*Delivery Plan 2015-2020*". Leeds: Highways England Publications Team.

HM Government (2015b). "*Road Investment Strategy: for the 2015/16 - 019/20 Road Period*". London: HM Stationery Office.

Howell, G.A. & Koskela, L. 2000, 'Reforming Project Management: The Role of Lean Construction' In: *8th Annual Conference of the International Group for Lean Construction.* Brigthon, UK, 17-19 Jul 2000.

Ellström, P.E. (2006). Two Logics of Learning. In: Antonacopoulou, A. et al. *Learning, Working and Living. Mapping the Terrain of Working Life Learning*. Palgrave Macmillan

Kahneman, D. (2011). "Thinking, Fast and Slow". Penguin Books.

Korb, S. & Ballard, H.G. (2018), 'Believing Is Seeing: Paradigms as a Focal Point in the Lean Discourse' In: *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018. pp 177-186

Koskela, L. , Ballard, G. & Howell, G. 2003, 'Achieving Change in Construction' In:, *11th Annual Conference of the International Group for Lean Construction.* Virginia, USA, 1-.

Münster, M. (2017). "Jytte fra Marketing er desværre gået for i dag, Sådan bruger du adfærdsdesign til at skabe forandringer i den virkelige verden (How to use behavioural design to create changes in the real world. In Danish). ISBN 0799702243581, Gyldendal A/S

Pink, D. H.. (2007). "Drive. The surprising truth about what motivates us". Canongate Books. ISBN 978 1 84767 769 3.

Ryan, R.M. and Deci, E. L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology* 25, 54–67

Schöttle, A., Arroyo, P., Christensen R. (2018). "Demonstrating the value of an effective collaborative decision-making process in the design phase." *26th Annual Conference of the International. Group for Lean Construction*, Chennai, India, 18-20 Jul 2018

Tezel, A. Aziz, Z., Koskela,.L., Tzortzopoulos, P. (2016). "Visual Management Condition in Highways Construction Projects in England" *24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston*, MA, USA, sect.6 pp. 133–142. Available at:.

Weick, K.E. (1995). *Sensemaking in Organizations.* Sage Publications Inc.

Ezzeddine, A., Shehab L., Hamzeh, F., Lucko, G. (2019). "Singularity Functions to Enhance Monitoring in the Last Planner System" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 287–298. DOI: https://doi.org/10.24928/2019/0134. Available at: <www.iglc.net>.

Ezzeddine, A., Shehab L., Hamzeh, F., Lucko, G. (2019). "Singularity Functions to Enhance Monitoring in the Last Planner System" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 287–298. DOI: https://doi.org/10.24928/2019/0134. Available at: <www.iglc.net>.

SINGULARITY FUNCTIONS TO ENHANCE MONITORING IN THE LAST PLANNER SYSTEM

Ali Ezzeddine[1], Lynn Shehab[2], Farook Hamzeh[3], Gunnar Lucko[4]

ABSTRACT

Many traditionally managed construction projects suffer from schedule delays. However, in Lean Construction, the Last Planner System ™ (LPS) stipulates planning tasks first at the macro (Master Schedule and Phase Schedule) and then at the micro levels (Look-ahead Planning and Weekly Work Plan, WWP) when the week of execution approaches. This paper aims to enhance the control aspect of LPS before the end of the execution in order to finish on schedule. Its objective is to improve the WWP by monitoring project progress on a daily basis to have enough time for corrective measures, catch up to the planned schedule, and minimize wastes in time and resources. The approach allows project participants to compare planned to actual progress, calculate required improvement if needed, and be alerted if cascading delays may occur. It calculates the Process Reliability Index (PRI) to check whether extra allocation of labor is needed to finish the required work, checks for congestion in work areas, and predicts the possible Percent Plan Complete (PPC) before the end of the execution week. Moreover, this paper proposes a new metric that shows the reliability of the team in applying the recommended improvements. This metric allows more realistic improvement plans compared to prior attempts. The monitoring approach can be applied to linear, repetitive, and location-based projects. Singularity functions are used as the core model because they are suitable for such schedules. They can be implemented in various computer applications. An example is used to evaluate the approach and finds it to be reliable.

KEYWORDS

Singularity functions; last planner ™ system (LPS); lean construction; percent plan complete (PPC); process reliability index (PRI); weekly work plan (WWP).

[1] Masters Student, Department of Civil and Environmental Engineering, American University of Beirut, Lebanon, ame109@mail.aub.edu

[2] Masters Student, Department of Civil and Environmental Engineering, American University of Beirut, Lebanon, aas113@mail.aub.edu

[3] Associate Professor, Civil and Environmental Engineering Dept., University of Alberta, Canada, hamzeh@ualberta.ca

[4] Professor of Civil Engineering and Director, Construction Engineering and Management Program, Department of Civil Engineering, Catholic University of America, Washington, DC 20064, lucko@cua.edu

INTRODUCTION

The goal of Lean Construction is minimizing waste and optimizing value and performance (Nguyen and Waikar 2018). According to LPS, a lean production management system, project control should be based on a proactive approach that allows corrective and preventive measures in addition to early identification and minimization of deviations (Hamzeh *et al.* 2012). Several metrics are currently being used and developed in the Last Planner System to track project performance, among them are Percent Plan Complete (PPC) and Process Reliability Index (PRI). PPC tracks reliable promising at the WWP level, which is the most detailed phase of LPS (Hamzeh *et al.* 2012). It is calculated at the end of the execution week by measuring the percentage of tasks completed relative to those planned (Hamzeh *et al.* 2008). PRI is a planning index that reflects the reliability of the value of the production rates given by the crews. It compares the actual activity progress to the planned progress (González *et al.* 2008). PRI is measured at the activity level and has been found to function better at quantifying the said reliability than PPC (El Samad *et al.* 2017).

Deficiencies exist in practice, because current metrics are a reactive or “thermostat” approach to problem solving (Liker 2004), leaving no chance for corrective measures. Merely detecting a problem after it has already occurred does not facilitate improving the performance. According to Lean principles, one should pull the cord once a defect (Liker 2004) (or deviation in construction terms) is detected allowing us to take proactive measures to solve the problem before it is too late. Another gap is found in the usage of PRI, where it has not been linked to the ability of the current number of workers to finish the required work. Finally, no metric has yet been developed to reflect the reliability and ability of the project team members to apply the required improvements on a weekly level.

Improving the reliability of WWP (i.e. increasing PPC) will improve overall schedule performance (Hamzeh *et al.* 2012). Moreover, PPC is correlated with cost deviation, thus the higher PPC the lower the cost deviation (Formoso and Moura 2009). Hence to improve project performance, PPC will be used as a corrective metric by forecasting its value before the end of the execution week. This way, project participants can detect deviations from the planned schedule and implement corrective actions to compensate for delays. This paper also links PRI to the capacity of the current crews. Lastly, a new metric is presented for the ability of the team to implement the required improvements and actually finish executing activities on time. It aids the principle of Kaizen or continuous improvement, a pillar of the Lean philosophy.

This paper was inspired by the Lean thinking. It aims to combine proactivity with continuous improvement by early detection of deviation in order to increase the performance by the end of the execution week. This can be achieved with the aid of singularity functions that facilitate the implementation of this method. A tool was developed for this purpose. It included input cells for data collected from linear schedules, and the outputs were automatically calculated showing the forecasted PPC, required improvement in production rates, resource allocation and congestion, and the risk of the occurrence of cascading delays. Several metrics for improvement were used and developed.

To identify and minimize deviations between planned and actual progress, a need exists for an accurate tool to monitor activity performance. Singularity functions offer a mathematical solution. Their format includes parameters like activity start times and productivity rates (Lucko 2009). Singularity functions are mathematical functions known for their mathematical operator (bracket), and they were previously used for analysing internal loads in structural beams. Their application in construction management is described in the following section.

LITERATURE REVIEW

SINGULARITY FUNCTIONS

Singularity functions offer a flexible mathematical description of discontinuous phenomena (Lucko 2007). They can be used on projects with horizontal (e.g. roads, tunnels, pipelines) and vertical (e.g. high rises, towers) geometry, and projects with longitudinal spatial or repetitive nature (Lucko 2007). Prior use in structural analysis saw singularity functions facilitate the analysis of beams under different types of loads (Beer *et al*. 2012). Their basic term is defined in Equation 1.

$$\langle x-a\rangle^n = \begin{cases} 0 \text{ } for\, x<a \\ (x-a)^n \text{ } for\, x \geq a \end{cases} \qquad (1)$$

Where x is the variable under consideration, a is the lower boundary of the current segment, and n is the order of the phenomenon that changes at the start of the segment. If n is zero, the term is a step function, but if it is one, it is a linearly growing slope. Table 1 lists various papers on their applications for the construction industry.

Singularity functions have advantages: They can model schedules both graphically and mathematically to facilitate the visual understanding by site personnel. They calculate finishes, can be added and subtracted, and represent varied behavior of activities over time (Lucko 2007).

Despite the various papers published on the usage of singularity function in construction management, no research has yet been done to integrate singularity functions with project control in Lean construction within the LPS.

LAST PLANNER SYSTEM

A primary principle of the construction management process is planning and control (Alarcón and Calderón 2003). LPS aids in enhancing project performance and planning reliability. It is used by contractors to enhance on-site workforce productivity and also allows for improvements in both safety and quality (Oakland and Marosszeky 2017). LPS acknowledges the shortcomings of all forecasts, because they are always wrong: The more detailed it is, the more off it will be, and the farther it looks into the future, the less accurate it becomes (Nahmias and Cheng 2009).

Table 1: Papers on Singularity Functions: Titles and Usages

Title	Usage
Computational Analysis of Linear and Repetitive Construction Project Schedules with Singularity Functions (Lucko 2007)	Used for any construction project characterized by its longitudinal spatial or repetitive nature, e.g. high-rise buildings, highway construction, piping
A Unified Quantitative Model for Project Management with Singularity Functions (Su and Lucko 2016)	Used for projects that are geometrically linear or repetitive in their operations. Unifies schedules, cash flow, and resources and transforms them from 2D into 3D
Modeling Cash Flow Profiles with Singularity Functions (Lucko 2010a)	Detailed analysis of cash flows in projects
Spatially-Constrained Scheduling with Multi-Directional Singularity Functions (Lucko et al. 2014)	Used in most projects because they all depend on the available workspace within a physical location. Starts by activity ordering, stacking, then finally spatial conflict resolution, taking into account possible time gains
Work-Path Modeling and Spatial Scheduling with Singularity Functions (Lucko et al. 2017)	Minimizing project duration and spaces occupied by crews
Productivity Scheduling Method: Linear Schedule Analysis with Singularity Functions (Lucko 2009)	Used for projects with horizontal (highways, tunnels, pipelines) or vertical (high rises and towers) linear geometry, and projects with repetitive operations. Singularity functions can be used for time and amount buffers to detect the critical path regarding each
Modeling Resource Profiles with Singularity Functions (Lucko 2010b)	Deals with optimum use of resources (primarily specialized labor or equipment) by using singularity functions to level them

LPS divides project planning into four steps. First is Master Scheduling (Should) to find the planned project duration via critical path method (CPM) calculations and sets milestones. Second is Phase Scheduling (Can) where gross constraints are identified, and reverse phase scheduling is performed. Phase scheduling links work structuring with production control (Ballard and Howell 2003). Third is Lookahead Planning (Will) that is spread over 2-6 weeks during which tasks are broken down and made ready. Fourth is the WWP (Did), where reliable promising is practiced, PPC is measured, and reasons of plan failure are acted upon (Hamzeh *et al*. 2009; El Samad *et al*. 2017). The WWP, which contains the highest level of schedule detail, should contain sound assignments that are made ready by removing any constraints that prevent them from becoming ready for execution. At this stage, learning from plan failures takes place in order to prevent their emergence in the future.

Metrics proposed by LPS aim to assess project performance by measuring anticipated tasks (TA) and tasks that are made ready (TMR). PPC is the percentage of completed tasks of those planned (Hamzeh *et al*. 2012): *PPC = Did/*Will (El Samad *et al*. 2017). PPC shows production planning efficiency and workflow reliability (Chitla and Abdelhamid 2003). It also indicates the reliability of the promises made, and it is related to labor productivity (Hamzeh *et al.* 2012). PPC is calculated at the end of the week of execution. Another metric is PRI, which is positively correlated to activity performance (González *et al.* 2008). PRI is the ratio of actual weekly activity progress to that forecasted: *PRI = Actual Production Rate / Forecasted Production Rate.* Since PRI compares actual to planned progress, an issue might arise if the plan was not optimal. Planners must ensure that the baseline that is to be met is near optimal for PRI to be relevant.

Recently, a new study by Abou-Ibrahim *et al.* (2019) addressed the effects of capacity planning on a project's performance. According to the study, several barriers hamper the planners' ability to accord between a crew's workload and capacity in the WWP during the lookahead planning. Two of which are (1) the planners' inability to predict the workload that can be handled by the crew and (2) the difficulty of specifying what activities will be unconstrained and ready for execution beforehand (*ibid.*). Load is defined as the amount of work that needs to be done in a predefined set of time, and capacity is the amount of work that crews can execute. The authors describe two types of planners; the first being informed Planners who assign weekly capacities according to their project's metrics. The second type is Un-informed Planners who assign a constant capacity for the whole project or assign the capacity through random guessing (*ibid.*). Informed Planners positively affect project performance on the level of project cost and schedule simultaneously. They also pay close attention while monitoring the execution of tasks to follow up with their project's metrics and to study the effect of their assigned capacities (*ibid.*.

Several attempts to develop tools that facilitate Lean Construction concept implementations – like LPS – have been made, including the Integrated Production Scheduler (Chua *et al.* 1999), which aims to achieve a schedule of quality, timeliness, and transparency (Chua *et al.* 1999). In the Integrated Production Scheduler, JavaBeans and XML were used to develop a scheduling model (Chua *et al.* 1999). A prototype called LEWIS assisted in making plans more reliable and assignments more constraint-free (Sriprasert and Dawood 2002). Newer methods of planning rely on computer simulation (Song and Eldin 2012; Taghaddos et al. 2012). Song et.al (2012) developed an adaptive real time tracking and simulation method in the attempt to enhance the lookahead phase in the LPS (Song and Eldin 2012).

The paper introduces a new practical method to the Last Planner System. The method enhances project monitoring and control at the level of the WWP by proactively calculating project measures such as actual finish dates based on the current status of the system, required improvements in production rates, worker allocation and congestion. The method also predicts the value of the PPC as the tasks progress, and a new metric is suggested to be added to the Last Planner System.

METHODOLOGY

Design Science Research (DSR) is the research methodology of this study. In construction management, DSR can be a proper tool when building problem solving objects that tackle real problems. It is considered a constructive research which connects research and practice

(Rocha *et al.* 2012), and this is the objective of this paper. In this study, integrating LPS with a mathematical model produces a new tool for monitoring actual activities on the WWP, and this is how research (LPS and singularity functions) is connected to practice (actual activities on the WWP). It integrates singularity functions to improve and nearly optimize project performance ahead of the end of the week of execution. An example of a small location-based schedule will test the validity of the proposed monitoring approach.

The approach is based on comparing planned and actual values of task progress. Forecasted data are taken from the WWP, while field personnel collect data on the actual progress. In graphical form, it allows detecting deviations and gives quantitative values for the required increase in production rates to improve the progress by the end of the week. Here singularity functions will facilitate both visual monitoring and automatic improvement in numerical form.

The purpose of this study is to present a method for quick adjustment during execution to evaluate project progress. It suggests a proactive approach by using actual task progress to forecast PPC to prepare corrective and preventive measures for improvement. This improvement should be based on reliable values of production rates by linking required improvements to PRI. Risks of cascading delays or congestion from reallocating resources can be proactively detected by functions in the model. Using numerical examples, this paper demonstrates the functionality in different performance scenarios. It encourages project participants to use this approach to increase their performance ahead of time and monitor their crews, and thus make their promises more reliable. Finally, an evaluative metric is developed to assess the overall weekly progress.

SINGULARITY FUNCTIONS FOR MONITORING AND PERFORMANCE IMPROVEMENT

This research focuses on using metrics such as PPC and PRI to actively control any deviations from the plan. The study focuses on controlling and not scheduling a plan, so the base plan is assumed to already be done and near optimal. The process starts by entering the base plan for the weekly work plan, which includes activities to be executed and information about them such as scheduled start and end times, quantity of work that needs to be done, and the number of workers executing it. With only these inputs, the model with singularity functions can graphically represent the activity as a forecast.

The next step in the process is site personnel recording actual activity progress. This can be done daily during the execution of the activity, (or the first three days of each week) to leave some time for improvements if needed. To allow the singularity functions to represent the actual activity progress graphically, only three inputs are needed: The time that the activity actually started, the time at which the data was taken, and the work done up to that moment. The user can visualize the actual progress, and the function will calculate the predicted finish time based on the actual productivity of the crew. At this point, the model automatically detects future cascading delays occurring if an activity is behind schedule and will affect its succeeding activities.

Singularity functions can quantify the needed improvement in the production rate to finish at a desired time. The user specifies said time, and the function automatically gives the required production rate needed to finish the activity on the desired time. For example, for an activity with a planned duration of 4 days and required work of 4 units, the following improvement using singularity functions can be done as shown in Figure 1 per Equations 2 and 3.

Actual work without improvement $W_n(t) = 0 \cdot \langle t - 0\rangle^0 + \frac{1}{2} \cdot \langle t - 0\rangle^1 - \frac{1}{2} \cdot \langle t - 8\rangle^1$ *(2)*

Actual work with improvement $W_i(t) = 0 \cdot \langle t\text{-}0\rangle^0 + \frac{1}{2} \cdot \langle t\text{-}0\rangle^1 + 1 \cdot \langle t\text{-}2\rangle^1 - 4 \cdot \langle t\text{-}4\rangle^1 - 3/2 \cdot \langle t\text{-}4\rangle^1$ *(3)*

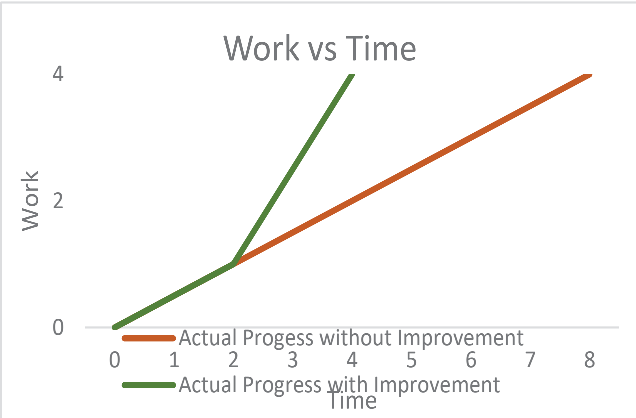


Figure 1: Graphical example of actual progress with and without improvement

(González *et al*. 2008) suggested the process reliability index (PRI). This new metric measures the effectiveness of planning from a commitment point of view. It is calculated by dividing the actual production rate of an activity by its forecasted production rate per Equation 4.

PRI = Actual Production Rate / Forecasted Production Rate *(4)*

As already mentioned, PRI is most effective if the base plan is already optimized as this study assumes. It uses PRI to make planning more reliable. Each crew has a normal production rate for planned progress, and a maximum production rate, which reflects the crew's maximum capacity. To ensure that the crew can execute the improvement calculated by the singularity function, the required improved production rate is compared with the maximum, but with a modification per Equation 5: The modified maximum production rate is defined as the maximum production rate multiplied by PRI. This way each crew's reliability in their production rates can be considered.

Modified Maximum Production Rate = Maximum Production Rate x PRI *(5)*

Then Equation 6 informs whether the crew is able to finish or must allocate extra workers.

Allocated Workers = (Required Improved Production Rate / Productivity)
– Current Number of Workers *(6)*

Congestion in construction can occur in work areas where the number of workers in it is more than how much the area can hold (Koskela 1999). It leads to a decrease in productivity and safety on the site. Therefore, the model gives an alert to notify of any congestion risk. Congestion can occur if the number of workers needed to complete the activity on time exceeds the acceptable limit. The acceptable density is determined by the user as model input in workers/m^2.

It is now possible to calculate the percent task complete (PTC) of the actual activity that will help in forecasting the PPC. PTC is the ratio of work done at any time to the total work needed to be done. Once PTC is calculated, the functions can detect at which date the activity will reach 100% PTC, and thus it can be counted in the PPC calculation as one of several inserted activities. Note how by few inputs into this model can give users the ability to forecast the value of the PPC while they are still at mid-week. The importance of this forecast lies in two main points: One is to identify an activity that is preventing PPC from reaching a desirable value. The second is to be proactive and take corrective measures so that the actual PPC at the end of week would increase.

Lastly, the new suggested metric is the Percent Improvement Complete (PIC). It is measured at the end of the execution week to quantify the team's reliability in completing the activities that needed improvement during the week. Essentially it measures the reliability of the promises that were made during the week of execution: It is the ratio of the number of activities that required improvement and were actually completed on the required end time, to all those that required improvement (including those that were and were not completed on their required end time). PIC can be used for future improvement to assess the capability of the control system to apply required improvements to activities' production rates by removing constraints on the spot.

PIC = Number of Activities That Needed Improvement and Were Completed / Number of All Activities That Needed Improvement (7)

Expressed in LPS terms, *PIC = Did Improve & Complete / Should Improve* as its definition.

APPLICATION EXAMPLE

A small example is analyzed to test the proposed tool. A five-story building project consists of sequential activities A, B, and C in the WWP. The area of each floor is 300 m^2 and the working area is 50 m^2. Input and output are labeled in Table 2.

Table 2: Program Input and Output per Activity

Item	Input	Output
Forecast Activity Data	Start time - End time - Work to be done - Actual start time	Planned production rate
Actual Activity Data (so far)	End time before improvement - Work done so far	Actual production rate - Warning of any cascading delays
Improvement of Activity	Required end time	Required improved production rate
Resources Data	Number of workers - Maximum production rate - Working area - Congestion limit	PRI - Modified maximum production rate - Warning if resource allocation is needed - Congestion warning

The output is calculated using singularity functions. For example, for activity A with a duration of 3 days (from day 0 till day 3), there are 5 units that must be done. The work started at day 0, and 2.5 units were completed up till day 2 (actual production rate = 1.25 units/day). In order to finish the activity at day 3, the required improved production rate must become 2.5 units/day.

$$\text{Actual work without improvement} = 0 \cdot \langle t - 0\rangle^{0} + 1.25 \cdot \langle t - 0\rangle^{1} - 5 \cdot \langle t - 4\rangle^{0} - 1.25 \cdot \langle t - 4\rangle^{1} \qquad (8)$$

$$\text{Actual work with improvement} = 0 \cdot \langle t - 0\rangle^{0} + 1.25 \cdot \langle t - 0\rangle^{1} + (2.5\text{-}1.25) \cdot \langle t - 2\rangle^{1} - 5 \cdot \langle t - 4\rangle^{0} - 2.5 \cdot \langle t - 4\rangle^{1} \qquad (9)$$

The results for activity B show that the actual progress would cause a cascading delay. It also appears that all activities need improvement to be completed on time. Therefore, the required production rates are calculated and shown. After inserting the maximum production rate, it is modified by the PRI. Productivity is then shown after inserting the current number of workers in the crew. Since all activities show some deviation from their plan, all maximum production rates are reduced. Activities B and C require extra resource allocation, while the crew for activity A is sufficient. Moreover, congestion is detected in activity B if the required number of workers is added. This shows that the required production rate cannot be implemented, so the end time for B must be extended. Figure 2 shows the planned, actual, and improved progress for A, B, and C.

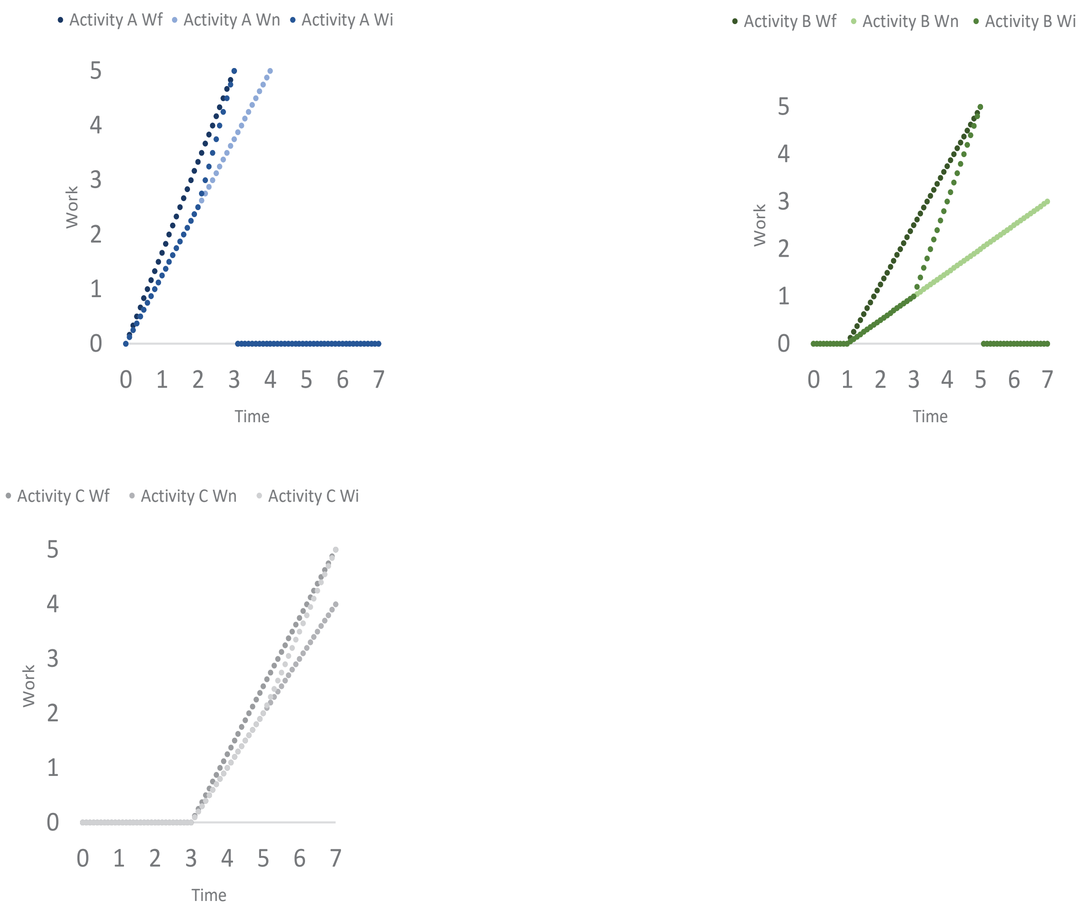


Figure 2: Forecasted, Actual, and Improved Progress for Activities A, B, and C respectively

PPC is forecasted before the end of the week at the "end time just before improvement", which allows the crew to proactively improve their progress (Table 3).

Table 3: Forecasted PPC in case no improvements were done

Actual No Improvement	MAX PTC at End of WWP	Status at End of WWP	# of Tasks on WWP	PPC forecasted
A	100	100		
B	60	60	3	33%
C	80	80		

The actual value of PPC is also calculated for the end of the week of execution (Table 4).

Table 4: Actual PPC after improvements were done

Actual with Improvement	MAX PTC at End of WWP	Status at End of WWP	# of Tasks on WWP	PPC
A	100	100		
B	100	100	3	100%
C	100	100		

Finally, the value of PIC is 67%, meaning that only 67% of the activities that were supposed to be improved were actually completed (Table 5).

Table 5: PIC value

# of Tasks that need Improvement	# of Tasks that need Improvement + can be completed	Percent Improvement Complete (PIC)
3	2	67%

CONCLUSION AND FUTURE RESEARCH

This paper has presented an approach and tool to monitor project performance at the level of the WWP of LPS. Previous research used singularity functions to construct linear schedules. Yet this study uses them to monitor and forecast activity progress. It offers a user-friendly tool that fits within the existing LPS philosophy and simple enough for most site personnel to understand. The tool has shown its accuracy in calculating the required data. Moreover, it does not have limitations on the number of activities that can be entered. Several metrics from the LPS are used in this research. The PPC is forecasted from actual activity progress during the execution week to show early signs of the reliability of the look ahead planning. The second metric is the PRI, which is used as a modification factor for the maximum production rate to calculate the resource allocation. A new metric is suggested, which is the PIC for the reliability to implement required improvements during execution. It is recommended that PIC is used along with the maximum production rates that are modified by PRI to ensure that the required improvements are rational and within the crew's capacity. While PPC shows the reliability of the promises made at the level of the WWP, PIC shows the reliability of the promises made during the week of execution when the improvements were promised to be done. Additional metrics can be developed showing the volume of improvement that was done by calculating the difference between old and new production rates for each activity and coupling it with the percent of completion. New metrics can be used along with PIC to show a more refined assessment regarding production rates.

This method should be tested on an actual project as a case study and refinements could be made. Improvements in the production rates should be linked to Takt Time for all the activities. Takt Time helps ensure a standardized schedule by preventing variations in production rates. Further developments could transform the current computer implementation into an interactive mobile application that offers more lean features to facilitate monitoring and controlling process.

REFERENCES

Abou Ibrahim, H., Hamzeh, F. R., Zankoul, E., Soren Lindhard, and Rizk, L. (2019), "Understanding the Planner's Role in Lookahead Production Planning ", Production Planning and Control, DOI: 10.1080/09537287.2018.1524163

Alarcón, L. F., Calderón, R. (2003). "A production planning support system for construction projects." *Proc. 11th Ann. Conf. Int. Group for Lean Constr.*, 2003.

Ballard, H. G., and Howell, G. A. (2003). "An update on Last Planner." *Proc. 11th Ann. Conf. Int. Group for Lean Constr.,* 22-24.

Beer, F. J., Johnston, E. R., DeWolf, J. T., Mazurek, D. F. (2014). *Mechanics of Materials*. 7th ed., McGraw-Hill, NY.

Chitla, V. R., Abdelhamid, T. S. (2003). "Comparing process improvement initiatives based on percent plan complete and labour utilization factors." *Proc. 11th Ann. Conf. Int. Group for Lean Constr.*, 2003.

Chua, D. K., Jun, S. L., Hwee, B. S. (1999). "Integrated production scheduler for construction look-ahead planning." *Proc. 7th Ann. Conf. Int. Group for Lean Constr.,* 287-298.

El Samad, G., Hamzeh, F., Emdanat, S. (2017). "Last Planner System – the Need for New Metrics." *Proc. 25th Ann. Conf. Int. Group for Lean Constr.*, 637-644.

Formoso, C. T., Moura, C. B. (2009). "Evaluation of the impact of the Last Planner System on the performance of construction projects." *Proc. 17th Ann. Conf. Int. Group for Lean Constr.*, 153-164.

González, V., Alarcón, L. F., Mundaca, F. (2008). "Investigating the relationship between planning reliability and project performance." *Production Planning and Control*, 19(5), 461-474.

Hamzeh, F. R., Ballard, H. G., Tommelein, I. D. (2012). "Rethinking Lookahead Planning to Optimize Construction Workflow." *Lean Construction Journal*, 2012, 15-34.

Hamzeh, F. R., Ballard, H. G., and Tommelein, I. D. (2009). "Is the Last Planner System applicable to design? —A case study. "Proc. *17th Ann. Conf. Int. Group for Lean Constr.*, 13-19.

Hamzeh, F. R., Ballard, H. G., Tommelein, I. D. (2008). "Improving construction workflow-the connective role of lookahead planning." *Proc. 16th Ann. Conf. Int. Group for Lean Constr.*, 635-646.

Koskela, L. (1999). "Management of production in construction: a theoretical view." 1999.

Liker, J. K. (2004). "The Toyota Way – 14 Management Principles from the World's Greatest Manufacturer." McGraw Hill, NY.

Lucko, G. (2007). "Computational analysis of linear and repetitive construction project schedules with singularity functions." *Proc. Int. Workshop Comp. Civ. Eng.*, 9-17.

Lucko, G. (2009). "Productivity scheduling method: Linear schedule analysis with singularity functions." *J. Constr. Eng. Mgmt.*, 135(4), 246-253.

Lucko, G., Cooper, J. P. (2010). "Modeling Cash Flow Profiles with Singularity Functions." *Proc. Construction Research Congress*, 1155-1164.

Lucko, G. (2010). "Modeling Resource Profiles with Singularity Functions." *Proc. Construction Research Congress*, 1165-1174.

Lucko, G., Said, H. M. M., Bouferguene, A. (2014). "Spatially Constrained Scheduling with Multidirectional Singularity Functions." *Proc. Construction Research Congress*, 1448-1457.

Lucko, G., Isaac, S., Su, Y., Dagan, D. (2017). "Work-Path Modeling and Spatial Scheduling with Singularity Functions." *J. Comput. Civ. Eng.*, 31(4), 04017008(14).

Nahmias, S., Cheng, Y. (2009). *Production and Operations Analysis.* 6th ed., McGraw Hill/Irwin, NY.

Nguyen, T. Q., Waikar, S. S. (2018). "A Relook at Plan Reliability Measurements in Lean Construction and New Metrics from Digitized Practical Implementation" *Proc. 26th Ann. Conf. Int. Group for Lean Constr.*, 1037-1046.

Oakland, J., Marosszeky, M. (2017). *Total construction management: Lean quality in construction project delivery.* Routledge, 121-129.

Rocha, C. G. D., Formoso, C., Tzortzopoulos, P., Koskela, L., Tezel, A. (2012). "Design Science Research in Lean Construction: Process and Outcomes." 2012.

Sriprasert, E., Dawood, N. (2002). "Next generation of construction planning and control system: the LEWIS approach." *eWork and eBusiness in Architecture, Engineering and Construction,* p. 175.

Su, Y., Lucko, G. (2016). "A Unified Quantitative Model for Project Management with Singularity Functions." *Proc. Construction Research Congress*, 2019

Garcia-Lopez, N.P., Fischer, M., and Alarcón, L.F. (2019). "Work structuring for flow" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 299 -310. DOI: https://doi.org/10.24928/2019/0156. Available at: <www.iglc.net>.

COMBINING TAKT PRODUCTION WITH INDUSTRIALIZED LOGISTICS IN CONSTRUCTION

Müge Tetik[88], Antti Peltokorpi[89], Olli Seppänen[3], Ari Viitanen[4], and Joonas Lehtovaara[5]

ABSTRACT

Construction industry has recently widely adopted takt production which stabilizes the production rhytm and improves flow of site operations. Based on the factory physics, it is known that when production flow is increased, external variation which can disturb the production should be eliminated simultaneously. Inappropriate material deliveries cause remarkable external variation and waste in construction operations. However, the reported studies of the takt production do not discuss in depth of the role of logistics and external variation. The purpose of this research is to investigate how takt production benefits from proper logistics solution. In practice, we explore the role of logistics in two project industries, shipyard and construction, in which takt production is implemented. The findings reveal improvements with regards to utilizing specific assembly and logistics units together with JIT delivery of material kits and integrated design and production information. In fact, results showed a reduction in the material waste and procurement costs as well as increase in the production rate in both industries but with different extent. The value of this research for practice and academia is that takt results improve when implemented with specific logistic solutions. Future research should investigate the impact of logistics in takt with using case studies and focusing on construction operations.

KEYWORDS

Takt production, logistics, lean construction, industrialized logistics.

[88] Doctoral Candidate, Dept. of Civil Enginering, Aalto University, Espoo, Finland, muge.tetik@aalto.fi

[2] Assistant Professor, Dept. of Civil Enginering, Aalto University, Espoo, Finland, antti.peltokorpi@aalto.fi

[3] Professor of Practice, Dept. of Civil Enginering, Aalto University, Espoo, Finland, olli.seppanen@aalto.fi

[4] Chairman of the Board, Carinafour, Turku, Finland, ari.viitanen@c4.fi

[5] Doctoral Candidate, Dept. of Civil Enginering, Aalto University, Espoo, Finland, joonas.lehtovaara@aalto.fi

INTRODUCTION

Many practices exist in the manufacturing industry to improve productivity and reduce waste. Logistics solutions are one of these practices that have important contributions to production activities. According to Christopher (2016), logistics is managing procurement, movement and storage of materials and the related information flows to maximize profitability with cost-effective fulfilment of orders. In the construction industry, advanced logistics solutions are gaining popularity not only to optimize material flow but also to improve productivity and flow of assembly operations on-site (Seppänen and Peltokorpi 2016). Studies indicate positive results when implementing different logistics solutions in construction, such as assembly kitting in the consolidation centre and delivery with JIT (Tetik et al. 2018), real time material tracking (Zhao et al. 2017) and on-site shops (Tanskanen et al. 2015). Proper logistic solution can be a tool to shorten construction time and save costs as it saves workers' time on site and decreases need for storage which leads to savings (Knaack et al. 2012). Dedicated logistics resources on-site prevent inefficiencies in work and therefore increase the utilization of the site resources (Sundquist et al. 2018).

Regarding the on-site production planning and control, construction industry has recently started to adopt takt production which originates from manufacturing industries. Takt is a lean concept which attempts to enable continuous flow and increase stability in production processes. The production proceeds with the same rhythm and the flow of the product is enabled by causing all the tasks to be grouped and balanced to a calculated takt time (Pattanaik and Sharma 2008). Takt time is the unit of time in which a product must be manufactured in order to match the rate that this product is demanded (Hopp and Spearman 2004). Using takt production displays huge improvements in productivity, quality and project lead time while decreasing the amount of work-in-progress, as in the case of ship cabin refurbishment production (Heinonen and Seppänen 2016). In the case of hospital construction, a project with takt production was completed six months ahead of its planned schedule (Linnik et al. 2013). 70% reduction in construction duration was identified by Binninger et al. (2018).

This paper builds on the argument that when takt production is applied in construction, the production system is more vulnerable for external variation of the process, and the role of a proper logistics solution is important in controlling that external variation. External variation refers to factors which are not absolutely regular and predictable and which therefore present variability for the production, such as irregular demand, product variety to meet market needs, interrupting operations to satisfy specific customer (Hopp and Spearman 2004), resource changes, machine failure, rushing orders, transport breakdowns and supplier related problems (Viswanadham and Raghavan 1997). According to Kingman's formula (1961), external variation or resource utilization must be reduced when adopting a single piece flow. If the flow efficiency is increased without reducing the variation, the resource needs to be increased exponentially, which is difficult to ensure in practice.

We argue that problems in material flow are major sources for external variation in construction operations. Especially when takt is utilized, challenges can arise, such as communicating the production plan and commitment of the project partners and material deliveries to the takt schedule (Frandson et al. 2013). Vatne and Drevland (2016) mentions a delay in completing work packages in a takt production case caused by the delivery of doors from the manufacturer in a construction project. Thus, material availability can effect the project duration and flow of operations when takt is used. On the other hand, material stockpiles on-site impact the available space and can interfere with the productivity (Seppänen and Peltokorpi 2016). Without JIT technique used in material delivery and handling, workers' productivity may decrease due to waiting or sorting the congested materials on-site (Ghanem et al. 2018). Providing all the required materials in the right moment and location can be a solution to ensure flow and productivity of operations. The successful takt implementation and continuous flow rely on careful planning and daily control of production (Tommelein 2017). Using proper centralized logistics management along with takt production, waste due to material and information handling problems can be solved.

Despite of the obvious role of the proper logistic solution in decreasing harmful external variation in takt production, none of the reported studies of takt production discuss in depth the role of logistics and external variation. Thus, there is a need for practical knowledge about the role and impacts of logistics solutions when applying takt in construction projects. The purpose of this research is to investigate how takt production benefits from proper logistics solution. In practice, we explore role of logistics in two project industries, ship yard and construction, in which takt production is implemented. The reason to explore those two industries is that we believe that more mature applications of takt and logistics solutions in ship yard industry would benefit to identify issues and potential solutions in more fragmented construction industry. The contribution of this paper is on the new knowledge of the role of logistics in takt production which has not been specifically studied and documented before in the construction context.

THEORETICAL BACKGROUND

Theoretically, this research combines two research streams: (1) Logistics solutions in construction area and (2) combining logistics solutions with takt production.

LOGISTICS SOLUTIONS IN CONSTRUCTION

Logistics solutions are neglected in construction industry due to problems in project budgets, although they improve productivity (Sullivan et al. 2011). There are many logistics solutions used in the construction industry to improve material handling and schedule. Kitting is one of the logistics solutions that can be applied in the construction operations. When products or components are organized, packed and delivered as one package, the term "kitting" is used (Bozer and McGinnis 1992). The idea is that the kit is prepared in a consolidation center and delivered to the place of work.

Just-in-time delivery is a lean concept which means the delivery of materials to construction sites to be installed immediately without being stored (Tommelein and Li 1999). This type of delivery can partially decrease the need for an on-site storage area (Jaillon and Poon 2014) and increase the quality and efficiency (Pheng and Hui 1999). The waste is reduced by delivering the required materials exactly when they are needed. Make-to-stock as well as engineer-to-order materials can be procured and delivered on a JIT basis. JIT delivery can be combined with the assembly kitting.

Kitting can be combined with just-in-time (JIT) and consolidation centers. Consolidation centers are logistics solutions where the consolidation facilities keep the materials for a period of time till their delivery to the shops or sites on a JIT basis by the logistics workers (Sullivan et al. 2011). Sundquist et al. (2018) suggest that logistics resources such as logistics hubs can be utilized in an efficient manner through expanding of the scale of the operations. Hamzeh et al. (2007) state that consolidation centers can be configured to be used for the purposes such as assembly and kitting as well as consolidation, sorting and breaking the bulks. Tetik et al. (2018) conducted research about the applicability and impacts of kitting in renovation operations revealing promising results.

In the advanced logistics solutions, one typical requirement is that procurement activities are organized in a centralized manner and not by trade contractors. Centralized procurement can strengthen the logistics solutions by procuring materials centrally and delivering them to the consolidation center. Control activities are enhanced by centralized procurement (Clifford et al. 2000). Centralized logistics can be applied through third party logistics (TPL). Using TPL decreases material logistics costs in construction projects (Ekeskär and Rudberg 2016).

COMBINING LOGISTIC SOLUTIONS WITH TAKT PRODUCTION

In this section, we will discuss how the suggested logistic solutions in construction would fit with takt production in site operations. Logistics solutions can be utilized with takt production. Vatne and Drevland (2016) mentioned that the logistics is a key aspect for takt planning. Implementing several lean concepts together such as combining kitting, JIT delivery and takt production leads further improvements. Linnik et al. (2013) mention using takt strategy for planning for materials and information where the takt is used to determine the kitting plan and JIT deliveries in construction context. Takt can motivate the trades to kit and deliver with JIT delivery.

Dallasega et al. (2013) state that to allow JIT delivery of engineer-to-order parts, the production process must be aligned with construction on-site. To ensure the delivery of the parts in the required time, the takt production sequence should be communicated well with every stakeholder and stakeholders should commit to the takt sequence which may not be fully possible in practice. Thus, centralized procurement of the parts and JIT delivery can be a solution to guarantee that the required materials to be available in the right moment.

Even though have not yet been identified, lean concepts have been used in practice in the past in the construction context. The construction of the Empire State Building includes determining the size of work teams and zones to fit a takt rate and consolidation centers were used to help ensuring the continuous work flow (Jacobsson and Wilson 2018). This provides efficient transportation of the materials and less on-site materials storage along with takt production benefits.

Utilizing takt can bring benefits in renovation projects. Renovation projects perform under schedule pressure where the area which was actively used cannot be used during the renovation operations (Alhava et al. 2015). Utilizing assembly kitting and JIT delivery logistics solution with takt production can be a good fit for renovation projects.

RESEARCH METHOD

We analyzed the role of logistics solution in takt production both in construction projects and marine industry projects. The access to data about the projects in both industries was get through a Finnish logistics service company which has originally operated with ship yards but recently widened their offerings to the construction industry. We collected both qualitative and quantitative data for data triangulation. The data analysis includes the analysis of interviews with the logistics service provider and documents analysis.

The qualitative part of research was carried out by utilizing interviews. The semi-structured interview was conducted with the chairman of the logistics service company of the main contractor. Quantitative part of the study includes documents obtained from the main contractor.

An alliance-based contract was made between the companies. The contractor company is one of the leading companies in Finland in terms of renovation projects. The logistics company serves the contractor with the Assembly and Logistics Unit (ALU) in which three logistics workers are working for five different construction projects. The contractor company aims to utilize the same solution with all of its pipe renovation projects and they have been using the logistics provider's service for 1,5 years now. In the ship yard industry, the similar ALU is utilized to serve centralized material deliveries to the ship yard.

FINDINGS

The logistics solution referred here is material kitting in the assembly and logistics center (ALU) with JIT delivery while procurement is centralized. Our findings indicate that using the logistics solution provided by the logistics company when applying takt results in multiple improvements in projects, including improved procurement quality, less material waste and ability to follow the predetermined takt sequence.

Based on our analysis of the interview data, the reasoning behind using the logistics solution together with takt includes (1) enforcing the production sequence by using single flow strategy, (2) easiness to control the production process, (3) centralizing procurement which leads to material cost savings, and (4) enabling shorter lead times due to controlling variation. Thus, benefits are on improving production on-site, reducing material waste and total material cost and higher flow efficiency with lower throughput times.

For the both industries, materials are delivered to the ALU where the logistics workers prepares the kits. In the ship yard industry, all materials are delivered to the ALU and then to the work site as kitted. Material picking and kitting activities take 3 hours in the ALU and delivery is faster because the ALU is closer to the production site. The amount of pre-assemblies is higher in the ship yard industry where fittings and insulation are already done in the ALU. The takt time in the ship yard industry is 40 minutes. The production rate increase is up to 20-40% with the takt production along with logistics solution and centralized procurement.

In the renovation projects, standard materials are delivered directly to the work site where there is an on-site shop. The rest of the materials are delivered to the ALU and then to the work site. Kits are prepared in the ALU and delivered to the worksite 2-3 times a week. Logistics provider makes sure that only the required materials are delivered to the worksite at the required time. The kits are apartment, day and team based. Material process can be seen in Figure 1. From the ALU, the kits are delivered to the site and then to the specific location based on the takt sequence. The same material process was used by the same main contractor in the past. In case of missing materials inside the kits, speed delivery is used to ensure the material availability. Any extra materials are either sent back to the ALU or moved to the next apartment. The latter includes updates on the kits for the next apartment in order to not cause extra materials in the next apartment. The packaging and wrapping materials are cleared out from the locations.

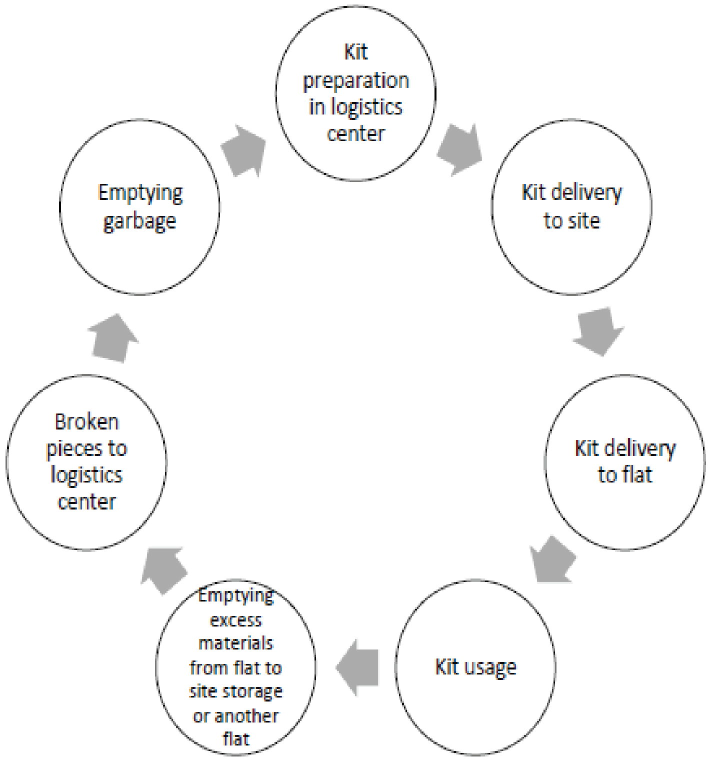


Figure 1: Material process of the logistics provider (Tetik et al. 2018)

The operations in the ALU are in Figure 2. Logistics provider also executes the procurement while the contractor company does the sourcing activities. Moreover, the logistics provider does the material inspection to increase the material quality. Procurement is done based on bill of materials (BOM) for each flat. Design process needs to be able to generate BOM per flat and manufacturing BOM where all standard and general parts are listed. The parts in the manufacturing BOM are delivered to the on-site supermarket without going through the ALU while BOM per flat materials are kitted in the ALU. The materials which are not included in the kits include electrical and technical parts. There is 3-8 days buffer for supplying the materials in the ALU. The communication between the construction site and ALU is continuously done via an online platform through which BOM and schedule changes are sent automatically.

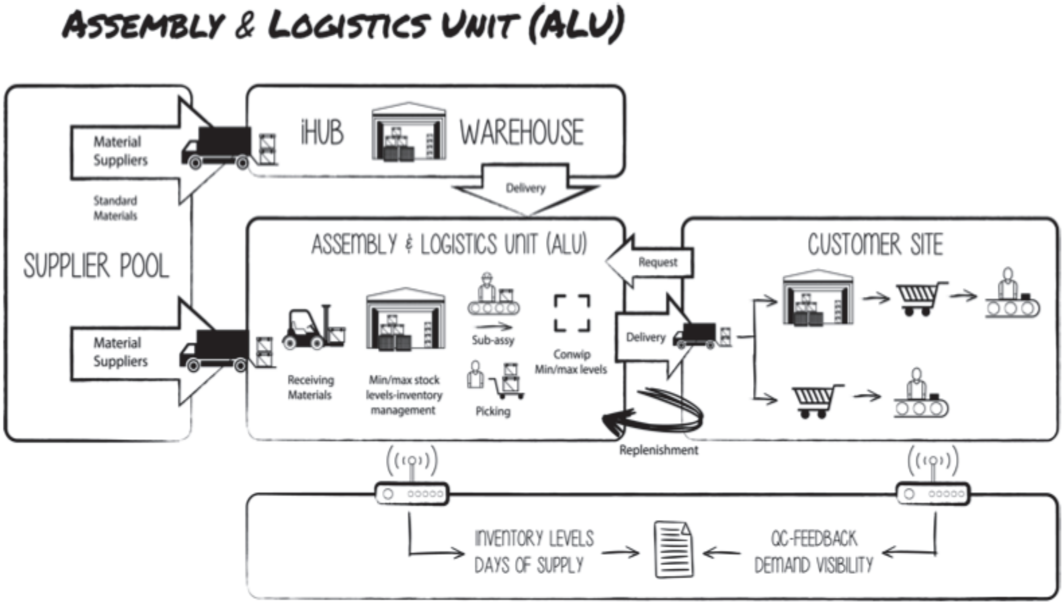


Figure 2: Operations in the ALU

Figure 3 illustrates the basics of the production system of the logistics provider. The logistics provider gets the rough schedule from the contractor 2-3 weeks before the installation start on the work site. The detailed fixed schedule is available 3 days before the installation of a specific location. This provides enough time for material picking and kitting in the ALU. In the ALU, one day is allocated for picking and kitting the materials.

Three logistics workers work in the ALU. These workers do pre-assemblies of plumbing parts as well as cutting some materials in addition to kitting. Only some plumbing parts are pre-assembled in the ALU. The takt time is one day and the takt area is one apartment and comprises the work of one team.

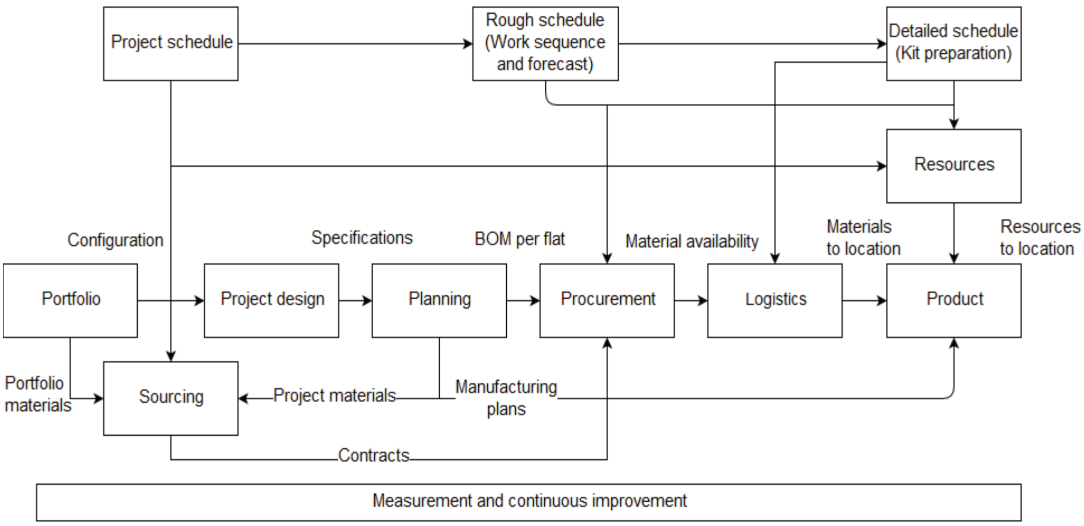


Figure 3: Production systems basic functions of the logistics provider

The external variation is reduced with the logistics solution where material availability is guaranteed. The materials arrive to the ALU two weeks before a project starts. When the materials are available and delivered to the professional who is going to use them, it is easier to measure the productivity due to reduced external variation. The total savings on materials is aimed to be 20% while it is currently 5%. The aimed increase in production rate is 20% while currently it is between 0 and 10%.

Table 1 illustrates the differences between ship yard and construction industries using both takt production and logistics solution. Maturity level of takt production and logistics solution is more advanced in ship cabin manufacturing.

Table 1: Differences between the ship yard and construction industries where takt production is used with logistics solution

Ship yard industry	Construction industry
ALU is next to production site	ALU is located around 20 km from the production sites
Takt time is 40 minutes	Takt time is 1 day
More pre-assembly done in logistics center (20-40%)	Pre-assembly amount is limited
Shorter material picking and kitting time (3 hours)	Material picking and kitting takes longer (1 day)
All materials are going through the ALU	Some subcontractors still deliver materials directly to the site

DISCUSSION

Comparing the ship yard and construction operations and using takt production with a logistics solution indicates that logistics increases the benefits that can be obtained through takt implementation. In ship yard industry, the level of implementation of takt production with logistics solution is higher than the construction industry. Moreover, centralized procurement is used in projects from both industries. According to Pesämaa et al. (2009), a systematic and holistic view is needed for successful construction management. Similarly, the logistics provider uses centralized procurement in order to reduce the material waste and cost.

Based on our findings, there are opportunities to further improve the developed logistics solution in construction. Pre-assembly and pre-cutting of the parts done in the logistics centers reduces the work load of the specialized workers on site. This brings savings to the main contractor as it can further shorten the construction time and the specialized site workers are more expensive.

Kitting reduces the time that is allocated for searching the required parts for assembly (Hua and Johnson 2010). Delivering the kits to the location where the parts are consumed increases productivity of the worker. The worker can focus on the task itself instead of searching for materials. In the construction context, a similar logistics solution to the one mentioned in this research was investigated where the workplace utilization rate was higher than the case in which logistics solution was not utilized (Tetik et al. 2018). Thus, the logistics solution which consists of centralized procurement, kitting in the ALU and JIT delivery can be used for higher productivity and quality.

Utilizing the logistics solution in takt implementation also enforces the takt sequence and schedule. Since the pre-determined schedule has to be followed and there is no material available on-site before its scheduled consuming time, there is no unplanned, off-schedule activities on-site. This reduces the rework that can be caused by unplanned activities. The control over the production process is increased.

According to our study, the design document serves several purposes in logistic processes. It informs the customer regarding the product description. It makes sure that required regulations determined by the authorities are followed. Lastly, BOM can be generated for procurement and sourcing activities from the design document. It guides the employees on how to install the materials. The latter two purposes are not fully used in the construction industry. Procurement and quality issues can be resulted from these problems.

Based on our findings, main problems encountered are related to planning and design processes. To establish the logistics service, detailed planning information is needed. However, the required maturity level in planning has not yet been reached in the construction industry. In the manufacturing industries, one main reason of generating the design model is to have accurate BOM which serves logistic processes. However, in the construction industry, the main aim is to calculate the project cost while detailed quantities per location are not available. Thus, the construction projects suffer from not being able to generate a detailed BOM for procurement and material delivery plan. These issues require further investigation.

CONCLUSION AND FUTURE RESEARCH

The role of logistics in enabling takt planning have not been studied before. We observed the combination in the construction context and provided preliminary findings. The case studies indicate that logistics is a significant enabler in takt implementation in construction, specifically in renovation context. Logistics is an important enabler for takt because material availability can be met through high quality logistics and procurement management. Moreover, having detailed planning available also enforces the takt schedule. Future research should investigate the effect of logistics in takt with utilizing case studies and focusing on more construction operations to compare and contrast the findings.

REFERENCES

Ala-Risku, T. and Kärkkäinen, M. (2006). “Material delivery problems in construction projects: A possible solution.” *International Journal of Production Economics*, *104*(1), pp.19-29.

Alhava, O., Laine, E. and Kiviniemi, A. (2015). “Intensive big room process for co-creating value in legacy construction projects.” *Journal of Information Technology in Construction (ITcon), 20*(11), pp. 146-158.

Bozer, Y. and McGinnis, L. (1992). "Kitting versus line stocking: A conceptual framework and a descriptive model." *International Journal of Production Economics*, 28(1). pp. 1-19.

Binninger, M., Dlouhy, J., Müller, M., Schattmann, M. and Haghsheno, S. (2018). "Short Takt Time in Construction – a Practical Study." In: 26th Annual Conference of the Int'l Group for Lean Construction. Chennai, India, 18-20 Jul 2018. pp 1133-1143.

Christopher, M. (2016). *Logistics & supply chain management*. Pearson UK.

Clifford P. McCue, Jack T. Pitzer. (2000). "Centralized vs. decentralized purchasing: current trends in governmental procurement practices." *Journal of Public Budgeting, Accounting & Financial Management*, Vol. 12 Issue: 3, pp.400-420.

Dallasega, P., Matt, D.T. and Krause, D. (2013). "Design of the building execution process in SME construction networks." In Proceedings of the 2nd International Workshop on Design in Civil and Environmental Engineering (pp. 7-15). WPI.

Ekeskär, A. and Rudberg, M. (2016). "Third-party logistics in construction: the case of a large hospital project." *Construction Management and Economics*. 34(3). pp. 174-191.

Frandson, A., Berghede, K. and Tommelein, I. (2013). "Takt-time Planning for construction of exterior cladding." In: Proc. 21st Ann. Conf. Int'l. Group for Lean Constr. Fortaleza, Brazil, August 31-2.

Ghanem, M. , Hamzeh, F. , Seppänen, O. and Zankoul, E. (2018). "A New Perspective of Construction Logistics and Production Control: An Exploratory Study" In:, 26th Annual Conference of the International Group for Lean Construction. Chennai, India, 18-20 Jul 2018. pp 992-1001.

Hamzeh, F., Tommelein, I., Ballard, G. and Kaminsky, P. (2007). "Logistics centers to support project-based production in the construction industry." In Proceedings of the 15th Annual Conference of the International Group for Lean Construction (IGLC 15) (pp. 181-191).

Heinonen, A. and Seppänen, O. (2016). "TAKT TIME PLANNING IN CRUISE SHIP CABIN REFURBISHMENT: LESSONS FOR LEAN CONSTRUCTION." In Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, IGLC, Boston, MA, USA.

Hopp, W.J. and Spearman, M.L. (2004). "To pull or not to pull: what is the question?." *Manufacturing & service operations management*, *6*(2), pp.133-148.

Hua, S. and Johnson, D. (2010). "Research issues on factors influencing the choice of kitting versus line stocking", *International Journal of Production Reseach, 48(3),* pp. 779-800.

Jaillon, L. and Poon, C.S. (2014). "Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong." *Automation in Construction*, *39*, pp.195-202.

Jacobsson, M. and Wilson, T.L. (2018). "Revisiting the construction of the Empire State Building: Have we forgotten something?" *Business Horizons*, *61*(1), pp.47-57.

Kingman, J.F.C. (1961). "The single server queue in heavy traffic." In *Mathematical Proceedings of the Cambridge Philosophical Society* (Vol. 57, No. 4, pp. 902-904). Cambridge University Press.

Knaack, U., Chung-Klatte, S. and Hasselbach, R. (2012). *Prefabricated systems: Principles of construction*. Walter de Gruyter.

Linnik, M., Berghede, K. and Ballard, G. (2013). “An experiment in takt time planning applied to non-repetitive work.” In 21st Annual Conference of the International Group for Lean Construction (pp. 31-2).

Pattanaik, L.N. and Sharma, B.P., (2009). ”Implementing lean manufacturing with cellular layout: a case study.” *The International Journal of Advanced Manufacturing Technology*, *42*(7-8), pp.772-779.

Pesämaa, O., Eriksson, P.E., Hair, J., (2009). ”Validating a model of cooperative procurement in the Swedish construction industry.” *International Journal of Project Management 27* (6), 552–559.

Pheng, L.S. and Hui, M.S. (1999). “The application of JIT philosophy to construction: a case study in site layout.” *Construction Management & Economics*, *17*(5), pp.657-668.

Seppänen, O. and Peltokorpi, A. (2016). ”A New Model for Construction Material Logistics.” In Annual Conference of the International Group for Lean Construction.

Sullivan, G., Barthorpe, S. and Robbins, S. (2011). *Managing construction logistics*. John Wiley & Sons.

Sundquist, V., Gadde, L.E. and Hulthén, K. (2018). “Reorganizing construction logistics for improved performance.” *Construction Management and Economics*, *36*(1), pp.49-65.

Tanskanen, K., Holmström, J. and Öhman, M. (2015). ”Generative mechanisms of the adoption of logistics innovation: the case of on-site shops in construction supply chains.” *Journal of Business Logistics*, *36*(2), pp.139-159.

Tetik, M., Peltokorpi, A., Holmström, J. and Seppänen, O. (2018). “Impacts of an assembly kit logistic solution in renovation projects: a multiple case study with camera-based measurement.” In Proc: 25th Annual EurOMA Conference 24-26 June 2018, Budapest, Hungary.

Tommelein, I. (2017). “Collaborative Takt Time Planning of Non-Repetitive Work” In:, 25th Annual Conference of the International Group for Lean Construction. Heraklion, Greece, 9-12 Jul 2017. pp 745-752.

Tommelein, I. and Li, A. (1999). “Just-in-time concrete delivery: mapping alternatives for vertical supply chain integration.” In *Proceedings IGLC* (Vol. 7, p. 97).

Vatne, M. E, and Drevland, F. (2016).“Practical Benefits of Using Takt Time Planning: A Case Study.” Proc. 24th Ann. Conf. of the Int’l. Group for Lean Construction, Boston, MA, USA, sect.6 pp. 173–182.

Viswanadham, N. and Raghavan, N.R.S. (1997). “Flexibility in manufacturing enterprises”, Proceedings in Engineering Sciences (Sadhana Academy) , Vol. 22 No. 2, pp. 135-63.

Zhao, J., Olivieri, H., Seppänen, O., Peltokorpi, A., Badihi, B. and Lundström, P. (2017). ”Data analysis on applying real time tracking in production control of construction.” In Industrial Engineering and Engineering Management (IEEM), 2017 IEEE International Conference on (pp. 573-577). IEEE.

STREAM 5: PLANNING AND WORKFLOW

Garcia-Lopez, N.P., Fischer, M., and Alarcón, L.F. (2019). "Work structuring for flow" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 311–322. DOI: https://doi.org/10.24928/2019/0140. Available at: <www.iglc.net>.

WORK STRUCTURING FOR FLOW

Nelly P. Garcia-Lopez[1], Martin Fischer[2], and Luis F. Alarcón[3]

ABSTRACT

Achieving smooth production flow has been one of the main objectives underlying lean manufacturing and construction. To achieve production flow, field managers rely on work structuring methods to enable them to structure activities and flows. Current work structuring methods enable field managers to structure activities, but they do not explicitly represent all seven construction flows or their movement through the project. Hence, field managers rely on their intuition and tacit understanding of flow sequencing, which can cause communication problems between stakeholders resulting in delays and productivity loss. This paper presents a work structuring method that allows field managers to explicitly represent construction activities, flows, and flow movement through the project. The work structuring method was tested prospectively at three construction sites with different scopes and planning methods. The work structuring method allows field managers to generate activity and flow-based schedules to plan and control the project. Furthermore, it improves stakeholder understanding of the plan by visually representing activities' and flows' interdependencies.

KEYWORDS

Work flow, work structuring, flow integration, production management, lean construction.

INTRODUCTION

Managing construction projects to achieve flow has been one of the ideas advocated by Lean production to deliver projects maximizing value and minimizing waste. Optimal production flow entails synchronizing the flow of operations, processes, and projects (Sacks 2016). Within a project, production flow is achieved when all flows needed to execute an activity are available at the right time and in the correct amounts for activities to be executed efficiently (Bertelsen et al. 2007). Good field managers actively think about construction flows when they are creating a plan. It is common for field managers to mention concepts such as planning the handoffs between trades, keeping the rhythm or pace, and feeding the activities (Garcia-Lopez 2017). Field managers rely on work structuring methods to answer these questions and ultimately enable them to generate schedules where activities and flows feeding those activities are coordinated among project

1 Project Director, Grupo Galopa, Bogotá, Colombia, +57 305 297 7320, ngarcia@grupogalopa.com

2 Kumagai Professor of Engineering and Professor of Civil and Environmental Engineering and Director, Center for Integrated Facility Engineering (CIFE), Stanford University, Stanford, CA, fischer@stanford.edu

3 Professor, Department of Construction Engineering and Management, Pontificia Universidad Católica de Chile, Santiago, Chile, +56 2 2354 7165, lalarcon@ing.puc.cl

stakeholders. To do this, work structuring methods must enable field managers to define what activities are needed to execute the project, what flows are needed to execute the activities, and how activities and flows need to be sequenced. Koskela (1999) classified construction flows into seven types: labor, equipment, workspace, materials, precedence, information, and external flows. While current work structuring methods allow field managers to structure construction activities and some of the construction flows, they do not explicitly represent all seven construction flows and their movement through the project. Hence, field managers still rely on a tacit understanding of flow requirements and flow movement, which can lead to miscommunication about the plan among project stakeholders resulting in construction delays in the field. This paper presents a work structuring method that enables field managers to explicitly structure activities, all seven flows, and their sequencing.

WORK STRUCTURING METHODS

In lean construction, production system design, or 'work structuring', entails connecting the facility design (product) with the processes, typically in the form of schedules, used to deliver the physical facility (Ballard et al. 2001; Tsao et al. 2004). The objective of work structuring is to enable field managers to generate reliable schedules, using methods such as Last Planner, where flows are coordinated so that handoffs between production units are clear to all project stakeholders, and flows are balanced so that their availability is synchronized with activity demand while maximizing flow utilization.

There are currently two main methods for work structuring: Ballard's work structuring method that has been advanced by other Lean construction researchers (Ballard 1999; Ballard et al. 2001; Tsao et al. 2004), and Takt planning (Tommelein 2017). Both methods allow field managers to structure activities and focus on explicitly defining precedence, labor, and workspace flows. However, information, material, equipment, and external flows are not explicitly represented.

Through six steps Ballard's work structuring method focuses on activity definition, sequencing, and assignment: (1) breaking down work into units that can be assigned to specialists (activity definition), (2) sequencing activities, (3) understanding how work will be handed off between specialists, (4) understanding whether work will be executed continuously between locations, (5) placing and sizing decoupling buffers, and (6) scheduling activities (Tsao et al. 2004). Precedence and workspace flows are fully structured by determining the activity and workspace sequencing. Labor flows are partially structured by assigning work to a specific specialist (i.e., labor flow class) and understanding how the specialist moves between workspaces, but labor mobilizations (off-site flows) are not included. External, information, material, and equipment flows are not supported.

Takt planning is another method for work structuring (Frandson et al. 2013; Frandson and Tommelein 2014; Tommelein 2017). The objective of Takt planning is to set a pace, known as Takt time, at which each trade can complete its assigned units of work in a zone. Takt planning is carried out in five iterative steps: "(1) data gathering, (2) zone and Takt time definition, (3) trade sequence identification, (4) determination of individual trade durations, (5) workflow balancing, (6) production schedule finalization" (Frandson and Tommelein 2014). Takt planning allows field managers to structure on-site flows related to labor, equipment, workspace, and precedence flow types. However, it lacks support for structuring material, information, equipment and external flows.

Another difficulty faced by field managers during planning is developing schedules that can be used to communicate the plan and control work in the field. This problem arises because existing construction models used to represent construction work do not fully represent all construction flows, and their sequencing and movement through the project (Garcia-Lopez and Fischer 2016). Critical Path Method (CPM) schedules represent precedence flows, and line-of-balance schedules represent workspace and precedence flows (Kenley and Seppänen 2009). While both schedule representations can include resources as activity attributes, they do not explicitly represent flow sequencing. Similarly, neither of the schedule representations represents off-site flows, which are flows that originate outside of the site, such as material deliveries, resource mobilizations, or information requirements. Hence, field managers' flow planning knowledge cannot be formally embedded in construction schedules and remains tacit in planners' minds. This can result in communication problems between stakeholders, low planning reliability, and reduced productivity in the field. To help close this gap, the authors developed an activity and flow model, called the Activity-Flow Model (AFM), that allows field managers to formally represent, track, and control construction activities and flows (Garcia-Lopez 2017). The work structuring method subject of this paper depends on the AFM representation. Hence, we will first present a summary of the AFM followed by the development of the work structuring method.

ACTIVITY-FLOW MODEL (AFM)

The AFM is a construction model composed of a set of production planning, production control, and prediction methods for managing activities and flows. It is based on the Construction Physics conceptualization which extends the seven-flow conceptualization introduced by Koskela (1999) by suggesting that flows can be viewed as physical entities feeding activities (Bertelsen et al. 2007).

Figure 29 summarizes the conceptual activity and flow model underpinning the AFM. Construction activities are defined as resources acting on components (Darwiche et al. 1988; Fischer and Aalami 1996) that need a certain set of flows to be executed efficiently (Bertelsen et al. 2007). There are two mechanisms that can cause variation in the readiness of flows feeding activities: the occurrence of variability factors such as bad weather, and late release of flows due to delays in upstream activities (González et al. 2009). Buffers can be implemented by field mangers to shield activities from variation in the flows (González et al. 2011). If a flow's readiness variation is larger than its time buffer, the flow delays the activity's start. At any time, one or more of the flows needed by an activity can be experiencing variations. The activity's start is constrained by the flow with the highest variation, which is known as the critical flow, i.e., even if the other flows were ready the activity would still be unable to start due to the unavailability of the critical flow (Bertelsen et al. 2006).

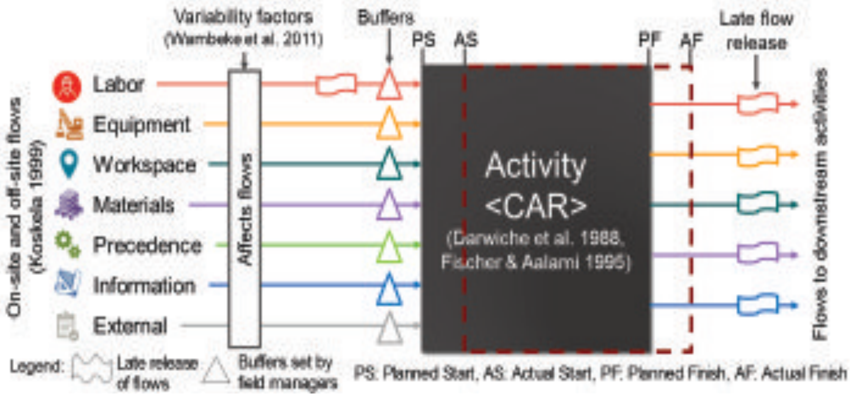


Figure 29: Conceptual activity and flow model showing a construction activity, the seven flows, and their variation mechanisms.

The AFM formalizes the conceptual activity and flow model in an ontology that was operationalized in a class diagram implemented in a web application. The AFM represents the schedule as a network of on-site flows joining the activities and off-site flows feeding the activities (Figure 30). During production control, field managers track the status of the activities and flows, which are used by the AFM to compute activity and flow variation metrics. The AFM leverages activity and flow data collected during production control to generate analytics and statistically significant predictions about the downstream activities that are most likely to face variations (Fischer et al. 2018). In test projects, these analytics and predictions have been used to allocate resources, size buffers, and modify the look-ahead schedule aiming at improving schedule conformance (Garcia-Lopez 2017).

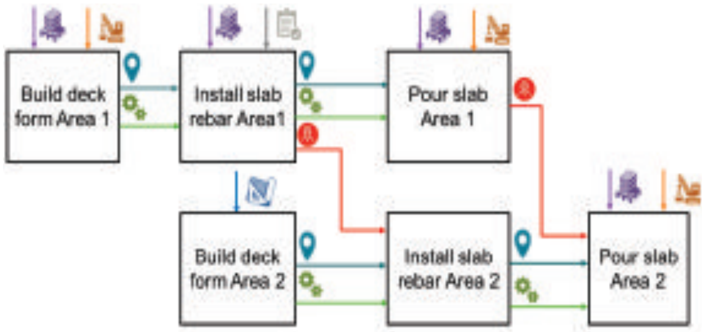


Figure 30: Example of schedule representation showing on-site flows joining the activities and off-site flows feeding the activities.

Activity and flow schedules can be generated and controlled using methods advocated by the Last Planner System (Hamzeh et al. 2012). The difference lies in the underlying schedule representation used by the AFM, which explicitly represents and tracks the status of both activities and flows. The AFM is initialized by inputting an activity and flow-based schedule that forms the basis for re-planning and controlling the project. Hence, field managers need work structuring methods that enable them to structure the project's activities, flows, and their sequencing to create activity and flow-based schedules.

ACTIVITY AND FLOW WORK STRUCTURING METHOD

The Activity and Flow-based Work Structuring Method (AFWSM) allows field managers to structure the activities and flows in a construction project to generate activity and flow-based schedules. Construction schedules are composed of fragnets, which are sequences of activity types that are repeated in different workspaces in the project. Hence, field managers only need to structure a construction fragnet's activities and flows, and then replicate the logic embedded in the fragnet into the full schedule.

Fragnets are determined by the construction method chosen by field managers to build different components on a project (Dong 2012; Fischer and Aalami 1996). For example, building a slab (building component) can be accomplished by choosing the construction method *cast in place slab* or *prefabricate slab*. The choice of construction method determines the activity types and flows that are needed to execute on-site work.

We developed the AFWSM by reviewing existing literature to understand what flow information was needed by field managers to plan and control on-site work and carried out interviews to inquire how that information could be elicited from field managers and be formally represented in a plan. We validated the work structuring method prospectively by implementing it on three construction test sites with different scopes, planning methods, and control methods.

The AFWSM has seven steps encompassing activity definition, activity sequencing, flow definition, and flow sequencing: (1) choose a construction method and identify activity types for the fragnet, (2) sequence activity types based on precedence flows for the fragnet, (3) identify workspaces and their sequencing, (4) identify on-site flows, (5) identify off-site flows, (6) identify flows interfacing with other fragnets, (7) identify stakeholders responsible for the flows. These steps are carried out for each of the fragnets needed to execute the project and are shown graphically in Figure 31, using the case example for the shell construction from one of the test projects.

The first step is to choose a construction method and identify activity types for the fragnet. Activity types are defined as <Component, Action, Resource> tuples. The second step is to identify the sequencing of the activity types based on their precedence flows only. Precedence flows represent physical or technical constraints between the activities. Notice that steps one and two mirror the first two steps of Ballard's work structuring method, which determine the activity definition and activity sequencing. The third step is to identify the workspaces where each of the activity types in the fragnet will be executed and the sequencing for the workspaces. This step is similar to zone definition in Takt planning or location sequencing in the line-of-balance scheduling method. Tommelein (2017) proposes an excellent method for defining zones by balancing work quantities used by the different activities in a project. The fourth step is to identify the on-site flows that are required to execute each of the activity types for the fragnet and how they are released between the activity types. This step identifies additional activity relationships that are not captured by precedence flows identified in step two. This is achieved by asking field managers: Why does activity type x go after activity type y? What does activity type x need from activity type y? The field manager's response is then classified into one or more of the seven types of flows. In the case example, the activity type "Install column forms" goes after the activity type "Install column rebar" because it occupies the same workspace (workspace flow - blue arrow), it encloses the rebar causing a precedence constraint (precedence flow - green arrow), and it works on the same column component (material flow - purple arrow). Generally, additional information needs to be asked regarding the labor flows to understand crew composition and how crews move between activity types and across workspaces. This is achieved by asking field managers: What crews execute each of the activity types? Is there more than one crew executing this activity type simultaneously in a different workspace? How do crews move between activity types (within the same workspace)? How do crews move between workspaces? The fifth step is to identify the off-site flows that are required to execute each of the activity types. This is achieved by asking field managers whether any information, external permits/inspections, materials, labor mobilizations, or equipment mobilizations are needed to execute each of the activity types.

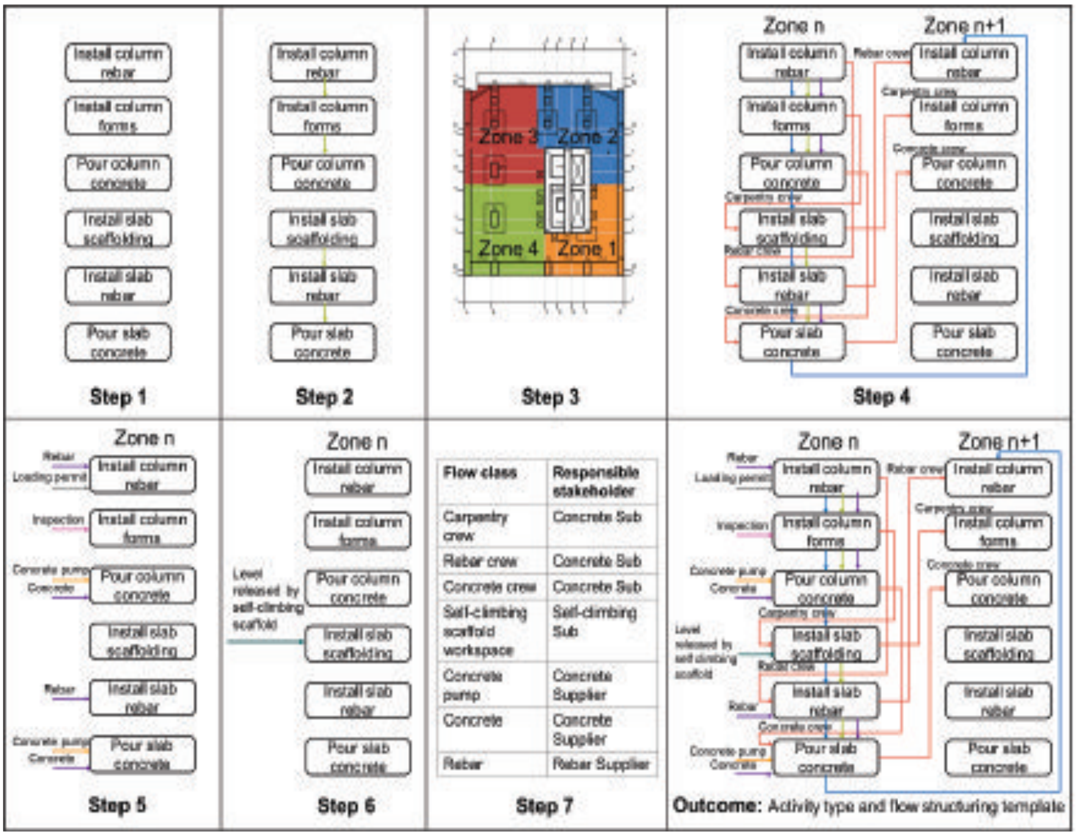


Figure 31: Figure showing an example of the steps of the AFWSM for a structural shell fragnet. The flows are color-coded as follows: labor in red, equipment in orange, workspace in blue, precedence in green, material in purple, information in pink, and external in gray.

The sixth step consists of identifying if any activity type needs a flow that originates from another fragnet. This allows the method to represent interdependencies between different fragnets in the project. In the case example, the activity type "Install slab scaffolding" requires the workspace occupied by the activity type "Raise self-climbing scaffold," which belongs to the elevator shaft fragnet. Step seven consists of asking field managers to identify the responsible stakeholder for each of the on-site and off-site flows.

Normally, the responsible stakeholder for the flow is the subcontractor responsible for executing the activity type. However, sometimes the responsible stakeholder can be a supplier, a designer, or the GC.

The outcome of the AFWSM is a template of the prototypical activity types and flow representation for a fragnet. The diagram shows on-site flows joining the different activity types, off-site flows feeding the activity types, and flows interfacing with activity types belonging to other fragnets. Hence, it explicitly shows the interdependencies between activities and flows.

The activity types and flows in the AFWSM template represent a typical fragnet. Since project schedules are composed of fragnets executed at different workspaces, each activity in the project schedule can be mapped to an activity type contained in the fragnet's activity type and flow structuring template. Hence, field managers can create activity and flow schedules that can be used to plan, track, and control the project using the AFM.

IMPLEMENTATION RESULTS

The AFSWM should be able to represent a wide variety of construction methods, be used to transform different schedule representations into an activity and flow-based representation and require a low time commitment from the field manager's team. This section presents the validation results of applying the proposed work structuring method on three test projects that had different scopes and planning methods.

The first project was the Ichma office building located in Peru. We tracked this project during a total of 18 weeks during its structural phase, with the lead researcher spending the first 4 weeks on site, the following 10 weeks remotely, and the final 4 weeks on site. This project was extremely sophisticated in using state of the art planning and control methods. Field managers implemented the whole Last Planner System (master schedule, phase schedule, look-ahead, and weekly). Additionally, they carried out Takt planning at the phase schedule level to design their operations: choosing how to break down the workspaces depending on the quantities and balancing the resources based on historical productivity rates. They controlled the project by using look-ahead, weekly, and daily planning. Each activity was assigned a clearly delineated workspace. Each project engineer created a daily plan for their scope of work and tracked the daily execution against the plan, assigning daily reasons for variation to the activities.

The second project was the Equilibrium residential building located in Colombia. We tracked this project for a total of four weeks during the foundations phase (deep caissons). This project used traditional CPM scheduling to plan the project. The CPM schedule was developed at very high level of detail, containing activities not exceeding one week in duration. Field managers used a CPM schedule to control the project by updating the actual start and actual finish for the activities to have a historic record of the project progress and assess schedule slippages. Additionally, they implemented the Last Planner's weekly planning and control process involving the subcontractors in a collaborative way.

The third project was the Frederikskaj residential blocks located in Denmark. We tracked this project for a total of four weeks during the interior finishing phase. This project used line-of-balance scheduling to plan the project and a Location-based Management System to control the progress.

All the field managers in the test projects were interested in improving the planning and control methods used in their projects. They wanted to understand whether the AFWSM could help them to better coordinate and communicate the plan among the different project stakeholders.

In each of the test projects we first used the AFWSM to model the flow logic for each of the fragnets contained in their look-ahead schedule. This was a collaborative process with field managers, who explained the construction methods and checked the representations. Second, we used the results of the AFWS to transform the project's existing look-ahead schedule into an activity and flow schedule.

AFWSM IMPLEMENTATION RESULTS

In total, we used the AFWSM to model 11 fragnets spanning from caisson foundations to interior finishes (Table 13). In the Ichma project, we modelled 5 fragnets: elevator shaft construction, structural shell construction, core beams and slabs, interior floors, and interior walls. For the Equilibrium project, we modelled 3 fragnets: caissons, in-caisson walls and columns, and foundation beams. Finally, we modelled 3 fragnets for the Frederikskaj project: walls and in-wall MEP, floor construction, and interior finishes. This provides evidence of the generality of the AFWSM, since it was used to represent fragnets spanning three key phases of a construction project.

Table 13. Summary of the fragnets modelled using the AFWSM.

Project	Fragnet	# Activity types	# Flows	# Flows/ #Activity types	Time (mins)
Ichma (Takt)	Elevator shaft	6	15	2.5	15
	Structural shell	6	22	3.7	20
	Core beams & slabs	7	23	3.3	20
	Interior floors	3	10	3.3	10
	Walls & in-wall MEP	4	15	3.8	20
Equilibrium (CPM)	Caissons	4	7	1.8	10
	In-caisson walls & columns	3	10	3.3	10
	Foundation beams	4	14	3.5	10
Frederikskaj (LOB)	Wall & MEP	6	13	2.2	20
	Floor construction	5	16	3.2	15
	Interior finishes	17	51	3.0	20
Total Avg.		**5.9**	**17.8**	**3.0**	**15**

Another important requirement was related to the time commitment needed from field managers to implement the method. The average time required to model a fragnet was 15 minutes, the longest time was 20 minutes, and the shortest time was 10 minutes. We asked field managers how much time they would be willing to spend per week to apply the AFWSM on their projects and the average reply was thirty minutes. Hence, the amount of time that it takes to apply the AFSWM is acceptable.

DEVELOPMENT OF ACTIVITY AND FLOW-BASED SCHEDULES

To develop activity and flow-based schedules, we transformed the four-week look-ahead schedule developed by field managers into an activity-flow representation by using the results of the AFWSM (Table 14). The Ichma project represented its look-ahead schedule in a spreadsheet using a takt representation where the rows represented the activity types, the columns represented time (days), and the cells contained the workspaces where the work was executed. The Equilibrium project used a CPM representation. Finally, the Frederikskaj project used a line-of-balance representation.

On average, we spent 1.4 hours transforming a project's look-ahead schedule into an activity and flow-based representation after applying the AFWSM. As expected, the time it took to transform the schedule into an activity and flow-based representation depended on the number of activities and flows that were in the schedule. The look-ahead schedule for the Frederikskaj project contained the biggest number of activities (311) and took 2 hours to create. The Ichma project contained 238 activities and took 1.2 hours to create. Finally, the Equilibrium project contained the lowest number of activities (111) and took 1 hour to create. It is necessary to reduce the amount of time it takes to transform the activity-based look-ahead into an activity and flow-based look-ahead for the method to be used extensively on construction projects.

Table 14. Number of activities and flows in the project 4-week lookaheads and time needed to prepare them.

Project	# Activities in look-ahead plan (4 weeks)	# Flows in look-ahead plan	Time (hours)
Ichma (Takt)	238	1,002	1.2
Equilibrium (CPM)	111	442	1.0
Frederikskaj (LOB)	311	1,210	2.0
Average	**220.0**	**884.7**	**1.4**

Overall, field managers valued how the AFSWM allowed them to formally map and structure construction flows: "I think it's very useful that we have a tool that formally maps the flows that are needed to execute an activity that is in the plan … These things pass through our heads, but there is no formal tool that allows us to check that all the flows are ready so the activity is not in danger" (Project engineer, Ichma). Additionally, they highlighted how the AFWSM allowed them to communicate the plan visually between stakeholders, especially regarding the movement of labor flows between activities and workspace handoffs, leading to improvements in project coordination and plan understanding.

CONCLUSIONS AND FUTURE WORK

The AFWSM extends current work structuring methods by allowing field managers to structure activity and flow sequencing for each of the fragnets on a project. The activity type and flow structuring template enables work structuring communication between project stakeholders and the understanding of the interfaces between the different activity types and flows. The AFWSM allows field managers to transform existing activity-based schedules into an activity and flow-based representation that can be used to plan and control the project using the AFM.

Future research is needed to evaluate the impact of the use of the AFWSM on project performance both by collecting qualitative evaluations from users and measuring quantitative impacts through case studies.

An important next step in this research is improving the time it takes to extend existing schedules into an activity and flow representation. A potential research avenue is to automate the matching process between the activity types in the activity type and flow structuring template and the activities in the look-ahead schedule using machine learning algorithms.

REFERENCES

Ballard, G. (1999). "Work structuring." *Lean Construction Institute. White paper 5*.

Ballard, G., Howell, G., and Zabelle, T. (2001). "Production system design: Work structuring revisited." *Lean Construction Institute. White paper 11*.

Bertelsen, S., Heinrich, G., and et al. (2007). "Construction Physics." *15th Annual Conference of the International Group for Lean Construction*, C. L. Pasquire and P. Tzortzopoulos, eds., East Lansing, Michigan, 13–26.

Bertelsen, S., Koskela, L., Henrich, G., and Rooke, J. (2006). "Critical flow – towards a construction flow theory." *14th Annual Conference of the International Group for Lean Construction*, R. Sacks and S. Bertelsen, eds., Santiago, Chile, 31–40.

Darwiche, A., Levitt, R., and Hayes-Roth, B. (1988). "OARPLAN: generating project plans by reasoning about objects, actions, resources." *Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*, 2(3), 169–181.

Dong, N. (Tony). (2012). "Quick generation of close-to-optimum look-ahead schedules for the finishing phase of complex projects." PhD Dissertation, Stanford University.

Fischer, M. A., and Aalami, F. (1996). "Scheduling with computer-interpretable construction method models." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 122(4), 337–347.

Fischer, M., Garcia-Lopez, N. P., and Morkos, R. (2018). "Making each workhour count: Improving the prediction of construction durations and resource allocations." *Advanced Computing Strategies for Engineering. EG-ICE 2018. Lecture Notes in Computer Science, vol 10863.*, I. Smith and B. Domer, eds., Springer, Cham, 273–295.

Frandson, A., Berghede, K., and Tommelein, I. D. (2013). "Takt time planning for construction of exterior cladding." *21st Annual Conference of the International Group for Lean Construction*, C. T. Formoso and P. Tzortzopoulos, eds., Fortaleza, Brazil, 527–36.

Frandson, A., and Tommelein, I. D. (2014). "Development of a takt-time plan: A case study." *Proc. Construction Research Congress*, B. Ashur and J. Irizarry, eds., Reston, VA, 1646–1655.

Garcia-Lopez, N. P. (2017). "An activity and flow-based construction model for managing on-site work." PhD Dissertation, Stanford University.

Garcia-Lopez, N. P., and Fischer, M. (2016). "A construction workflow model for analyzing the impact of in-project variability." *Proc. Construction Research Congress*, ASCE, Reston, VA, 1998–2007.

González, V., Alarcón, L. F., Maturana, S., and Bustamante, J. A. (2011). "Site management of work-in-process buffers to enhance project performance using the Reliable Commitment Model: Case Study." *Journal of Construction Engineering and Management*, American Society of Civil Engineers, 137(9), 707–715.

González, V., Alarcón, L. F., and Molenaar, K. (2009). "Multiobjective design of work-in-process buffer for scheduling repetitive building projects." *Automation in Construction*, 18(2), 95–108.

Hamzeh, F. R., Ballard, G., and Tommelein, I. D. (2012). "Rethinking lookahead planning to optimize construction workflow." *Lean Construction Journal*, 2012, 15–34.

Kenley, R., and Seppänen, O. (2009). *Location-based management for construction: planning, scheduling and control*. Spon Press, Abingdon, Oxon, UK.

Koskela, L. J. (1999). "Management of production in construction: a theoretical view." *7th Annual Conference of the International Group for Lean Construction*, Berkeley, CA, 241–252.

Sacks, R. (2016). "What constitutes good production flow in construction?" *Construction Management and Economics*, 34(9), 641–656.

Tommelein, I. D. (2017). "Collaborative Takt time planning of non-repetitive work." *Proc., 25th Annual Conf. of the Int. Group for Lean Construction*, K. Walsh, R. Sacks, and I. Brilakis, eds., Herkalion, Greece, 745–752.

Tsao, C. C. Y., Tommelein, I. D., Swanlund, E. S., and Howell, G. A. (2004). "Work structuring to achieve integrated product–process design." *Journal of Construction Engineering and Management*, 130(6), 780–789

Häringer, P. and Borrmann A. (2019). "Improving flow in Concrete Constructions by Avoiding Spatial Conflicts Between Pour Cycles." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 323 - 334. DOI: https://doi.org/10.24928/2019/0189. Available at: <www.iglc.net>.

IMPROVING FLOW IN CONCRETE CONSTRUCTIONS BY AVOIDING SPATIAL CONFLICTS BETWEEN POUR CYCLES

Paul Häringer[1] and André Borrmann[2]

ABSTRACT

Supervisors and formwork engineers divide construction sections into multiple pour cycles in order to achieve a good production flow in concrete constructions. A pour cycle consists of one or more disconnected casting segments. Casting segments in the successor pour cycle often fill the gaps between the disconnected casting segments in the predecessor pour cycle. We call such a meeting of two neighbour casting segments "topological dependency" because it effects spatial conflicts between pour cycles and different trades cannot work on the next casting segment until the previous ones are completely finished. Because of the long curing times, trade crews have to wait or move to other locations. In this research, we introduce a new structure of a cycle planning option, which can avoid such spatial conflicts. We evaluated our cycle planning option by using a stochastic discrete event simulation model and compared it with three practical cycle planning options from one supervisor and two formwork engineers. The criteria for the evaluation were the total construction time as well as the stable production rate and balanced work. In addition, we discuss the potential benefit by using a mix of concrete precast elements and casting segments to achieve an even better production flow.

KEYWORDS

Work flow, flow integration, simulation, building information modelling (BIM)

INTRODUCTION

Supervisors and formwork engineers use cycle planning (CP) to plan cast in-situ constructions. They divide a construction section such as a floor into multiple pour cycles in order to achieve a good production flow in concrete constructions. A pour cycle consists of one or more disconnected casting segments. Current analysis of practical CP options show that there is a fundamental problem regarding the achievement of a good production flow due to dependencies and time variations.

[1] Research Associate, Chair of Computational Modeling and Simulation, TUM Department for Civil, Geo and Environmental Engineering, Technical University of Munich, Germany, paul.haeringer@tum.de

[2] Professor, Chair of Computational Modeling and Simulation, TUM Department for Civil, Geo and Environmental Engineering, Technical University of Munich, Germany, andre.borrmann@tum.de

Gregory A. Howell (1999) mentioned the importance of dependencies and variations when he postulated that the combined effect of dependency and variation in managing the interaction between activities is essential if we are to complete projects in the shortest possible time. Dependencies in terms of space are very important because, unlike manufacturing where the work moves to people, on a construction site the people move to the work (Ballard and Howell 1998). The work is performed at locations on site so that space becomes an important resource, which has to be considered when planning construction projects (Frandson et al. 2015). Flow represents a fundamental concept in the production design process, it incorporates both continuity (absence of stoppages) and speed (Ballard et al. 2001).

Technological reasons, especially the shrinking process of cast in-situ concrete constructions, are leading to the construction of smaller, disconnected casting segments for a pour cycle. The time needed for the activity of pouring the concrete as well as the subsequent curing time greatly depends on external conditions. Unfavourable weather and temperature conditions in particular lengthen the time needed for pouring and extend the duration of curing. Therefore, the time between pouring and striking the formwork may vary greatly between different pour cycles. Consequently, if casting segments in the successor pour cycle meet or touch any other casting segments in the predecessor pour cycle (defined as a topological dependency), unpredicted waiting times can occur.

This research shows the impact of topological dependencies, which have the capacity to slow down and even stop the production process. It outlines an alternative concept for creating and structuring a CP option in terms of avoiding topological dependencies.

BACKGROUND

In an earlier case study, we investigated how supervisors and formwork engineers were planning to construct cast in-situ constructions for a residential building (Häringer and Borrmann 2018). The task at hand to create a suitable plan for the construction of the concrete walls and to maintain a working time frame of ten working days. The unit under construction consisted of four apartments and a staircase with an elevator shaft. We received three different CP options made by three different practitioners. The CP options are called CP-A, CP-B and CP-C.

In a CP option, one single casting segment is defined as *zone* and a group of segments as *area,* representing a pour cycle. The term *zone* is used as a construction segment which is fully covered by formwork elements (Biruk and Jaskowski 2017). Both the terms *zone* and *area* are used in the Lean Construction literature when referring to takt time planning (TTP) (Frandson et al. 2013).

Independent of the number of trade crews, a zone with dependencies to a zone in the predecessor area can only begin when the zone in the successor area is completely finished. Formwork elements block the space needed to construct the neighbouring casting segment in the predecessor area. Figure 32 illustrates this space conflict for CP-B. Zones 4, 5, 6, and 7 have topological dependencies to their neighbouring zones in the successor area. For example, Zone 5 meets Zones 2 and 3 – the bulkhead formwork blocks the space for Zone 5, so that a trade crew cannot fully set the formwork for Zone 5 and has to wait until the construction process of Zones 2 and 3 is finished.

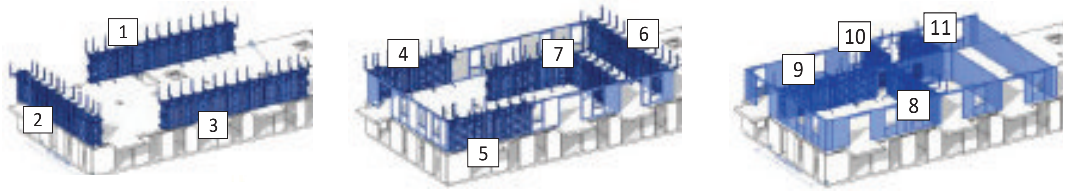


Figure 32: A typical structure of a CP - the walls of a construction unit (like a floor) are divided into segments (the zones numbered from 1 to 7), a group of disconnected segments represents the areas, area 1 with Zones 1 to 3, Area 2 with Zones 4 to°7 and Area 4 with Zones 8 to 11

RESEARCH METHOD

The research method is based on three steps. In the first step, we created a basic generic building information model, which can represent all the different CP options. In the second step, we used this model to create the three different practitioner CP options, as well as to generate a partly automated optimised CP option, which has fewer topological dependencies between pour cycles. In the third and last step, we implemented a stochastic discrete event simulation model to analyse and evaluate the generated CP options in relation to the total construction time, stable production rate and balanced work. According to Sacks (2016), the stable production rate is the variation within each trade crew's takt time and balanced work is the variation between different trade crews.

The process of constructing a casting segment is a sequential execution of the following six activities:

[1] Setting the formwork on one side (setting 1); [2] Mounting the rebar (reinforcing); [3] Setting the formwork on the second side (setting 2), [4] Pouring the concrete (pouring); [5] Waiting until the concrete is strong enough (curing) and [6] Removing the formwork (striking).

Taking into account the fact that the supervisor as well as the both formwork engineers used slightly different values for the performance factors, we decided to use a triangle distribution and set a minimum, mean and maximum value for each activity's performance factor (PF). A triangle distribution is linear and values close to the mean value are more likely to be chosen. This type of distribution has been successfully applied in Monte Carlo simulations to estimate the probability of the total time of reinforced concrete work (Hofstadler 2007).

The supervisor mentioned a time of around 12 hours as a practical value for the curing time. This means that the concrete can be poured in the evening so the formwork panels can start being removed the next day. The formwork engineers told us that it could take up to 36 hours. We decided to set the curing time to 24 hours, a time, which lies between 12 and 36 hours.

Table 15 shows the minimum, mean and maximum values employed of the performance factors for each activity.

Table 15: Minimum, mean and maximum values of the performance factors (PFs) for each activity as input for the triangle distribution

Type of PF	Min Value	Mean Value	Max Value	Unit
PF_setting1	0.13	0.15	0.17	h/m²
PF_setting2	0.13	0.15	0.17	h/m²
PF_reinforcing	14	16	18	h/tonnes
PF_pouring	0.5	0.7	0.9	h/m³
PF_curing	24	24	24	h
PF_striking	0.11	0.13	0.15	h/m²

The supervisor as well as the both formwork engineers calculated on using two trade crews; trade crew 1 executed the activities setting1, setting2, pouring and striking, while trade crew 2 performed the activity of reinforcing. Taking into account the fact that they used slightly different numbers of workers in a trade crew, we decided to use an empirical distribution. Table 16 details the different number of workers employed in each trade crew and their frequency as a percentage in order to depict the probability for the empirical distribution.

Table 16: Number of workers for trade crew 1 and 2

Number of workers in trade crew 1	Frequency [%]	Number of workers in trade crew 2	Frequency [%]
2	30	3	30
3	40	4	40
4	30	5	30

The equation for the duration of an activity is:

$$Duration\ acitivity = \frac{Amount\ of\ x\ for\ a\ zone\ (casting\ segment) *\ PF_y}{number\ of\ workers\ in\ a\ trade\ crew\ z}\ ;$$

$x \triangleq$ *unit of measurement* $[m^2, m^3$*, tonnes*$]$; $y \triangleq$ *type of PF*; $z \triangleq$ *trade crew for the activity*

CYCLE PLANNING DESIGN PROCESS

The cycle planning design process describes our workflow for generating, analysing and evaluating different CP options. A location breakdown structure (LBS) is used to define the location for a CP option. Kenley and Seppänen (2010) describe three different hierarchy levels for LBSs. The highest hierarchy level divides buildings into sections and risers, the middle hierarchy into floors and the lowest into apartments. We propose a middle hierarchy level such as the floor represented in Figure 32 in order to begin detailed construction planning.

MODEL AND DATA PREPARATION

The design of the building represented by a building information model (BIM) describes the value that has to be produced for the customer. In order to be flexible as to how to construct the walls, we split them into small slices. This splitting follows a rule of not splitting through openings and it is performed automatically by using a splitting algorithm, which we devised ourselves, for Autodesk Revit (Häringer and Borrmann 2018).

Pursuing the concept of achieving a good location flow without any waiting times between the pour cycles, we needed to reduce the topological dependencies. Consequently, we propose a method where neighbouring zones are separated from each other in order to reduce the dependencies between zones in successor areas. According to Borrmann and Rank (2009), the solid representation of a BIM is suitable for obtaining topological information and thus for deriving the spatial relationships between elements. Consequently, we used graph theory to get the topological relations between every element in a BIM. In our case, an adjacency matrix was suitable for representing the relations between all the elements. If two elements are neighbours and the second element has the same alignment (for example it still runs along the x-axis in the coordination system), then it is given the value "AA" in the adjacency matrix. If the second element does not have the same alignment (for instance the second element is rotated through 90° and now runs along the y-axis), then it represents a cross member and the value becomes "AT". The first element in such an "AT" relation represents a node with high topological dependency (NWHTD).

Figure 33 illustrates the process of splitting the model into small slices (split model) and in Figure 34 the creation of a CP option (CP-B) from the split model can be seen. Figure 35 represents our optimised CP option by using NWHTDs to decouple the zones between them.

Figure 33: Splitting process

Figure 34: Creation of a CP option

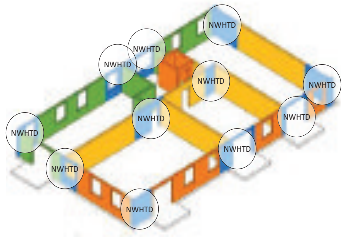


Figure 35: optimised CP option

PLANNING AND CHECKING

The "Planning and Checking" describes the procedure for creating or generating a CP option. After identifying all the NWHTDs, we calculated the distance between them using a breadth-first search algorithm (Cormen 2005). All the elements (the small slices) between two NWHTDs are our zones. We used the information on the distance measured to adjust the zones, so that the length of every zone became similar. The idea is that similar zones could be constructed in the same way just as with standardised products.

An algorithm takes two NWHTDs and checks whether the length between them is between 7.00 m and 9.00 m. If it is more than 9.00 m, slices are then added to the NWHTDs until the length is under 8.50 m; if it is less, then nothing need be done. This algorithm works well if the distance between all the NWHTDs is similar. However, how should one proceed with small distances that are around 1.00 m in length? They are too small to have a zone of their own. One method could be to add them to those which are in the range of approx. 4, 5 or 6 m. Thus, a smaller zone can approach 8 m in length. No algorithm has yet been implemented for this, so we calculated it manually to check whether it could be a good way to handle this problem or not.

The Last Planner System (LPS) identifies which work should and could be done, then tracks the commitments for what will be done (Ballard and Howell 2003). It focuses more on the social process of planning and commitments to improve quality and reliability by involving the trade crews (Seppänen et al. 2010). The process "Planning and Checking" needs human decisions, especially to determine the number of areas and to allocate the zones to areas. This is a crucial process because it has an immediate impact on the trade crew's work. Referring to the LPS, this process should provide information and possible suggestions on how the work can be done.

We received the information from the supervisor that external walls needed to be constructed first. The main reason was to avoid blocking the walking routes with interior walls. Another reason was that it provided more safety because the exterior walls prevent falls from a height. The experts proposed solutions with three or four areas (pour cycles). The estimate of the number of areas was based on a mix of expert knowledge, referring to the total amount of concrete needed, the total wall length and the curing time for each pour cycle. Figure 36 and Figure 37 illustrate our proposed optimised CP option (CP-D). The numbers in Figure 36 and Figure 37 represent the zones and the same colour defines the pour cycles (areas). In order to compare CP-D with the other three CP options, we considered a group of NWHTDs as one zone. We defined three zones, numbered as 1, 2, and 3, as shown in Figure 36.

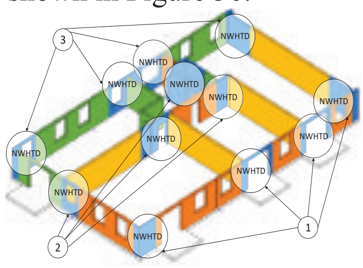


Figure 36: Optimised CP option with Zones 1 to 3

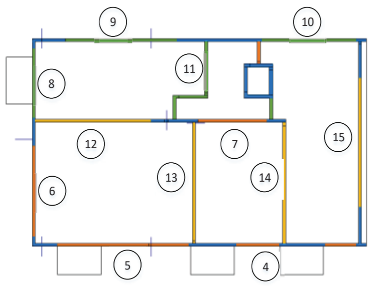


Figure 37: Optimised CP option with Zones 4 to 16.

The NWHTDs are dynamic and change their size, so that we can obtain almost similar zones. Apart from zone 4, which consists of two smaller segments, all the zones are between 5.5 m and a maximum of 8.5 m.

SIMULATION AND EVALUATION

The "Simulation and Evaluation" describes the procedure for simulating and evaluating a CP option. The process of constructing a casting segment (zone) of a CP option, as well as the input parameters and variables used are described in the research method section.

The sequential execution of pour cycles (areas), as well as the casting segments (zones) of area 1, are fixed in our simulation model and both are determined by the user before the simulation starts. For example, CP-B (Figure 32) starts with Area 1, which includes the fixed sequence of Zone 1, Zone 2 and Zone 3 followed by Area 2 and Area 3. The sequence of the zones in Areas 2 and 3 is dependent on whether there is a connection to the last zone in the predecessor area or not. It should be remembered that the information on the connection, as well as the type of connection, is defined in the adjacency matrix. If the last zone of an area is in the curing activity, then trade crews will be available to work on the next zone in the successor area. However, the trade crew can only work on the next zone if there is no connection, otherwise there will be a spatial conflict. The model prevents such a spatial conflict by changing and sorting the sequence of zones in the successor areas, so that "not connected" zones will be executed first. However, this is only possible if the CP option has one or more "not connected" zones between the predecessor and successor area.

On construction sites, there is frequently no fixed shift schedule. The work usually starts at 7 am and ends at any time between 5 pm and 9 pm. The shift end often depends on whether the trade crew wants or has to pour a casting segment that day or not. A limited shift schedule could give a disadvantage or advantage to a particular CP option, so we decided to simulate it with a shift schedule of 24 hours and 7 days.

We wanted to evaluate and compare the different CP options in terms of the total construction time (TCT), balanced work (BW) and stable production rate (SPR) criteria. First, we simulated three scenarios, each for one of these criteria. Before we started with a fourth scenario, which had the goal of finding the best CP option by considering all the criteria in an evaluation function, we had to choose the weight of each criterion and determine its impact factors. The following equation represents the evaluation function by considering all the above-mentioned criteria.

$$eval\ (CP\ option) = TCT * factorTCT + BW * factorBW + SPR * factorSPR$$

The factor weights the criteria and is zero if the criteria are not considered. If only one criterion is considered, the value of the factor for this criterion is one. The simulation results of the first three scenarios showed that the TCT value of the *eval (CP option)* evaluation function was roughly 55 times higher than the SPR value and 350 times higher than the BW value. It is clear that the TCT value is very high because it takes the total construction time into consideration, which is in the range of approx. four to six days. The SPR value was measured as the mean deviation within a trade crew for each activity over all locations (zones). The BW value was measured as the mean deviation between two trade crews and their activities. Both values were in the range of minutes and hours but the BW value was approximately seven times lower than the SPR value. One reason could be that the BW value was only measured between the activities setting1 and reinforcing as well between reinforcing and setting2. These are the activities that are performed by different trade crews.

Consequently, the factor values for the fourth scenario, called composite criteria (CC), was one for the TCT factor, 55 for the SPR factor and 350 for the BW factor. We performed 3000 simulation runs per scenario to find the best candidate in each CP option. The best candidates in each CP option and scenario are listed in Table 17. The CP option, which had the best candidate of all CP options, is shown underlined and in italics. The results show that the best candidates for scenario [1] TCT and [3] SPR, as well as for [2] BW and [3] CC were the same.

Table 17: Simulation results for each scenario [1] TCT, [2] BW, [3] SPR and [4] CC with the values of the most suitable candidates for each CP option

	CP options	No. Run of simulation	Min value	Total time [dd:hh:mm]	No. Crew 1	No Crew 2	PF_setting1 [h\m²]	PF_reinforcing [h/tonnes]	PF_setting2 [h/m²	PF_pouring [h/m³]	PF_curing [h]	PF_striking [h/m²]
[1] Total Construct ion Time (TCT) [3] Stable Production Rate (SPR)	CP-A	881	520302 **[1]** 15013 **[3]**	6:00:31	4	5	0.14	16.88	0.14	0.56	24.00	0.13
	CP-B	2194	400446 **[1]** 7169 **[2]**	4:15:14	4	5	0.14	15.66	0.14	0.56	24.00	0.13
	CP-C	*881*	492734 **[1]** *3874* ***[3]***	*5:16:52*	*4*	*5*	*0.14*	*16.88*	*0.14*	*0.56*	*24.00*	*0.13*
	CP-D	881	*350605* ***[1]*** 5120 **[3]**	*4:01:23*	*4*	*5*	*0.14*	*16.88*	*0.14*	*0.56*	*24.00*	*0.13*
[2] Balanced Work (BW) [4] Composite Criteria (CC)	CP-A	1055	1487 **[2]** 2129504 **[4]**	6:15:58	3	5	0.14	14.93	0.14	0.62	24.00	0.13
	CP-B	112	1184 **[2]** 1388235 **[4]**	5:08:01	3	5	0.15	14.98	0.15	0.61	24.00	0.14
	CP-C	2517	1108 **[2]** 1218661**[4]**	6:10:41	3	5	0.15	14.98	0.15	0.81	24.00	0.13
	CP-D	*2596*	*773* ***[2]*** *1014382* ***[4]***	*4:11:23*	*3*	*5*	*0.16*	*15.06*	*0.16*	*0.69*	*24.00*	*0.12*

The optimised CP option (CP-D) provided the best candidate for scenario [1] Total Construction Time, [2] Balanced work and [4] Composite Criteria. The simulation run No. 2596 represents the best candidate for CP-D in scenario [2] as well in [4]. Apart from the results in scenario [3] SPR, the optimised CP option (CP-D) provided the best candidate.

A standard line-of-balance chart can illustrate the location and trade flow in one diagram (Sacks, 2016). Consequently, it is suitable for illustrating and analysing our simulation results. The structures of CP-A, CP-B and CP-C are similar. As a result, all of them have many topological dependencies between pour cycles (areas). Both CP-B and our generated and optimised CP-D with fewer topological dependencies are displayed in this paper, so it is reasonable to show the effect of topological dependencies by comparing CP-B with CP-D. Because of the topological dependencies, the trade crews in CB-B are unable to work during the curing activity (Figure 38). The trade crews in CP-D can work during the curing activity after all NWHTDs in Area 1 have been completely constructed (Figure 39). Consequently, the trade crews are not forced to pour the castings segments at the end of the day in order to use the time over night for the curing. CP-D can prevent waiting times and improve flow, however this might give rise to more inventory (formwork panels).

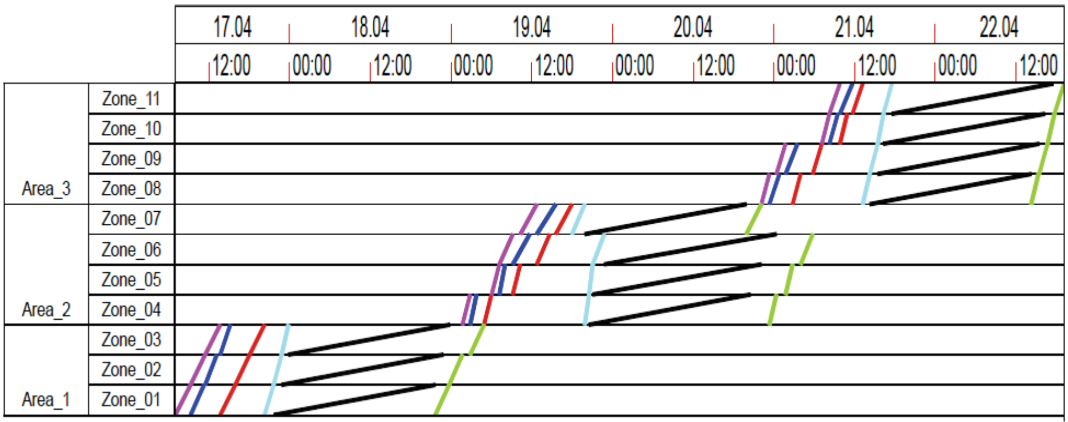


Figure 38: Line-of-balance chart - CP-B:

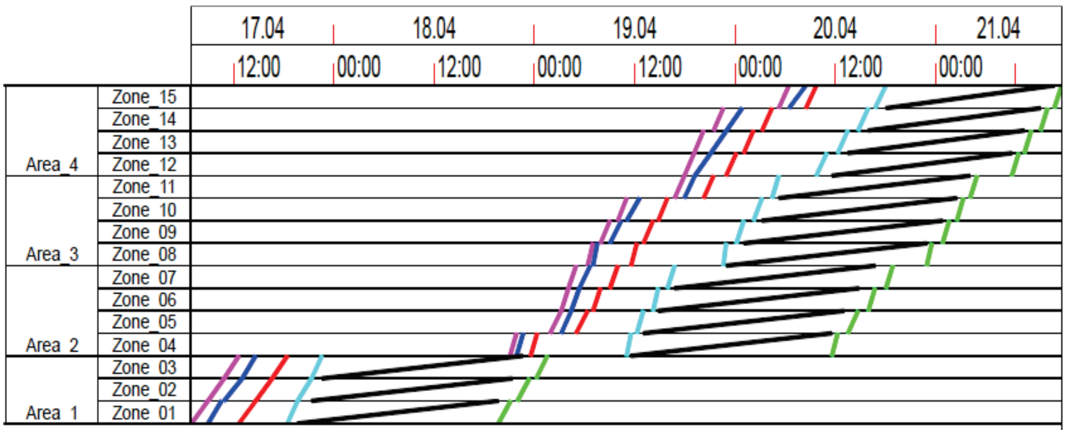


Figure 39: Line-of-balance chart - CP-D

CONCLUSION

Practical solutions for scheduling the execution of cast in-situ concrete constructions show breaks in location flow. This interrupts the on-site work and reduces the general production flow. We identified one reason as being spatial conflicts due to topological dependencies between casting segments in the predecessor and successor pour cycle. With the introduction of a new planning design by separating casting segments through nodes with high topological dependencies (NWHTDs), we can create solutions with fewer dependencies. Our simulation results show that such an optimised solution can achieve a better production flow. The simulation does not consider the material flow. More inventory (formwork panels) might arise from using our proposed planning design, which could be a disadvantage. We think that production flow could be improved by using a combination of precast elements to construct the NWHTDs, as well as cast in-situ concrete for the casting segments between them. This needs to be analysed in further research.

ACKNOWLEDGEMENTS

The authors would like to thank the companies Pöttinger GmbH & Co. KG, Doka GmbH, Peri GmbH and Dr. Prautsch & Partner Ingenieure PPI – Informatik for providing information to assist in the development and validation of our work. This research has been supported by the Bavarian Research Foundation.

REFERENCES

Ballard, G., & Howell, G. (1998, August). What kind of production is construction. In Proc. 6 th Annual Conf. Int'l. Group for Lean Construction (pp. 13-15).

Ballard, G., & Howell, G. (2003). Lean project management. Building Research & Information, 31(2), 119-133.

Ballard, G., Koskela, L., Howell, G., & Zabelle, T. (2001, August). Production system design in construction. In Annual Conference of the International Group for Lean Construction (Vol. 9).

Biruk, S., and Jaskowski, P. (2017). "Optimization of Vertical Formwork Layout Plans Using Mixed Integer Linear Programming." Int J Civ Eng, 10.1007/s40999-016-0090-6, 125–133.

Borrmann, A., & Rank, E. (2009). Topological analysis of 3D building models using a spatial query language. Advanced Engineering Informatics, 23(4), 370-385.Cormen, T. H. (2005). Introduction to algorithms, MIT Press; McGraw-Hill, Cambridge, Mass., Boston, Mass.

Frandson, A., Berghede, K., & Tommelein, I. D. (2013, August). Takt time planning for construction of exterior cladding. In Proc. 21st Ann. Conf. of the Int'l Group for Lean Construction.

Frandson, A. G., Seppänen, O., & Tommelein, I. D. (2015, July). Comparison between location based management and takt time planning. In Proceedings of the 23rd Annual Conference of the International Group for Lean Construction (pp. 28-31). Perth: IGLC.

Howell, G. A. (1999, July). What is lean construction-1999. In Proceedings IGLC (Vol. 7, p. 1)..

Häringer, P., and Borrmann, A. (2018). "Evaluation of a Case Study to Design a BIM-Based Cycle Planning Concept." 26th Annual Conference of the International Group for Lean Construction, 10.24928/2018/0224.

Hofstadler, C. (2007). Wahrscheinlichkeitsüberlegungen—Berechnung der Dauer. Bauablaufplanung und Logistik im Baubetrieb, 413-429.

Kenley, R., & Seppänen, O. (2006). Location-based management for construction: Planning, scheduling and control. Routledge.

Sacks, R. (2016). What constitutes good production flow in construction?. Construction management and economics, 34(9), 641-656.

Seppänen, O., Ballard, G., & Pesonen, S. (2010). The Combination of Last Planner System and Location-Based Management System. Lean construction journal.

Abdelmegid MA., Gonzalez VA., O'Sullivan M., Walker C.G., Poshdar M., and Alarcon, LF. (2019). "Establishing A Link Between the Last Planner System and Simulation: A Conceptual Framework." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. xx–335 – 346 DOI: https://doi.org/10.24928/2019/0200. Available at: <www.iglc.net>.

ESTABLISHING A LINK BETWEEN THE LAST PLANNER SYSTEM AND SIMULATION: A CONCEPTUAL FRAMEWORK

Mohammed A. Abdelmegid[1], Vicente A. González[2], Michael O'Sullivan[3], Cameron G. Walker[4], Mani Poshdar[5], Luis Fernando Alarcón[6]

ABSTRACT

The Last Planner System (LPS) is considered one of the most established lean-based construction planning methods due to its ability to stabilise construction production and to increase plan reliability. Several technologies have been proposed to support the implementation of the LPS such as simulation modelling, BIM, and spreadsheets. Simulation modelling is proven to support construction project management by providing a virtual means to test decisions before real implementation. This study aims at establishing a link between the LPS and simulation modelling to support the implementation of the LPS in the construction industry. The scope of this study is focused on the Conceptual Modelling (CM) phase of simulation studies. CM encompasses the planning process of how a simulation model should be developed and how it relates back to the real system. The intended link is established by matching the elements of the LPS with simulation CM to develop an integrated LPS/CM framework. A case study of a stadium expansion project, in which the LPS was fully implemented, is presented to illustrate the applicability of the integrated framework.

KEYWORDS

Lean construction, last planner system, collaboration, simulation, conceptual modelling, first-run studies.

[1] Ph.D. Candidate, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand (Corresponding author), +64 9 373 7999, E-mail: mabd556@aucklanduni.ac.nz

[2] Senior Lecturer, Department of Civil and Environmental Engineering, The University of Auckland, Auckland 1142, New Zealand, +64 9 923 4106, E-mail: v.gonzalez@auckland.ac.nz

[3] Senior Lecturer, Department of Engineering Science, The University of Auckland, Auckland, New Zealand, +64 9 923 7907, E-mail: michael.osullivan@auckland.ac.nz

[4] Associate Professor, Department of Engineering Science, The University of Auckland, Auckland, New Zealand, +64 9 923 7009, E-mail: cameron.walker@auckland.ac.nz

[5] Lecturer, Department of Built Environment Engineering, Auckland University of Technology, Auckland 1142, New Zealand, +64 921 9999, E-mail: mani.poshdar@aut.ac.nz

[6] Professor, Department of Construction Engineering and Management, Pontificia Universidad Catolica de Chile, Santiago, Chile. E-mail: lalarcon@ing.puc.cl

INTRODUCTION

Computer simulation modelling has proven to be a potent decision-support tool for construction project management (Martinez 2010). Extensive research has been ongoing to utilise simulation modelling to solve complex construction management problems for more than four decades. However, there is a consensus in the construction research community that simulation modelling suffers from a lack of large-scale adoption within the industry (Leite et al. 2016). Among the reasons identified are the need to invest considerable time and effort to develop simulation models and the lack of technical simulation training among construction practitioners (Leite et al. 2016). Based on the observation by Bernold (1987), introducing new technologies to the construction industry requires integrating the technologies with the traditional methods of construction. Therefore, this study is motivated by the effort to address the gap of lack of simulation adoption in the construction industry through the integration of computer simulation with current practices of construction management.

CM incorporates the planning phase of simulation studies as it provides a software-independent description of the simulation model (Robinson 2014). Van der Zee (2012) concluded that aligning CM with engineering management environment can help in integrating simulation modelling into engineering practices. Thus, CM can be integrated with construction planning to initiate a link between simulation and construction. The LPS was selected for the integration as it is a well-established construction planning methodology which has gained popularity within the industry due to its ability to stabilise construction production and to increase plan reliability (González et al. 2008). The LPS and CM share commonalities in several fundamental aspects that motivated the integration. First, the granularity of information in both methods follows a hierarchical way to breakdown the plan from a high-level abstract representation of the project to a detailed operation design. Second, the fact that the LPS implementation structure is composed of a number of steps at different planning levels makes the integration to CM a feasible avenue of development for the LPS in the construction simulation domain, representing another opportunity for improving production planning and control in construction projects. Third, the LPS and CM include collaborative activities that encourage the engagement of stakeholders to promote transparency and trust building (Hamzeh et al. 2015; Van der Zee 2012). Another motivation for the integration is the proven benefits of CM in stimulating creativity (Kotiadis et al. 2014), which matches the group creativity techniques required to implement several activities in the LPS (Daniel 2017).

The implementation of the LPS requires a detailed design of operations (Ballard et al. 2007). First-run studies (FRS), sometimes referred to as prototyping (Daniel 2017), is suggested as an approach to support operations design by providing a better understanding of the construction process before the real implementation on site (Daniel 2017). FRS must be executed in as realistic a way as possible to test operations, learn how to perform them best, identify requirements, understand their interactions with other processes, and capture best practices (Ballard et al. 2007). FRS is performed physically or virtually, and they usually take place during the lookahead planning stage (Hamzeh et al. 2015). Based on the description of FRS, it is clear that there is an excellent opportunity to exploit the advanced capabilities of computer simulation to assist in virtually conducting FRS. However, there is a scarce of research on the use of computer simulation to conduct virtual FRS. In general, FRS received minimal interest in LPS-related research (Daniel et al. 2015). Therefore, this paper proposes the use of an integrated framework to assist in building simulation models, to support conducting virtual FRS during the LPS implementation.

LITERATURE REVIEW

THE USE OF SIMULATION MODELLING IN LEAN CONSTRUCTION RESEARCH

Simulation modelling has been heavily employed by the lean construction community to evaluate the effectiveness of lean construction measures in improving project performance. It has been proven that simulation modelling offers an excellent tool to virtually implement lean construction principles, quantify their impact, and demonstrate their applications (Al-Sudairi et al. 1999; Farrar et al. 2004; Mao and Zhang 2008). Moreover, several studies provided good examples of using Discrete Event Simulation (DES) in lean-based production system design methods (Halpin and Kueckmann 2002; Schramm et al. 2008; Tommelein 1998). These studies provided DES models to test the effect of different production system design choices on project performance indicators such as buffer size, project duration, and productivity measures. However, the scope of these studies did not include a methodology to integrate the practices of lean-based production system design methods and simulation modelling.

THE USE OF SIMULATION MODELLING IN THE LPS

Several studies used simulation modelling to demonstrate the concepts of the LPS and to improve its processes. For instance, Hamzeh et al. (2015) applied DES to study the effect of improving the ability of construction teams to properly anticipate tasks during the lookahead planning phase of the LPS on the overall project duration. Faloughi et al. (2014) used DES to test a prototype for a visual information software platform (SimpLean), which aims at enabling construction companies to implement the basic elements of the LPS. Moreover, System Dynamics (SD) was employed by Mota et al. (2010) to help understand the behaviour of the LPS performance indicators by testing the effect of variability and delays on project performance. In conclusion, simulation modelling has been mostly utilised in the LPS literature as a support tool to test research hypotheses and to improve understanding of the LPS.

Xie (2011) asserted that an interesting relationship can be identified between the LPS and simulation modelling. However, his observation was only limited to short term planning and project control aspects of the LPS by matching the elements of weekly work plans with DES models. González et al. (2013) introduced a simulation-based methodology to design and manage buffer in construction projects at three planning levels (which are very similar to the LPS planning levels): strategic, tactical, and operational. Even though the study provided an excellent example on the integration of construction planning with simulation modelling, the objective of the proposed framework was limited to designing and managing buffer in repetitive construction projects without explicitly linking the planning activities with the practices of simulation modelling.

RESEARCH METHOD

Due to the practical nature of the implementation of the LPS, case study approach has been the prominent research method in LPS-related literature (Daniel et al. 2015). However, the use of proactive research methods such as design science research has been favoured in lean construction research (Daniel et al. 2015; Koskela 2008). Design science research can be defined as a research method in which a researcher addresses a specific problem by creating an innovative artefact, which contributes new knowledge to the body of research (Koskela 2008). It employs a stepwise approach to build an artefact then assess its contribution and utility (Koskela 2008). Therefore, this paper follows the steps of the design science research method as defined by Kasanen et al. (1993) (see Figure 1).

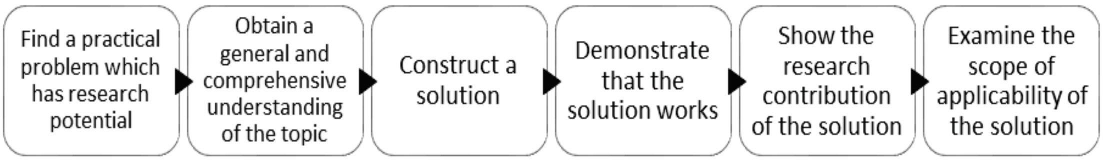


Figure 40: Design science research (Kasanen et al. 1993)

The first and second steps of the design science research method have been accomplished in the introduction and literature review sections of this paper. An integrated framework is developed to embody the innovative solution in the third step of the design science research method. A case study of a construction project, in which the LPS was fully implemented, is conducted to demonstrate the utility of the solution based on the fourth step of the research method. The conclusion of this paper explains the research contribution and future research directions to examine the scope of applicability of the integrated framework.

THE INTEGRATED LPS/CM FRAMEWORK

In order to initiate a link between the LPS and computer simulation, integration of the data/information and the processes of the LPS and CM was completed based on the recommendations of Van der Zee (2012) for systems integration. In order to perform the integration, the LPS was analysed to identify its detailed processes and information generated during implementation. The description of the LPS in Ballard et al. (2007) and Hamzeh et al. (2015) was utilised to aid the analysis. On the other hand, the CM framework for construction simulation proposed by Abdelmegid et al. (2017) was used to guide the integration. This framework is based on other CM frameworks in the operations research literature with several alterations to suit the unique nature of construction systems. The left side of Figure 2 shows the LPS stages and the generated information through different stages, while the right side illustrates the processes and flow of information for the CM framework. Visualising the LPS and CM side by side helped in revealing the link between them by identifying the similarities in processes and information. As depicted in Figure 41Figure 2, the CM framework pulls all the required information from different stages in the LPS to build the model. Then, solutions are fed back to the LPS through the implemented computer model. However, in some cases, solutions for the problems in hand can spark during the CM process thus diminishing the need to proceed with the full computer modelling study (Robinson 2014).

It is important to point out that the directions of the arrows in the CM framework are to show the sequence of the steps. However, with the advancement of the processes of CM, improved understanding of the system can be obtained which may require adjustments to the deliverables of previous steps (Robinson 2014). Additionally, the implementation of the LPS may vary depending on the size and type of construction projects (Ballard et al. 2007). Therefore, the application of the proposed framework should be flexible to adapt to any variation from the original design.

CASE STUDY

The integrated LPS/CM framework has been applied in a case study of a construction project to expand and renovate a multi-use public stadium in Chile. The project duration is 382 days and is estimated to cost USD 11,350,000. It consists of several multi-storey buildings for seating terraces, shops, warehouses, gates, ticket offices and public bathrooms in addition to an expansion of the surrounding landscaping and parking areas. The LPS was fully implemented to plan and control the project with detailed documentation of each level. The project included several construction activities such as demolition, earthwork, reinforced concrete construction, steel structure erection, and finishing. The scope of the case study was limited to the reinforced concrete operations for building foundations, columns, and walls. The following is a discussion of the steps of the integrated framework accompanied by examples from the conceptual model that was developed for the case study.

SIMULATION STUDY INITIATION

As a formal start to the simulation study, a proposal should be developed to include a description of the simulation team, a preliminary timeline, data requirements, and the involvement effort required from the construction company. This step aims at managing clients' expectations by justifying the feasibility of the simulation study. The master plan of the LPS can assist the modeller to initiate the simulation study by providing stakeholders' information, project constraints, and timeline.

PROBLEM FORMULATION

The first deliverable of this step is a formal representation of the problem under consideration. Additionally, the modeller might need to make some assumptions due to the lack of information at this stage. These assumptions should be updated during the life cycle of the study to incorporate new information at each step.

By analysing the problems listed in the LPS documentations of the case study, it was found that delays in reinforced concrete operations were repeatedly reported due to the lack of labour and materials, poor coordination between resources, and bad weather. Moreover, reinforced concrete activities were scattered between 11 site locations. Therefore, the main problem identified for this case study was the need for effective coordination and optimised allocation of resources to avoid delays and disruptions.

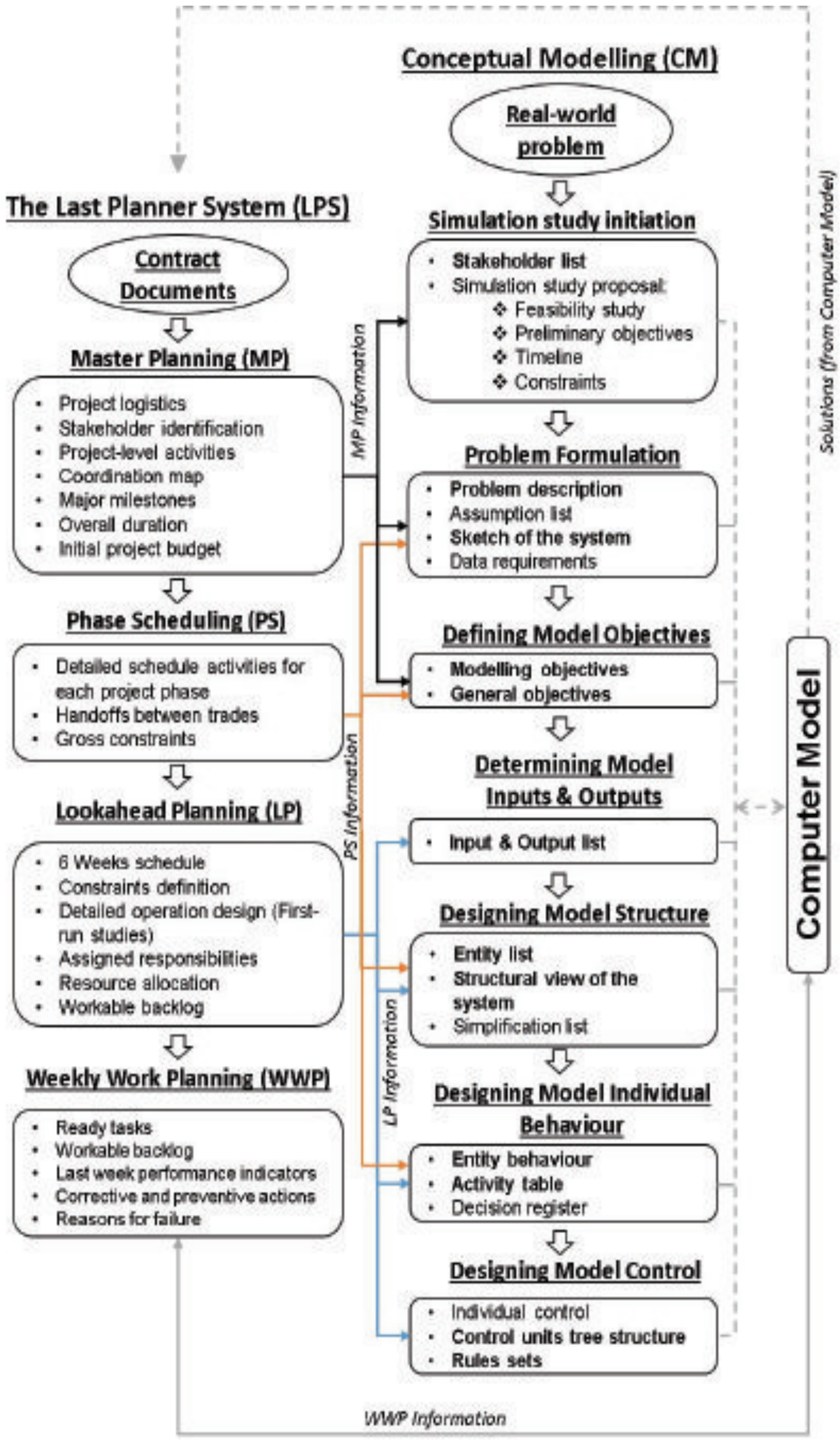


Figure 41: The integrated LPS/CM framework

DEFINING MODEL OBJECTIVES

The integrated framework defines objectives in two categories: general objectives and modelling objectives (Robinson 2014). The modeller can use the information in the master plan of the LPS to define general objectives such as timeline and model flexibility. The definition of modelling objectives extends the problem formulation from the last step. These objectives can be defined collaboratively during the phase scheduling stage of the LPS. Table 1 summarises all the modelling and general objectives of the case study.

Table 18: Model objectives

General Objectives	
Study duration	Two months
Visualisation	A simple site layout that shows site sectors and flow of materials and crews
Flexibility and Reusability	The model should be flexible to allow for the addition of live information during weekly work planning
Modelling objectives	
Calculate total execution time of reinforced concrete operations for different sets of scenarios	
Calculate productivity and idle time of reinforced concrete crews	

DETERMINING MODEL INPUTS AND OUTPUTS

This step requires a deep understanding of the system. In the LPS context, a detailed operation design takes place during the lookahead planning. Therefore, determining model inputs and outputs is best integrated with the lookahead planning stage.

In the case study, the inputs were set to be the sequence of sectors for concrete operations and the number of crews for each reinforced concrete trade. The outputs were set to be the total time for each scenario to find the most effective job sequence and the productivity and idle times for construction crews to assess the design of operations.

DESIGNING MODEL STRUCTURE

At this step, model entities and their relationships are identified. In the integrated framework, the modeller can utilise the information available in the resource allocation in the LPS to identify the entities and their relationships. Table 2 lists the entities of the case study. Figure 3 depicts the structural view of the case study. Crews and materials are the active entities that flow through the system. Site sectors, labour area, and storage area are passive localised entities.

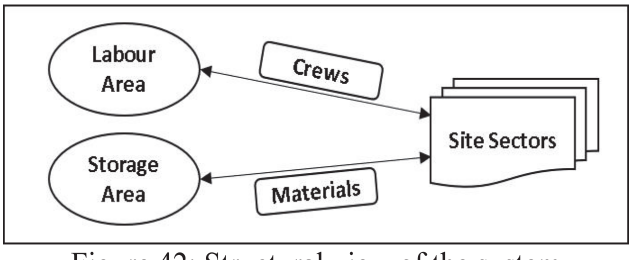


Figure 42: Structural view of the system

Table 19: Entity list

Entity	Type	Attributes
Crews (Excavation, Rebaring, Formwork, Concrete)	Active	Number, Productivity
Materials (Reinforcement Steel, Formwork, Concrete)	Active	Quantity for each sector, Arrival rate
Site sectors	Passive	Area, Location
Storage area	Passive	Location, Capacity
Labour area	Passive	Location, Capacity

DESIGNING MODEL INDIVIDUAL BEHAVIOUR

At this step, active entities are individually analysed to define their activities. We recommend the use of a Business Process Model and Notation (BPMN) diagrams as they are able to represent the location of each activity, which fits the dynamic nature of construction systems. Figure 4 shows an example of the individual behaviour of the Excavation crew. Another deliverable for this step is a list of all activities recorded in the BPMN. These activities are analysed to define their attributes, participating entities, start and end types, state changes, and control units (which will be described in the next step).

Information to design entities individual behaviour can be extracted from the detailed activity schedule during the phase scheduling, with the aid of system observation if needed. Table 3 lists the activities of the reinforced concrete operations in the case study.

DESIGNING MODEL CONTROL

The last step of the framework is to define the behaviour of the system. This step is performed by analysing the control units in the BPMN diagrams. Two deliverables are produced by this step: (1) A tree structure representing the hierarchy of control units (Figure 5), and (2) Logical flow diagrams to represent governing rules of control units (Figure 6). Responsibilities and handoffs between trades, which are determined during the lookahead window of the LPS, can be used to identify control units and assign their responsibilities. Additionally, information can be extracted from the operation design in the LPS to develop logical flow diagrams for the conceptual model.

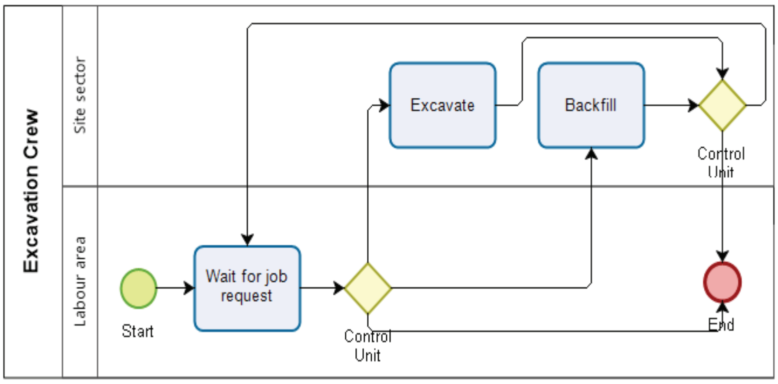


Figure 43: Individual behaviour of Excavation crew

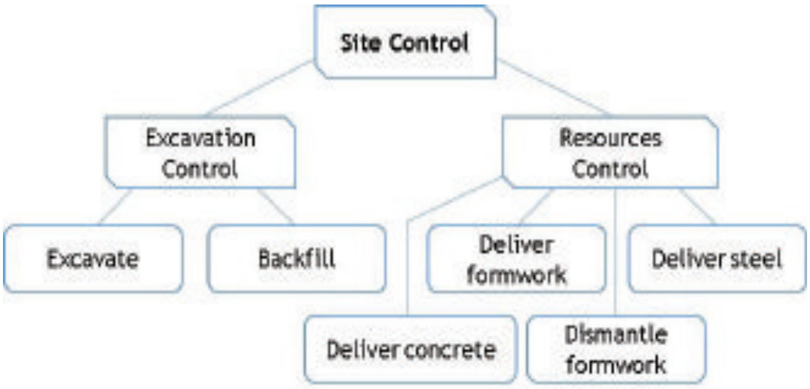


Figure 44: Control units of the case study

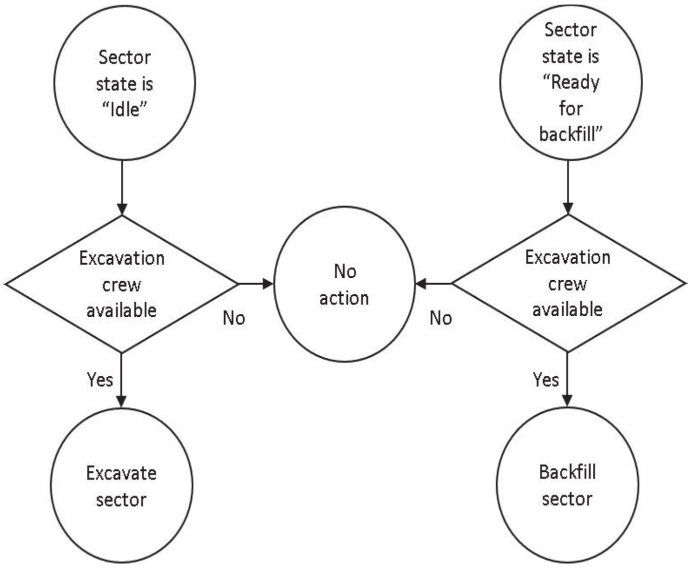


Figure 45: Control policies for the excavation control unit

SUMMARY OF THE CASE STUDY

It can be concluded that most of the information needed to build a conceptual model was available in the documentation of the LPS. As illustrated in Figure 2, the master plan was most useful for the first three steps of the CM framework. The phase schedule and lookahead plan provided technical information for the later advanced CM steps. Moreover, it was found that information in the weekly work plans was not useful for the conceptual model as such information is focused on monitoring project performance. However, weekly plans can provide information to update and validate the computer model based on live data from the site. Moreover, the design of the model may be altered, depending on the nature of operations in the weekly plans, to allow for more flexibility especially in repetitive environments (i.e. work as a template for the construction operation).

CONCLUSION

This paper examines the applicability of an integrated framework to link the LPS and simulation modelling by a real-life case study. The integrated framework utilises the synergy between the LPS and a simulation CM framework. It exploits the information available in the LPS to develop a simulation conceptual model. Daniel et al. (2015) asserted that the LPS has been evolving through its integration with other systems. Therefore, this paper contributes to LPS research by providing an integrated framework that can improve the LPS performance and adherence by assisting in building virtual decision-support tools through simulation modelling. Moreover, the framework aims at avoiding effort duplication by utilising available information to build the model rather than building it from scratch. Therefore, it contributes to the body of knowledge in construction simulation research by providing a means to enable rapid building of simulation models.

This study has potential limitations. The integrated framework was applied retrospectively on the case study, and the resulted model was not used in the real project. Future work should investigate the ability to utilise the integrated framework to conduct a complete simulation study side by side while the LPS is being implemented.

Table 20: Activity list of the case study

No.	Activity	Entities	Start Type	End Type	Control Unit
1	Excavate sector	Excavation crew Site sectors	Requested	Scheduled	Excavation control
2	Deliver formwork to sector	Storage area Site sectors	Requested	Scheduled	Resources control
3	Formwork erection	Formwork crew Site sectors	Sequential	Scheduled	*N.A.*
4	Deliver steel to sector	Storage area Site sectors	Requested	Scheduled	Resources control
5	Rebaring	Rebaring crew Site sectors	Sequential	Scheduled	*N.A.*
6	Deliver concrete to sector	Storage area Site sectors	Requested	Scheduled	Resources control
7	Concrete pour	Concrete, Formwork & Rebaring crew Site sectors	Sequential	Scheduled	*N.A.*
8	Dismantle formwork	Concrete crew Site sectors	Requested	Scheduled	Resources control
9	Send formwork back to storage	Storage area Site sectors	Sequential	Scheduled	*N.A.*
10	Backfill sector	Excavation crew Site sectors	Requested	Scheduled	Excavation control

REFERENCES

Abdelmegid, M. A., Gonzalez, V. A., O'Sullivan, M., Walker, C. G., Poshdar, M., and Naraghi, A. M. "Towards A Conceptual Modeling Framework for Construction Simulation." *Proc., 2017 Winter Simulations Conference (WSC)* 2372-2383.

Al-Sudairi, A. A., Diekmann, J. E., Songer, A. D., and Brown, H. M. (1999). "Simulation of construction processes: Traditional practices versus lean principles." *USA: University of California*, 39-50.

Ballard, G., Hamzeh, F., and Tommelein, I. (2007). *The Last Planner Production Workbook-Improving Reliability in Planning and Workflow*.

Bernold, L. E. (1987). "Automation and robotics in construction: a challenge and a chance for an industry in transition." *International Journal of Project Management*, 5(3), 155-160.

Daniel, E. I. (2017). "Exploratory study into the use of Last Planner® System and collaborative planning for construction process improvement." Nottingham Trent University.

Daniel, E. I., Pasquire, C., and Dickens, G. (2015). "Exploring the implementation of the Last Planner® System through IGLC community: twenty one years of experience."

Faloughi, M., Bechara, W., Chamoun, J., and Hamzeh, F. "Simplean: An effective tool for optimizing construction workflow." *Proc., 22nd Annual Conference of the International Group for Lean Construction*, 281-292.

Farrar, J. M., AbouRizk, S. M., and Mao, X. (2004). "Generic implementation of lean concepts in simulation models." *Lean Construction Journal*, 1(1), 1-23.

Furian, N., O'Sullivan, M., Walker, C., Vössner, S., and Neubacher, D. (2015). "A conceptual modeling framework for discrete event simulation using hierarchical control structures." *Simulation Modelling Practice and Theory*, 56, 82-96.

González, V., Alarcón, L. F., and Mundaca, F. (2008). "Investigating the relationship between planning reliability and project performance." *Production Planning and Control*, 19(5), 461-474.

González, V., Alarcón, L. F., and Yiu, T. W. J. J. o. t. O. R. S. (2013). "Integrated methodology to design and manage work-in-process buffers in repetitive building projects." 64(8), 1182-1193.

Halpin, D. W., and Kueckmann, M. "Lean construction and simulation." *Proc., Winter Simulation Conference Proceedings*, 1697-1703.

Hamzeh, F. R., Saab, I., Tommelein, I. D., and Ballard, G. (2015). "Understanding the role of "tasks anticipated" in lookahead planning through simulation." *Automation in Construction*, 49, Part A, 18-26.

Kasanen, E., Lukka, K., and Siitonen, A. (1993). "The constructive approach in management accounting research." *Journal of management accounting research*, 5(1), 243-264.

Koskela, L. (2008). "Which kind of science is construction management?" *16th Annual Conference of the International Group for Lean Construction*, The University of Salford, Manchester, UK, 51-60.

Kotiadis, K., Tako, A. A., and Vasilakis, C. (2014). "A participative and facilitative conceptual modelling framework for discrete event simulation studies in healthcare." *Journal of the Operational Research Society*, 65(2), 197-213.

Leite, F., Cho, Y., Behzadan, A., Lee, S., Choe, S., Fang, Y., Akhavian, R., and Hwang, S. (2016). "Visualization, Information Modeling, and Simulation: Grand Challenges in the Construction Industry." *Journal of Computing in Civil Engineering*, 30(6), 04016035.

Mao, X., and Zhang, X. (2008). "Construction process reengineering by integrating lean principles and computer simulation techniques." *Journal of Construction Engineering and Management*, 134(5), 371-381.

Martinez, J. C. (2010). "Methodology for Conducting Discrete-Event Simulation Studies in Construction Engineering and Management." *Journal of Construction Engineering and Management*, 136(1), 3-16.

Mota, B. P., Viana, D. D., and Isatto, E. L. "Simulating the last planner with systems dynamic." *Proc., 18th Annual Conference of International Group for Lean Construction (IGLC-18), Haifa, Israel*.

Robinson, S. (2014). *Simulation : the practice of model development and use*, Houndmills, Basingstoke, Hampshire ; New York, NY : Palgrave Macmillan. 2014.

Schramm, F., L. Silveira, G., Paez, H., Mesa, H., Formoso, C., and Echeverry, D. (2008). *Using discrete-event simulation for the support of decision-makers in production system design and operation*.

Tommelein, I. D. (1998). "Pull-driven scheduling for pipe-spool installation: Simulation of lean construction technique." *Journal of Construction Engineering and Management*, 124(4), 279-288.

Van der Zee, D. J. "An integrated conceptual modeling framework for simulation - Linking simulation modeling to the systems engineering process." *Proc., Simulation Conference (WSC), Proceedings of the 2012 Winter*, 1-12.

Xie, H. (2011). "Improving Dynamic Project Control in Tunnel Construction." NR89561 Ph.D., University of Alberta (Canada), Ann Arbor.

Oprach, S., Steuer, D., Krichbaum, V., and Haghsheno, S. (2019).''Smart Data – Dealing with Task Complexity in Construction Scheduling'' In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland. pp. 347 - 358. DOI:* https://doi.org/10.24928/2019/0155. Available at: <www.iglc.net

SMART DATA - DEALING WITH TASK COMPLEXITY IN CONSTRUCTION SCHEDULING

Svenja Oprach[1], Dominik Steuer[2], Viktoria Krichbaum[3] and Shervin Haghsheno[4]

ABSTRACT

Due to the numerous influencing factors, construction scheduling is a complex task. As construction projects are having a unique character, scheduling takes time and often uses high time buffers to cover uncertainties. Using historic project data with artificial intelligence applications show potentials to supportvalid and simple scheduling in the future. The construction industry already deals with large volumes of heterogeneous data and the amount of data is expected to increase exponentially with the Internet of Things (IoT). Smart data filters and analyses big data for useful information and creates a subset of information that is important and valuable. Therefore smart data sets a data management structure according to the lean principles.

Due to fragmented data management practices and a misunderstanding of the needed informationen in construction, data management practices in construction projects are far behind other industries. By adapting existing applications of artificial intelligence to construction scheduling, the gap of data management practices gets more visible. This paper identifies in three case studies relevant data (smart data) in and current challenges for construction scheduling based on historic data. Further research is needed to close the existing gap in construction data management.

KEYWORDS

Knowledge management, Smart Data, construction planning, digitalization, data analytics

INTRODUCTION

Defining the duration of a construction task is a complex activity. Factors such as the location, the size of the area, the experience or the motivation of the construction worker play an important role. Due to the unique characteristics of a construction project, time buffers are often added and the complexity in creating a valid schedule is very high. Good knowledge management practices are needed to reduce the existing complexity. Statistically more than nine out of ten companies rate knowledge management as very

[1] Research fellow, Karlsruhe Institute of Technology, Germany, +49-721-608-43650, svenja.oprach@kit.edu

[2] Research fellow, Karlsruhe Institute of Technology, Germany, +49-721-608-44122, dominik.steuer@kit.edu

[3] M. Sc. Student, Karlsruhe Institute of Technology, Germany, +49-721-608-43650, svenja.oprach@kit.edu

[4] Professor, Karlsruhe Institute of Technology, Germany, +49-721-608-42646, shervin.haghsheno@kit.edu

important according to a survey by the Fraunhofer Institute (Siegberg et al. 2006, p. 32). Knowledge can be reused repeatedly without losing value, in some cases even gaining worth with the amount of data. Studies have shown that the application of knowledge management correlates positively with revenue growth, market share, profit, innovativeness, competitiveness as well as the employee motivation (Pawlowsky et al. 2011, p. 22 f.).

Construction data as the generated knowledge of each construction company is typically voluminous, heterogeneous, and dynamic (Aouad et al. 1999). This data can occur in forms of correspondence, schedules, contracts or pictures. It is often rarely structured (Bouchlaghem 2004, Manyika et al. 2011). Fully analysing this unstructured and big data for valuable information in construction scheduling makes the task even more complex. According to general data management studies so far just about 1% of all information is used for further analysis (Burn-Murdoch 2012) and approximately 80% of time is used to clean noisy datasets before embarking on analytics (Bilal et al. 2016, p. 518). Although chances in data management are high for construction industry; the way construction projects are organized has not changed much (Streule et al. 2016, p. 269). On the one hand, after a project, knowledge often continues to exist in the minds of certain employees and is not systematically available to all participants. On the other hand, the amount of collected data increases with the technological development in the construction industry. The data in construction is expected to increase as exponentially as technologies such as embedded devices, project management software, data from Building Information Modelling (BIM) and the Internet of Things (IoT) are commoditised (Bilal et al. 2016, p.500-501). Out of this big data, focus on relevant and valuable data (smart data) regarding construction scheduling needs to be taken. To handle data in general, in the 1950s researchers first used the term *intelligence* as part of artificial intelligence. In the 1990s the term *Business Intelligence* (BI), in the late 2000s *Business Analytics* as part of BI and afterwards *Big Data Analytics* (BDA) became popular (Davenport 2006). The systematic evaluation of certain data in construction projects can generate advantages for simple, valid and data-driven scheduling. This provides transparency and an interchange between different professional skills involved in a construction project. Construction planning based on an accurate foundation is a key to deliver a project on schedule and within budget (Chan 1996). If scheduling is based on realistic and already proven durations, trades do not have unnecessary capital commitment costs for their employees and machines due to the elimination of unnecessary buffers. Also time pressure upon employees with results in demotivation, security issues and a loss of quality can be prevented (Rogel, p.232). With these benefits in data management, it is worth investing time to aggregate and disseminate experiences in the form of documented data. This is the only way to link various construction projects. Such a connection gets more important as construction projects are becoming noticeably more complex, competition is getting tougher (Issa 2013 p. 699) and redundant information transfer is increasingly important due to the growth of international teams (Hari et al. 2005, p. 533).

Potential structures of databases storing the valueable construction information are already focused on in research (Bouchlaghem et. al 2004). The aim of this paper is to uncover challenges in scheduling construction tasks with historic smart data. The research question therefore is is: What challenges exist in scheduling construction tasks with smart data? By doing this, the above described benefits will be targeted. Three case studies will analyse the complexity of data management and identify possible solutions as a basis for further research.

METHODOLOGY

To uncover challenges in construction scheduling with smart data a three-stage process was done, following the method of value stream mapping (Rother et. al 1999).

First a target design was done in a real-world construction project. Identifiying requiredinformation of process and product features for construction scheduling to establis a Smart Data database. For this database further data out of IoT application were analysed. This derives in a visionary state.

Secondly, the current state of data management practices with the identified information features were analysed in detail. Three case studies demonstrate origings of failure with machine learning in construction. The cases studies orient on the needed data and essential data for construction scheduling: tasks, the duration per task orienting on the location. The three case studies reveal the task complexity existing in construction. To define the term "task complexity" in construction a literature research was done as first part of the second step.

Third and final, to overcome the task complexity possible solutions were identified in a discussion part to each of the three case studies. These solutions need to be analysed in further research project.

VISIONARY STATE: DEFINING SMART DATA

CASE STUDY 1: SMART DATA FOR CONSTRUCTION SCHEDULING

Smart data is a specification of big data. Big data generally has four attributes, also called big four V's of Big Data: Volume (terabytes, petabytes of data and beyond), variety (heterogeneous formats like text, sensors, audio, video, graphs and more), velocity (continuous streams of the data), and veracity or verification (quality, accuracy, truthfullness of the data documentation) (Beulke 2011). With the lean lenses it is important to review the value of the available data from the beginning, to reduce and eliminate waste in data documentation and usage. Smart data is like a filter on big data for needed and useful information. It creates a subset of information out of the available data that is important for companies and researchers (Triguero 2016, p.859). Smart data can be seen as the fifth ‚V' with its value generation.

Smart data for construction scheduling can be seen as the aggregation of relevant product and process information. This includes documenting numerous project related product features (e.g. geographical location, required quality, contract model, building regulations, environmental construction constraints, functionalities within the construction project) and breaking down the process into single tasks with its work sections and their durations (process features). The tasks of the process are the fundamental structure. They are influenced by the product features and determine the sublayer of the overall construction process. By defining the detailed features of each construction work section, the resulting information stacks of different construction projects can be compared with each other and transferred to new construction projects (Siami-Irdemoosa et al. 2015, p. 88; Makarfi Ibrahim et al. 2009, S. 389). Smart data in construction scheduling is an information stack covering both process and product features. Figure 1 shows a real-world construction project. The project was a 30,000 sqm demolition of an industrial building from the 1960s in the UK. Here, a high-quality project database was established, documenting in short-cycle intervals process as well as product features. Defined process features were the work packages in sequence, with their duration, needed resources and a link to the product features. Product features are further information to the component, such as geometry, size, weight or location.

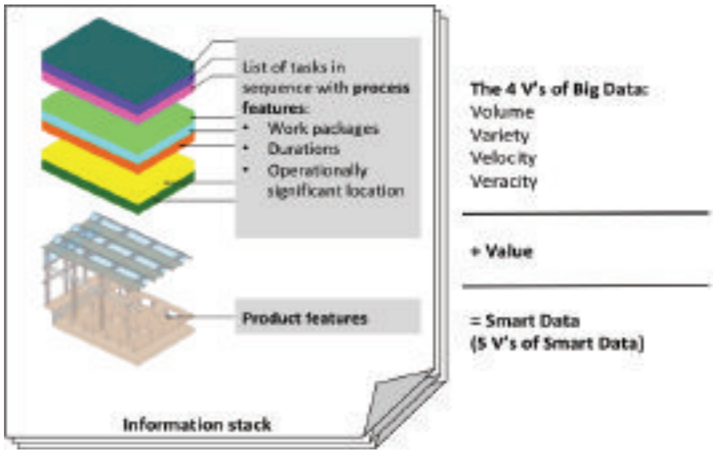


Figure 1: Smart Data information stack for scheduling in construction

Further on, by adding e.g. following data sets to the information stack the 5 V's of Smart data are increased by sensor data and picture of trades, machines and equipment, open data pools like building regulations and local standards and available information in the internet like environmental construction constraints

Birrel stated in 1980: '... the fact that any construction process is made up of a finite set of tasks from an existing feasible set of tasks came out by the construction industry'. Hence, tasks in general are comparable but the complexity of the process features has a direct influence on the volume, variety, velocity, veracity and value of the construction data. Analysing the complexity of the process features is therefore relevant in reducing existing barriers in data management.

CURRENT STATE: TASK COMPLEXITY

THEORETICAL BACKGROUND

Construction projects are often planned under uncertainty. Uncertainty is defined as 'the difference between the amount of information required performing a particular task and amount of information already possessed by the organization' (Galbraith 1973 p. 5). Missing information creates uncertainty. This uncertainty derives from the complexity of construction tasks. The task complexity in construction can be further defined according to Norvig (p. 69-72):

Fully observable or partially observable tasks: A fully observable environment means that data is recorded at any time by Internet, sensors or knowledge management methods. However, construction projects often contain gaps in their documentation due to the high number of influencing factors and non-recordable manual processes. As a result explicit knowledge is only documented incompletely. Also, the 2004 NIST report (Gallaher et al. 2004, p. 2-7) identifies most stakeholders reticent to convert to electronic systems. Implicit or personal knowledge is very high in construction. This kind of knowledge is difficult to articulate and is based on experience, intuition, feelings and subjective views. A complete documentation about the project duration in short cycle intervals about all process steps and their influencing factors is not given at present. However, electronic systems based on IoT strives to a continuous recording of data.

Deterministic or stochastic environment: If the prospective state is clearly triggered by the current state, the environment is called deterministic. Many real situations appear to be stochastic because they are influenced by many input factors. For reasons of simplification, also in construction, a theoretical deterministic situation is solved in a stochastic environment due to the high number of influences.

Episodic or sequential tasks: In episodic environments, current decisions have no direct influence on the following tasks. In contrast, in sequential environments decisions have a direct influence on all further processes and short-term actions can lead to long-term effects. Also a decision in construction planning can have a far-reaching effect in the execution process. Potential challenges and decisions must therefore be documented by a clear structure for follow-up projects.

Static or dynamic tasks: A static environment is one in which the environment does not change during decision-making. Due to the strong fragmentation in construction projects, parallel decisions can be made that influence each other. Therefore, we speak of dynamic task environments in construction projects.

Discreet or constant tasks: Discreetness or continuity refers to the temporal state of perceptions or actions. Construction planning units and construction trades move in a space of constant values.

Known or unknown tasks: Unknowingness refers to the level of knowledge of the involved people and to the rules of their environment. In an unknown environment, the effects of decisions about time must be learned. The rules may or may not be known depending on the knowledge management approach and repetitiveness of the project.

Single agent or multiagent environment: A single agent is someone who can solve a problem in its overall context on his own. Multiagent environments contain multiple agents that make decisions based on each other. In many construction projects, the number of participants quickly exceeds 100. There are typical dependencies between construction planning, execution, owner user groups, the owner's purchase, the facility management, etc. Due to strong fragmentation, construction projects are in a multi-agent relationship. These agents compete or cooperate to some extent.

Due to the partially observable, stochastic, sequential, dynamic, continuous and often unknown tasks, it is complicated to document all the process features within an information stack. This restricts the volume, velocity and variety of the data. The multi-agent relationship, on the other hand, generally limits the veracity of the data. Therefore, it is highly important to define valuable information in the beginning.

Within stationary production, the Methods-Time Measurement (MTM) was developed for the standardised documentation and evaluation of performance factors on basis of the constant framework conditions within stationary production. Here, simple elementary movements were classified out of the contractor's work. Standardized activity durations are also already documented in construction and can be compared with the MTM values. In addition to these classified activity durations, Lowry, Maynard and Stegemerten developed the LMS method (named after the inventors), which determines the worker's performance on the basis of MTM. The MTM values are based on the effort of a medium-well-trained person who is able to perform this work in the long term without work fatigue. Further factors influence the performance of the worker. According to LMS these are dexterity, effort, uniformity of movement and independent influences such as weather, lighting, odours, noises, heat, etc. According to the LMS Performance Rating Table, a maximum range of -60% to +38% of the respective activity duration can be achieved, depending on the design of the factors. For each category there is a subdivision of six to 16 states, which leads to a percentage increase or decrease in the rating. (Karger, p. 31) Eventough, stakeholders are known in the stationary industry and production processes are inside and under same conditions, big variations in time may exist. Still, detail obersverations of work steps are done to analyse influencing factors and eliminate wastes. As conditions in construction are different, new methods are needed in documenting process and product features.

Each of the following case studies will focus on one of the information dimensions described in the visionary state: Tasks with their duration (process feature) and the location (product feature). The first case study is based on a construction project data evaluation. The second and third case studies are based on a broader literature research in comparison to the stationary industry.

CASE STUDY 1: NAMING OF WORK PACKAGES

Projects are structured in a work breakdown structure (WBS) as a list or diagram (DIN 69901-5:2009-01, 3.82) with subprojects, work packages and activities as well as the relationships among themselves (DIN 69901-5:2009-01, 3.79). In the first case study 66 construction time schedules of an industrial fit-out of an internationally active client were analysed and compared.

In table 1, the example of the electrician illustrates the different naming between different projects. In the work package 'First Fix ELT' ('ELT' = electrician) a total of nine different naming's were found, in the work package 'Second Fix ELT' seven naming's for the same work content were found. 'First Fix ELT' often is used for raw installation in the electric trade. 'Second Fix ELT' is the final installation of the electrician. Hence, different projects use a different naming and just human experience can compare and understand with the gained knowledge similarities.

Table 1: Different naming of the work packages of an electrician

First Fix ELT	Second Fix ELT
Electrical installations I	ELT Installations, Light fixture
ELT Cable duct	ELT-Final installation
ELT Assembly/Installation of trays	Lights/Sockets
Wiring	ELT Precision assemblies
Basic installation electro	

The data differs often from project to project in terms of naming and also in the level of detail. Consequently, without any prior knowledge and accurate data construction projects cannot be compared (veracity). Reasons for the different naming are the multi-agent environment and the missing rules for it. Due to international activities with varying project participants, a different language is used for the naming of work packages depending on the project and the experience of the site manager. This results in a multitude of different sequences without including linguistic differences from the respective country.

CASE STUDY 2: ACTIVITY DURATION

The number of different influencing factors on the execution time and the activity durations of each trade lead to further uncertainties. The definition of the activity duration seems to be stochastic and makes a complete manual documentation of the durations from area to area as well as from construction project to construction project difficult.

Table 2: Additional time for individual performance and non-value adding activities (Karger, p. 31; Boenert and Bloemeke 2013)

Individual performance (LMS)		MUDA 1		MUDA 2	
Skills	-22% to +15%	Transports	0% to +19,8%	Disturbances	0% to +3,5%
Effort	-17% to +13%	Ways	0% to 5,6%	Personnel stops	0% to +10,3%
Consistency	-4% to +4%	Searching materials	0% to 1,1%	Absence	0% to +8,9%
Conditions	-7% to +6%	Cleaning & sorting	0% to 5,8%	Others	0% to +14,1%
Sum	-60% to +38%	Sum	0% to 32,3%	Sum	0% to +36,8%

Example of a potential variation of the activity duration
*= Activity duration * (1 + 0,38 LMS + 0,323 MUDA 1 + 0,368 MUDA 2)*
*= activity duration * 2,071*

To the LMS Performance rating table non-value-adding activities need to be added. They can be divided into MUDA type 1 (unavoidable, but reducible work) and MUDA type 2 (eliminable work). In the Lean philosophy ‘MUDA’ is a Japanese word for waste. In construction industry there are seven typical kinds of waste: transportation, inventory, motion, waiting times, over-processing, over-production and defects. According to Boenert and Bloemke (2013), they can be broken down as shown in table 2. If LMS values as well as MUDA 1 and MUDA 2 are added to the individual performance, durations can differ by about twice as much. A calculation of the construction schedule with the expected value can lead to a considerable underestimation of the project. ‘It is well known that replacing random durations with their expected values always results in underestimating the expected duration of the project’ (Elmaghraby 2005, p. 310). Furthermore, the pure activity duration can depend on weight, material, quality, diameter, size or length as well as the available manpower.

However, with complete information, these values are calculable but the large quantity of influencing factors makes a systematic recording complex and therefore stochastic methods must be used. A wrong calculation can have fast effects on the subsequent trades. Here, the partially observable environment and continuous development of the construction project are decisive.

CASE STUDY 3: OPERATIONALLY SIGNIFICANT LOCATIONS

By breaking the construction project in smaller areas, the value of the client can be planned more precisely. As every area with a different functionality (e.g. sanitary areas and office areas) produces different work packages and activity durations, information stacks are different and for further analysis they need to be classified according to their function. There are several planning methods in construction using the space as a main dimension in the time schedule. The location breakdown structure (LBS) is the planning basis (Kenley and Seppänen 2010). The four best known methods are: Line of Balance (LOB), flowline technique, Location-Based Management System (LBMS) and Takt Planning and Takt Control (TPTC).

Nevertheless, general project scheduling software like Microsoft Office Project (Microsoft Corporation), Primavera Project Planner (Oracle Corporation) or PS8 (Sciforma Corporation) are widely used but regarding data analytics not up to date (Demeulemeester and Herroelen 2009, p. 17; Kolisch 2001). These schedules specify start-finish relationships of individual activities and are usually planned over the entire project or larger subproject sections. Although the trades are constantly moving, durations are converted into discrete values to simplify the scheduling. It is not possible to extract single independent areas out of these schedules. Data is therefore only available on the aggregated level within the schedule and the total gross floor area. Here the veracity of an accurate documentation or the volume of space-related data instead of project-related data is missing.

DISCUSSION

Additional analytical methods are needed to get an understanding of the mechanism behind the complex data structures of construction. ‘High value-added products (and services) are characterized by complex production processes and are complex themselves - the credo of simplicity is a manifesto for economic decline’ (Rycroft and Kash, 1999). Construction projects will continue to contain complex relationships. Statistical methods cannot solve the complexity to its full content. Many simple statistical case studies show the high potential in failing as there are more influencing factors involved in project prediction (Magnussen et al. 2006, Potts 2005, Walker 1995, Flyvberg et al. 2002). Hence, Smart data structures as well as advanced data analytics in form of artificial intelligence are needed. Establishing artificial intelligence methods in the building industry has increased significantly in recent years (e.g. Fox et al., 1983; Hendrickson et al., 1987; Chevallier and Russell, 2001; Navinchandra et al., 1988; Dzeng and Tommelein, 1993; Darwiche et al., 1988; Fischer and Aalami, 1996). By using methods such as data mining and machine learning existing data is analysed in order to transfer findings for further projects.

A possible solution is the **naming of work packages.** Choo et al. (1998) propose a standardised working catalogue for construction projects as a solution. The work packages are stored with a code, a standardized description, deposited costs and further relevant information. Within the stationary production a standardized description of work packages is already common practice. The standard worksheets represent a user guide for the employees on site to optimise work processes and train new employees (Traeger 1994, p. 14). The standardised work catalogue in the form of content management systems, groupware systems, or project databases falls into the area of knowledge management of semantic knowledge. As a standardized naming structure can be a solution for a single company, globally work packages will be named differently regarding content and detail level. A possible solution is establishing a semantic wiki to classify and compare the naming of the work packages. With text mining methods, letters of the work package naming are compared in accordance to the semantic wiki and filtered to the clusters. With doing this, further on methods of (sequential) pattern mining can detect unknown rules in sequences. Pattern mining is for example done when analysing a market basket of a customer with the target to predict the next product item or most brought items together. These product items are comparable to construction work packages. As with the FP-Growth algorithm most possible package sequences are at any time detected and proposed to the scheduler and construction workers. AliceTechnologies is an example Software, detecting sequence alternatives and comparing them regarding time and costs.

Another solution is the improvement of **activity duration** data. The first option is to reduce non-value adding activities as reason for high variations by outsourcing these activities to logistic experts. Secondly, with electronic devices and especially using sensor data the volume of data, the velocity and veracity can be increased. Also, robotos and drones can observe and documents the construction progress (see for example Doxel, www.doxel.ai). Lastly, when having high-quality and accurate informations stacks available, influences can be analysed and categorized with applications of machine learning. Available software solutions like NPlan or Lili.ai analyse the information stacks according to their patterns. With decisions trees and random forest documented informations can be clustered. Neuronal networks further on, detect and include information not visible for scheduler.

The third presented solution is the definition of **operationally significant locations**. Besides using the described location-based schedules, also Building Information Modelling (BIM) is a possible exchange platform that supports spatial data documentation. Here, the components with additional information (geometry, weight, location) can be derived during planning stage and linked with the construction schedule. Also construction scanner can scan and identify during construction with applications of image segmentation single components and their location (see Doxel).

In total, increasing data volumes and adding data analytics lead to various implications that need to be taken into account. The filtering, storage and evaluation of Smart Data causes hardware and software costs to be carried by the construction companies. Internet must be available on the construction sites. Finally, the question of data security and ownership needs to be clarified. As with data collection across business units and along partners even more benefits can be analysed (Bilal et. al 2016, p. 518).

CONCLUSIONS

The creation of time schedules in construction projects is currently made under great uncertainties: The documentation of construction projects is often chaotic and the quantity of influencing factors makes the documentation complex. The cause of the uncertainty is the complexity in the construction process features. Construction projects are only partially observable, stochastic, sequential, dynamic, continuous, and rules are often unknown. Although a large amount of data is already collected during the life cycle of a construction project, data losses in terms of volume, velocity and variety exist. The multi-agent environment makes data veracity difficult. A complete and accurate data collection, analysis and use of all this data can bring great advantages for construction projects, such as revenue growth, market share, profit, innovation capability, competitiveness and employee motivation.

Table 3: Challenges and possible solutions in construction scheduling with Smart Data

Challenge	Solution	Solution with Smart Data (Analytics)
1) Work packages	Standardized naming	Clustering with sematic wikis, (Sequential) pattern mining, Data recording with electronic devices
2) Activity duration	Outsourcing of non-value adding work	Data recording with robots and drones, analysing with applications of machine learning
3) Operationally significant location	Using location based schedules	Documentation with Building Information Modelling (BIM)

Table 3 summarizes potentials solutions to overcome the challenges in low data quality in construction industry. Here, smart data focuses on relevant information compared to big data. Therefore, in construction projects, the customer value and the goal of the data evaluation must be clarified. Considering construction scheduling, the work packages, the activity duration and the locations are relevant. Introducing electronic devices with IoT applications and BIM to construction supports the data collection (table 3). Artificial intelligence supports analysing influences and with the support of pattern mining methods the construction sequence can be predicted. By doing this, smart data management can reduce uncertainties in a complex environment and close the gap to other industries in this area.

REFERENCES

Aouad, G., Kagioglou, M., Cooper, R., Hinks, J., Sexton, M. (1999). "Technology management of it in construction: a driver or an enabler?", *Log. Inform. Mgt.* 130–137.

Beulke, D., (2011). "Big Data Impacts Data Management: The 5 Vs of Big Data", (online: Jan 20, 2019).

Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Ajayi, S.O., Akinade, O.O., Owolabi, H.A., Alaka, H.A., Pasha, M. (2016). "Big Data in the construction industry: A review of present status, opportunities, and future trends" *Adv. Eng. Informatics,* 500- 521

Boenert, L., Bloemeke, M. (2003). "Logistikkonzepte im Schlüsselfertigbaz zur Erhöhung der Kostenführerschaft". *Bauingenieur*, Springer VDI Verlag.

Bouchlaghem, D., Kimmance, A.G., Anumba, C.J. (2004) "Integrating product and process information in the construction sector", *Industr. Mgt. & Data Sys.,* 218-233,

Burn-Murdoch, J. (2012). "Study: less than 1% of the world's data is analysed, over 80% is unprotected", (online: Jan 20, 2019).

Chevallier, N.J., Russell, A.D. (2001). "Developing a draft schedule using templates and rules". *Journal of Construction Eng. and Mgt. 127(5),* 391–398.

Choo, H. J., Tommelein, I. D., Ballard, G., Zabelle, T. R. (1998). "Workplan: Database for work package production scheduling". *Proc. IGLC '98*

Davenport, T. H. (2006). "Competing on Analytics" *Harvard Business Review (84:1),* 98-107.

Darwiche, A., Levitt, R., Hayes-Roth, B. (1988). "Generating project plans by reasoning about objects, actions and resources". *AI for Eng. design, analysis and manu.*169–181.

Demeulemeester, E., Herroelen, W. (2009). "Robust Project Scheduling. Foundations and Trends in Technology, Information and Operations Management", *Inc.*, Delft, Boston.

Dzeng, R.J., Tommelein, I.D. (1993). "Using Product Models to Plan Construction". *Proc. 5th Intl. Conf. on Computing in Civil and Building Eng.*, ASCE, 1778–1785.

Elmaghraby, S. E. (2005). "On the fallacy of averages in project risk management". *European Journal of Operational Research, 165*, 307-313.

Fischer, M., Aalami, F. (1996). "Scheduling with Computer-Interpretable Construction Method Models". *Journal of Construction Eng. and Management, 122(4)*, 337–347.

Flyvbjerg, B.; Holm, M.S.; Buhl, S. (2002): Underestimating cost in public works projects: error or lie?, *Journal of the American Planning Association* 68(3) 279–295.

Fox, M.S., Allen, B.P., Smith, S.F., Strohm, G.A., Surnniary, S., Fos, R.S. and Smith, S.F. (1983). "ISIS: a constraint-directed reasoning approach to job shop scheduling".

Galbraith, J. (1973). "Designing complex organizations". Addison-Wesley, Reading, MA.

Gallaher, Michael P., O'Connor, Alan C., Dettbarn, John L., Jr., and Gilday, Linda T. (2004). „Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry". *U.S. Department of Commerce Technology Administration National Institute of Standards and Technology.*

Hendrickson, C., Zozaya-Gorostiza, C., Rehak, D., Baracco-Miller, E. und Lim, P. (1987). "Expert System for Construction Planning". *J. of Comp. in Civil Eng., 1(4)*, 253–269.

Issa, U. H. (2013). "Implementation of lean construction techniques for minimizing the risks effect on project construction time". *Alexandria Eng. Journal, 52(4*), 697–704.

Karger, D. W., Bayha, F. H. (1987). “Engineered Work Measurement: The Principles, Techniques, and Data of Methods-time Measurement Background and Foundations of Work Measurement and Methods-time Measurement”. *Industrial Press*.

Kenley, R., Seppänen, O. (2010). “Location-based management system for construction”. *London: Spon Press*.

Kolisch, R. (1995) “Project Scheduling under Resource Constraints - Efficient Heuristics for Several Problem Classes”. *Physica*, Springer, Heidelberg.

Magnussen, O.M.; Olsson, N.O.E. (2006): Comparative analysis of cost estimates of major public investmentprojects, *Intl. Journal of Project Mgt. 24*, S. 281–288.

Makarfi Ibrahim, Y., Kaka, A., Aouad, G., Kagioglou, M. (2009). “Framework for a generic work breakdown structure for building projects”. *Con. Inno. 9* (4), 388–405.

Manyika, J., Chui, M., Brown, B., Dobbs, R., Roxburgh, C., Hung Byers, A. (2011) “Big Data. The next frontier for innovation, competiotion and productivity” (Jan 20, 2019).

Maynard, H. B., Stegemerten, G.J., Schwab, J. L. (1948). “Methods-time Measurement”. *McGraw-Hill Book Compony*, New York.

Navinchandra, D., Sriram, D. und Logcher, R. D. (1988). “Project Network Generator”. *Journal of Computing in Civil Eng.*, ASCE, Band 2, 239–254.

Norvig, R. (2012). “Künstliche Intelligenz”, *Pearson Verlag*

Potts, K. (2005): “The New Scottish Parliament Building—a critical examination of the lessons to be learned”, *CITC-III Advancing Eng., Mgt. and Tech*., Athens, 534–539.

Rogel, D., Osebold, R. (2013). “Exploring Uncertainity”. *Springer*, 209-244

Rother, Mike, Shook, John: “Learning to See – Value-stream mapping to create value and eliminate muda”. *Lean Enterprise Institute.*

Rycroft, R., Kash, D. (1999). “The Complexity Challenge”. *London: Pinter*.

Siami-Irdemoosa, E., Dindarloo, S. R., Sharifzadeh, M. (2015). “Work breakdown structure (WBS) development for underground construction”. *Auto. in Con. 58*, 85–94.

Traeger, D. H. (1994). “Grundgedanken der lean production.“ *Springer* Wiesbaden.

Triguero, I., Maillo, J., Luengo, J., García, S., Herrera, F. (2016). “From Big Data to Smart Data with the K-Nearest Neighbours Algorithm”. *2016 IEEE Intl.Conf. iThings, IEEE GreenCom and IEEE Cyber, IEEE SmartData*, Chengdu, 859-864.

Walker, D.H.T. (1995): “An investigation into construction time performance”, *Construction Mgt. and Economics 13*, 263–274.

STREAM 6: MOTIVATION AND LEARNING

Richert, T. and McGuffey, J. (2019). “Enthusiasm for Lean” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Christine Pasquire & Farook Hamzeh (eds.)*, Dublin, Ireland, pp. 359–368. DOI: https://doi.org/10.24928/2019/0160. Available at: <www.iglc.net>.

ENTHUSIASM FOR LEAN

Tom Richert[1] and Joanna McGuffey[2]

ABSTRACT

Despite implementing the continuous improvement and respect for people principles as understood from the current research, many lean transformations fail. This paper provides an argument that there is a missing yet important set of elements supporting these principles that needs to be understood.

For many lean leaders and coaches a primary concern is obtaining the full engagement of everyone on a project team in lean practices. This paper recommends a new area for research and experimentation, tapping the holistic aspects of lean, not only as they apply to the enterprise or project, but also as they apply to the individual. It examines new ideas about how enthusiasm for lean can be methodically generated in the building design and construction industry.

Borrowing from her work in business culture change, one of the authors (McGuffey) has developed a ‘legacy transformation model’ that identifies the elements at work in the early years of the Toyota Motor Corporation. The model was tested against prior research to determine if testing the model on building projects in a comprehensive manner is warranted; the results of which are reported herein. Further research requiring the commitment of project teams to pilot a lean transformation process based on the legacy transformation model is proposed.

KEYWORDS

Transformation, commitment, language, purpose, connection, core identity, enthusiasm.

INTRODUCTION

The primary reasons for the intergenerational success of the Toyota Production System (TPS), and therefore lean practices, have been misunderstood. This is a result of the background and biases of the people attracted to the study of TPS. They bring with them a vocabulary based on production processes. When that was found to be incomplete attention was turned toward the design of social systems. While production processes and social system design are important components of the success of TPS, the foundation for this success was based on widespread deeply personal connections to a meaningful purpose.

This gap in understanding came to light during a 2017 workshop the authors led, focused on understanding how artists would interpret what is known as “lean thinking.”

[1] Principal, Lean Project Consulting, Inc., Westford, MA 01886-3031, USA, +1 978 808-4668, trichert@leanproject.com

[2] Founder, Unconventional Works LLC, Dayton, OH 45458-4510, USA, +1 703 586 7901, joanna@unconventional.works

The workshop was held because lean has largely been observed and interpreted by people with an engineering and social science mindset. Since our biases and vocabulary affect how we interpret the world we observe it was theorized, and subsequently demonstrated, that artists have insights into lean and TPS that had heretofore been elusive.

The artists' insights, along with business culture development work, provoked research into the history of Toyota extending back to the Meiji Restoration and the early development of Sakichi Toyoda. This history, set in the context of the rapid social changes transforming the people of Japan, along with research into human performance, led to the observation that four integrated elements are present that cause transformations to be sustained. This observation led one of the authors (McGuffey) to develop a transformation model that establishes a methodology for developing and integrating these four elements. They are as follows:

- Connection: Nurturing of personal relationships with an individual's work team, including the composition of a shared core identity aligned with the team's purpose.
- Cognition: Daily awareness of others and the surrounding world through observational experience practiced along with the mindfulness of knowing how you, as an individual, show up in relationship to purpose.
- Commitment: Engaged dedication and clarity regarding understanding one's core identity, team shared core identity, responsibilities to others on and outside the team, and the challenge the team has undertaken.
- Challenge: A meaningful goal, aligned with purpose, that is not possible given the team's current capabilities and knowledge. This impossibility informs the team's needed growth.

This paper looks at evidence that some or all of these elements have contributed to the implementation of lean practices, reports on how the four elements were present within Toyota prior to the beginnings of TPS, and proposes research to refine the application of the transformation model methodology.

CURRENT KNOWLEDGE

IGLC RESEARCH

Searches of IGLC papers using the terms "engagement," "passion," and "enthusiasm" were undertaken. Nineteen papers were identified using the term "engagement." No papers were identified using the term "passion." Four papers were identified using the word "enthusiasm."

Nine of these twenty-three papers addressed in part the importance of project team engagement or enthusiasm for using lean practices. While no comprehensive application of the 'legacy transformation model' is evidenced, there are references to elements of the model being employed in the work studied by these papers. There were experiences reported from case studies that reinforced the premise that engagement at the individual or personal level is an important consideration. The consideration is also important outside the building design and construction industry, with comments such as "People engagement is the hardest thing to achieve – that to me is clear" by a veterinarian using lean principles in his practice being an example (Tassasón 2018).

Connection: Preceding research indicates a relationship between specific elements of the transformation model and engagement in lean practices. A case study from Scandinavia found that the element of Connection, described as the degree of familiarity and community, and the willingness to take others' perspectives, correlates to the degree of engagement and collaboration in lean work (Skinnarland and Yndesdal 2010). It is difficult to connect with others when we value others based on some classification. An example is the prevalence of gender bias on projects, whether they use lean practices or not. There is evidence that lean projects may be even more susceptible to gender bias (Arroyo et al. 2018). The practice of applying labels and expectations on people because of gender, race, religion or other group distinctions hinders people from connecting with each other. Distinctions between professional affiliations and education are other common areas where bias occurs.

Cognition: A case study of what practices support value generation on a project looked at aligning actions purposefully with project goals. It found that having a means of regularly reviewing how goals were being met and adjusting actions accordingly enables teams to pursue value (Tillman et al. 2013). This regular review, in the context of seeking to understand project conditions as they really are, is a form of cognition.

Commitment: The focus on securing buy in among trade contractors for lean working practices was a focus of a case study in which a number of activities were employed to develop a common understanding of rules and guiding principles for the project (Pasquire and Court 2013). It was found that a common understanding delivered progress toward eliminating waste and safely increasing productivity.

Challenge: Related to the model is the lean principle of "respect for people," which has had little direct research in design and construction and is necessary for sustaining continuous improvement efforts (Korb 2016). This paper specifically mentions the need to engage the eyes, hearts, brains, and hands of the people in an organization – in the context of continuous improvement as a way to challenge the development of individuals in a project organization. Past work acknowledges the need for eyes, go and see; brains, the Toyota Thinking System; and hands, experiments. The inclusion of hearts relates to the importance of Connection and Challenge – seeking to engage the heart as well as the head in a holistic manner.

CURRENT APPROACH TO CHANGE

Much of the literature regarding lean related change discusses the need to induce new behaviors, with the expectation that people can act their way into lean practices. This inducing of behaviors utilizes strategies such as peer pressure (Raghavan et al. 2016). It is argued that a focus on leadership behaviors should take precedence over lean tools (Orr 2005). The inducing of behaviors, whether by reward or punishment, is behavior modification, or behaviorism. This focus on behavior is part of the mainstream in lean practice. A search of the Lean Enterprise Institute website for work related to "behaviors" yields seventy-two articles, sixteen case studies, and twenty-four workshops. Much of this work focuses on behavior change through reward, punishments, or peer pressure.

BEHAVIOR IS A SYMPTOM, NOT A ROOT CAUSE

A focus on behavior however deals with a surface action, and not the root cause of a human action, and a lean practice seeks to understand the root cause of a concern. In terms of human action, root causes are related to a person's conception of their nature. Ideally this nature is a projection of their authentic self, however even small traumas in a human life can cause protective personas to mask the authentic self (Bennett 2017 pp. 24–32).

While the idea of modeling lean behaviors is to demonstrate a more productive way of working, there is a case against using behaviorism. Research finds four significant concerns with behaviorism (Enright 2018).

- Nominalism: Behaviorism implies that we do not have a common nature as humans, and that our capacity for action is limited by experience. Yet as humans we do have common needs, including an innate need for connection, as well as respect, appreciation, and satisfaction.
- Materialism: Behaviorism implies that only a material world exists, and that the spiritual world is not real. Love and friendship for example therefore must be a behavior, and not related to a need informed by our inner conscious.
- No Free Will: If our actions are informed by the behaviors modeled for or forced upon us, then we do not have free will. All our actions result solely from the reinforcements and punishments we experienced
- No Purpose in Life: If there is no free will, then we cannot determine a purpose toward which we decide to strive. The concept of a common purpose cannot exist, as we will have experienced different behavioral stimuli.

Clearly the founders of Toyota and the early developers of the Toyota Production System did not exhibit any of these characteristics. Quite the opposite, in word and action there was a clear understanding of human connection, spiritual connection, self-determinism and commitment to a meaningful purpose. Just as clearly, behaviorism is directly opposed to the *respect for people* principle, which has also be translated as *respect for human nature (ningensei)* (Miller 2018).

Life experiences demonstrate the futility of behaviorism. We recognize that demanding that a child apologize will affect behavior temporarily, and yet if the behavior was to appease the demand and not reflective of any true feelings of remorse we have accomplished very little. Simply changing behavior is insufficient, and does not result in lasting change. If we however can appeal to that child's connection to the aggrieved on a human level and the importance of all such similar connections, then we have an opportunity for the child to apologize appropriately. Importantly this appeal to connection may fail if through continued exposure to a behavior based discipline the child has developed coping strategies that hinder connection to other people (Dweck 2016 pp. 242–243).

ARTISTS' PERSPECTIVE ON LEAN

In 2017 the authors made an assessment that the lack of widespread acceptance of lean practices was related to the way the Toyota Production System (TPS) was being interpreted. The people studying TPS largely have engineering and scientific backgrounds, which have been invaluable from the perspective of understanding process. The authors speculated that these process oriented backgrounds and accompanying vocabulary failed to capture holistically the development of TPS, and in turn lean practices. Lean is after all an interpretation of the Toyota story made largely to fit an understanding of what men with an engineering perspective thought would improve work processes and therefore earn more profit in less time. The Respect for People principle only gained traction after Jeffrey Liker included it in his book The Toyota Way. While many people cite the principal, Toyota turns out to be a rare example of making better humans who help other humans be better workers and better people. Unfortunately, much lean writing focuses on making more productive workers as if they are machines. People with a different perspective on work and life may see what happened at Toyota differently.

To test this assessment the authors organized a three-day workshop wherein a group of seven artists were introduced to lean through conversations with lean experts and a tour of the Toyota manufacturing facility in Georgetown, Kentucky. The lean experts included Robert Martichenko, Deborah McGee, Niklas Modig, Karyn Ross, John Shook, and David Verble. The workshop participants included professional artists from music, literature, theatre, visual arts, and poetry. These seven people provided three insights relevant to the developing enthusiasm for lean (Richert 2018).

The first insight is that lean is a creative ethic. This challenges the idea that lean is the scientific method applied to work. The term scientific method does not refer to an abstract methodology, as the term is a rhetorical device that serves to assure others that facts and reason were the basis for a course of action (Thurs 2015). By understanding that lean generally, and the Plan, Do, Check, Act (PDCA) cycle specifically, are about learning and creativity the artists start to open lean to a wider audience.

The second insight is that the roots of lean stem from spiritual influences. This assertion came during a discussion with John Shook wherein he was explaining the influences informing the development of TPS. While the influences spanned a wide range, from social, technical, scientific, craft and spiritual practices, it was the spiritual that the artists recognized as providing the energy serving as the catalyst for what became TPS. They understood Buddhism, Bushido, and Nichiren as far more impactful than Darwin, Ford, and Taylor.

The third insight is that lean is a practice in search of a language, meaning the language of lean is incomplete. People able to generate enthusiasm for lean appear to have a vocabulary that allows them to fill in the missing parts of this incomplete language. Most people cannot, and therefore do not accept that lean approaches are preferable to practices they already employ.

Taken together, these insights explain why generating a sustained enthusiasm for lean is difficult. Lean is explained to people in a manner that does not capture the holistic nature of its development; therefore, practices that for process minded people appear eminently rational make little sense to most people. It also explains that while people will engage with lean when led by a strong leader committed to lean, once that leader moves elsewhere and is replaced by a different minded leader, the lean practices are easily replaced as well (Liker and Convis 2012).

WHAT HAPPENED AT TOYOTA

Most interpretations of the lean story start with Taiichi Ohno and his work developing TPS. There are passing references to the role Sakichi Toyoda played in developing the concept of autonomation for the mechanical loom, however Sakichi's influence runs far deeper than his technical expertise in mechanical invention. Similarly, there is relatively little mention of Kiichiro, Sakichi's son and founder of the Toyota company, and yet it was Kiichiro that established the practice of standardized work and who foresaw the need for just-in-time part delivery.

As, if not more, important was Kiichiro's documentation of five precepts he attributed to Sakichi. These precepts became not the values, but the spirit of the Toyota Motor Company. The distinction is important. Values define ideal traits a person or organization seeks to portray. Spirit is the essence of who a person or organization is at the core. English translations of the precepts vary. The following are the precepts ("Toyoda Precepts: The base of the Global Vision" 2012).

- Be contributive to the development and welfare of the country by working together, regardless of position, in faithfully fulfilling your duties.
- Always be studious and creative, striving to stay ahead of the times.
- Always be practical and avoid frivolousness.
- Always strive to build a homelike atmosphere at work that is warm and friendly.
- Always have respect for God and remember to be grateful at all times.

Here is what the artists, because of their focus, background, and vocabulary, recognized.

- The key to Toyota's success, the success of the Toyota Production System, and the success of lean when it can be sustained, is that there is a shared spirit of contribution to a greater cause. The work is meaningful, and that meaning is felt at a personal level.

Through researching the history of Toyota, along with the history of Japan including the distinctions between Japan's rural and urban cultures in the late nineteenth and early twentieth centuries, it is apparent that the four elements of the McGuffey transformation model, Connection, Challenge, Commitment, and Cognition are at work.

CONNECTION

The "respect for people" principle of The Toyota Way derives from a longstanding practice of viewing the employees of Toyota as members of an extended family. These familial relationships at Toyota differ than the other Japanese companies, and the distinctions arise from the differences between the rural background of the Toyoda family and the urban nature of other companies. Whereas in many Japanese companies patriarchal structures serve as a way of communicating hierarchical authority in a familiar context, at Toyota the relationships embodied the spirit of the rural community, where people bonded together and looked after each other. This greater connectedness was necessary in farming societies where my neighbor's bad fortune regarding a poor harvest this year may be my bad fortune next year. Supporting each other was a matter of survival (Togo and Wartman 1993 p. 8).

Likewise, the early years at Toyota Motor were a mutual struggle for survival. In the 1930s this struggle was economic, as the company competed against U.S. and domestic automobile makers. In the post World War II period the struggle for survival was literal, as the average Japanese diet consisted of seven hundred calories per day and the Toyota employees farmed the land around the factory for food for their families (Togo and Wartman 1993 pp. 87–94).

Today Toyota Motor continues a focus on relationships through a team approach to manufacturing and design, making funds available for team social activities outside work, daily coaching, and a policy of not laying off workers during slow economies. The aspect of the Toyota Georgetown plant that most surprised the artists during the 2017 workshop was the social nature of a workplace they wrongly presumed to be cold, machine-like and impersonal.

Cognition

The model applies the practice of Cognition to the understanding by an individual of their personal core identity, and how that identity is aligned with the purpose of their work. While the Toyoda family and other leaders of the Toyota Motor Company through the development of TPS may not have been deliberate about understanding this alignment in terms of personal core identity, this is what happened. A review of the personal history of these people reveals that beginning with Sakichi, they persisted in pursuing work consistent with their identity. Sakichi, for example, was expected to work as a farmer and carpenter as his father did. He rejected these expectations to pursue work as an inventor.

Understanding their identities, these early leaders of Toyota connected themselves to a purpose with meaning important to them – the elevation of the Japanese people from feudal medieval lives to lives on par with the wealthier nations of the west. Today Japan is an economically strong nation and Toyota is a global company. Toyota's meaningful focus has shifted toward serving. They impact communities and contribute to a cleaner global environment ("Toyota Global Vision" 2019). Connecting all employees to this meaning is a continuous focus of management.

Commitment

Commitment in terms of the transformation model is a deeper concept than promise making. Commitment requires clarity to self-understanding, purpose, relationships, and to the way people will work together for mutual benefit with purposeful intent. The documenting of the Five Precepts was the first step Toyota Motor took toward creating this kind of clarity. Additional examples are found in their approach toward creating standardized work, A3 problem solving, and Kanban cart communication systems. Visual management, audible signals, and physical layout are very sensory-oriented methods Toyota Motor uses to establish clarity in communications.

CHALLENGE

It was a goal of Sakichi Toyoda that his son, Kiichiro, establish the best automobile company in the world. This was an audacious challenge given that General Motors and Ford Motor Company had already established dominant positions in the global market, and would soon be building cars in Japan. As daunting, while the Toyoda Loom Works company Sakichi has founded supplied the initial funds required to start the automobile venture, the industry was shifting into a capital intensive, mass production mode of operating that conventionally would require additional investment. In the 1930s the Japanese banks and government were not convinced that the automotive industry was one in which a Japanese manufacturer could compete.

Not only did Toyota Motor have this large challenge of becoming the best automotive company in the world; the company structured its approach to this challenge as a series of smaller, yet significant, challenges. Learning how to accomplish just-in-time parts delivery is one example of these smaller challenges. The TPS approach to problem solving, a term coined from a western mind-set, is structured as a series of challenges. Most importantly, the TPS approach seeks to establish shared clarity about the nature of the challenge being addressed.

PROPOSED FOCUS

TRANSFORMATIONAL LEGACY MODEL

While the elements of the McGuffey transformation model, Connection, Challenge, Commitment, and Cognition, are present where successful engagement in lean practices take place there remains no example of where a deliberate application of all four elements of the model have been applied. Even as the Toyota Motor case history employed these elements, the application was developed organically out of a recognition of who these people were and what meaningful challenge they wanted to achieve. Cultural practices of stemming from pre-twentieth century rural Japan reinforced this development.

Based on the research and work with clients, a test of the following program will provide more definitive feedback on the impact of implementing all four elements of the transformation model together. The work should focus on strengthening project teams at the workface and at each leadership level. The specific methodology follows.

- Provide a seminar to principals and senior managers of all the organizations participating on the project.
- Designate a core engagement group of up to twelve people representing a vertical cross section of the project. This includes representatives from the field crews, crew supervisors, engineering and design offices, project management, project executives, and owner representatives. This cross section ideally includes people that are no more than one person removed from every person working on the project.
- Provide training to the core engagement group in the fundamentals of the transformation model, including a daily cognition process each member commits to practicing, cultivating human connections and fulfilling a purpose.

- Assist the core engagement group in developing and disseminating engagement practices through the project through a network of mentor and peer based coaching. This may include training selected team members in the fundamentals of the transformation model.
- Provide the team with monthly assessments to sharpen their use of the model.

The focus of this research program is not on improving the project schedule and financial performance. There is other research that demonstrates successful implantation of lean processes result in superior project performance. What will be tested is the degree to which project participants, regardless of role, felt more enthusiastic about lean practices toward the end of their participation on the project in comparison to when they first started. This will be measured via surveys taken when they start and finish their work on the project. The surveys will also measure the degree to which people assess they have grown professionally and personally.

CONCLUSION

The elements of the McGuffey legacy transformation model, developed outside both manufacturing and the construction industry, are clearly visible throughout the history of the Toyota Motor Corporation. The elements can also be found to contribute to successful construction project teams as demonstrated in a review of published lean construction research. These elements are Connection, Cognition, Commitment and Challenge. While these elements can be linked to successful teams there remains a need to test a deliberate incorporation of all four elements into the daily practice of a project team. Such a test is proposed as the step in researching effective means for cultivating enthusiasm for lean practices on the part of construction project teams.

ACKNOWLEDGMENTS

We are grateful for the support of several people and organizations that helped support the application of this transformation model to lean work, including the Lean Enterprise Institute, the Lean Construction Institute, and Lean Frontiers. The paper was greatly improved through feedback from Rocco Gallo, Sean Graystone, Chris Moran, Pamela Neckar, Sarah Rozman, and Bryan Wahl. We also thank the participants in our transformation workshops this past year – we learned from you as you learned from us.

REFERENCES

Arroyo, P., Schöttle, A., Christensen, R., Alves, T., Bastos Costa, D., Parrish, K., and Tsao, C. (2018). "Impact of Gender Bias on Career Development & Work Engagement in the OAEC Industry & Lean Practice." Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC), Chennai, India.

Bennett, M. S. (2017). Connecting Paradigms: Trauma-Informed & Neurobiological Framework for Motivational Interviewing Implementation. Bennett Innovation Group, L3C, Denver, CO, USA.

Dweck, C. S. (2016). Mindset: The New Psychology of Success. Penguin Random House LLC, New York, NY, USA.

Enright, R. (2018). "Behavior Modification and the Image of Humanity." Psychology Today.

Korb, S. (2016). "'Respect for People' and Lean Construction: Has the Boat Been Missed?" Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA.

Liker, J. K., and Convis, G. L. (2012). The Toyota Way to Lean Leadership: Achieving and Sustaining Excellence Through Leadership Development. McGraw-Hill, New York, NY, USA.

Miller, J. (2018). "Respect for 'Respect for Human Nature.'" Gemba Academy.

Orr, C. (2005). "Lean Leadership in Construction." Proceedings IGLC-13, Sydney, Australia.

Pasquire, C., and Court, P. (2013). "An Exploration of Knowledge and Understanding - The Eighth Flow." Proceedings IGLC-21, Fortaleza, Brazil.

Raghavan, N., Delhi, V. S. K., Mahalingam, A., and Varghese, K. (2016). "Introducing Lean Construction Philosophy in E-P-C Phases of a Large Industrial Project." Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA.

Richert, T. (2018). Lean Conversations: The Energy of the Creative Ethos in Your Life and Work. LeanProject Publishing, Bloomington, MN, USA.

Skinnarland, S., and Yndesdal, S. (2010). "Exploring the Development of Collaboration in Construction Projects: A Case Study." Proceedings IGLC-18, July 2010, Technion, Haifa, Israel.

Tassasón, J. (2018). "The Lean Veterinarian." Planet Lean: The Lean Global Network Journal.

Thurs, D. P. (2015). "The Scientific Method is a Myth." Discover.

Tillman, P., Tzortzopoulos, P., Formoso, C. T., and Ballard, G. (2013). "Contributions of Existing Practices to Pursuing Value in Construction Projects." Proceedings IGLC-21, Fortaleza, Brazil.

Togo, Y., and Wartman, W. (1993). Against All Odds: The Story of the Toyota Motor Corporation and the Family that Created It. St. Martin's Press, New York, NY, USA.

"Toyoda Precepts: The base of the Global Vision." (2012). Toyota Motor Corporation.

"Toyota Global Vision." (2019). Toyota Motor Corporation.

Hunn LK., and Fyhn, H. (2019). "Building and Sustaining a Culture with a Mindset for Disruptive Performance: A Case Study from Bispevika Norway" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 369–382. DOI: https://doi.org/10.24928/2019/0172. Available at: <www.iglc.net>.

BUILDING AND SUSTAINING A CULTURE WITH A MINDSET FOR DISRUPTIVE PERFORMANCE: A CASE-STUDY FROM BISPEVIKA NORWAY

Lars Kristian Hunn[1] and Håkon Fyhn[2]

ABSTRACT

In this case study from the building industry we present a framework for, and experiences with building and sustaining an organizational culture to create teams with a collaborative mindset for disruptive performance driven by extraordinary ambitions. It demonstrates that it is possible to develop a culture and mindset for success by actively combining concepts from social anthropology and team- and performance leadership. This is achieved by developing a cultural mythology; creating rituals for learning, developing, sharing and coordinating mindset; connecting collective and personal goals using personal goal plans; managing mindset using mindset map and digital organization charts.

The study also shows that developing organizational culture cannot only be approached as a method with structured set of rules to follow. It also needs to be acknowledged as form of craft provided by a combination of experienced leadership highly skilled in enterprise- and team development where the motivation to change is fueled by extraordinary ambitions of disruption. Last, the leaders must commit and reinvest in sustaining the culture both in economic and emotional terms. Here transparency is required, and this must be done regularly to maintain a high level of trust among all the members of the organization, so all the people can be active in developing and impacting their own culture – there is no room for bystanders.

KEYWORDS

Mindset, organizational culture, disruptive performance.

INTRODUCTION

This case study from Team Bispevika in Norway is a very large project in Norwegian context. A common view is that the construction industry is suffering from low productivity. The main contractors generate low revenue and construction work generate high costs and less value compared to other industries. (Klakegg et al. 2019). Large projects

[1] Chief Transformation Officer, Team Bispevika AFGroup, Lars Kristian Hunn, +4790104774, lars.kristian.hunn@afgruppen.no

[2] Senior researcher, NTNU Social Research, 7491 Trondheim, +47 81743561, hakon.fyhn@ntnu.no

typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget. Construction productivity has actually declined in some markets since the 1990s. Financial returns for contractors are often relatively low—and volatile. (Agarwal et al. 2016). Today building projects are complex, involving many different expertise and stakeholders. The industry has become more and more fragmented. Every company seems to work towards their own economic goals to secure income for themselves. Increased complexity also hampers productivity due to more difficulties communicating and collaborating efficient between different stakeholders across the value chain. (Bygg 21, 2015).

The construction industry is facing a coming disruption where change within the industry itself increases complexity where the business environment is changing with increasing interdependencies and specialist competence (Klakegg et al 2019, Teece, 2010). This industry is also among the least digitized, where information flow is affected by the fragmentation of the industry (Rashasingham 2019). Yet, this is one of the largest industries with a significant impact on society worldwide.

What can be done in order, not only to change this trend but to transform the industry to reap the value potential in large investment building projects? The authors of this paper argue that answers are to be found, both within and outside the industry. Disruption and change is not only initiated from within a project team, but also spurred by the extraordinary ambitions on the client side; an outside factor impacting the project team from within. In other terms this describes the motivation to change as an external factor.

As this case study in certain terms is not an 'ordinary' construction project – due to size, scale and time – the complexity is higher to than most case studies on traditional construction projects in Norway. However, with time scope of 5 years the authors have a chance to follow the project team over a much longer time span than most projects – making the research not only viable for the construction industry, but for temporary network organizations as such. This makes Team Bispevika a very interesting case in terms of studying the efforts and effects of combing social anthropology and team- and performance leadership to build and sustain a *culture* which can meet the challenges of a contemporary organization under the pressure of meeting extraordinary ambitions of achieving maximum value creation.

The research questions and approach are developed in an on-going creative dialogue with the leaders of the organization in study, and the development of the case itself. The following research question has guided the work: How can one build and sustain a robust culture with a collaborative mindset for extraordinary performance?

This questions is divided into several sub-questions:

1 What kind of leadership, experience and deeper understanding of people and culture is required to achieve this?

2 What kind of investments is necessary to achieve this? (i.e. culture work)

3 How can extraordinary ambitions influence this goal and what kind of motivation for change can the study observe (which conditions make it meaningful to be here).

4 Can these findings lead to a higher understanding of how to create and sustain a performance culture?

5 What are the triggers for the mindset in Bispevika?

METHOD

This paper is based on an action research approach (McNiff and Whitehead 2002) where empirical studies and organizational development go hand in hand; findings of the empirical studies suggest improvement to management, if they are considered to be productive they are implemented and evaluated without further delay. As such empirical studies and implementation have moved in a continuous hermeneutic circle towards better understanding and better practice (Gadamer 1975). The empirical studies are conducted by the second author who is a social anthropologist, the methods are qualitative, based on ethnographic methodology. The primary method is participatory observation (Ellen 1983) where the second author took part in the activities of the Bispevika Team at the building site in periods between November 2017 and December 2019, altogether three weeks at the building site. In particular, activities connected to mindset relevant work was observed.

The observation activity implied participation in relevant activities, informal discussions with team members, making fieldnotes and giving feedback to the team, discussing and questioning the validity of the findings. Participatory observation is a method suitable for detecting the tacit dimension of interaction and the unsaid in what goes on at a workplace (Watson 1999), aspects of great importance for detecting changes in qualities of culture and mindset. In addition to observation, semi-structured, qualitative interviews were conducted with members of the team; four in the early stage of the observation period, six at the end of the period. There has been put strong emphasis on not involving the CTO in interviews in order to allow informants to feel free to criticize the leader group. A separate aspect of the action research methodology has been an on-going dialogue with the Chief Transformation Officer.

The need to re-visit the cultural work– is recognized by the leaders. In collaboration with the social anthropologist the leaders developed a survey to map the current state of the mindset and performance culture. The survey was launched in a big team meeting held in the late of February 2019. These team meeting are held about every 6th week, giving information of the current state of the project, leadership focus and on the organization as such. This survey was important in several terms. First for the team members. It showed that the team leaders take the cultural aspects seriously and are willing to re-invest again to map the state of the culture. It also showed the willingness of the leaders to get direct feedback from the organization on how the current state will give transparent knowledge on both mindset and level of performance.

Given the limited space of this paper, the authors will here focus on some of the practical implications from the results of the survey so the leaders of Team Bispevika can get feedback and new knowledge to improve the team-performance. 75% of the team members answered all the questions in the survey, which was in a digital form and fully anonymous. It investigated the level of experienced core values, level of team collaboration, experience of tools to develop the team culture, use of personal goal plan, performance and alignment of goals for the team and the individual, mindset and performance, and how the single team member can influence and be seen as an individual.

Second, the authors will also research the term mindset as such, asking the team members on how they feel about different aspects of this matter.

Third, it will give the authors a unique chance of researching and investigating on not only a large and long-term running project in the construction industry, but also the chance to develop generic knowledge which is relevant for other transformative processes.

THEORY

This case study has both a theoretical and a practical approach which is merged during a period of 18 months as an answer to the real-life challenges and obstacles of building and sustaining an organizational culture to create teams with a daredevil collaborative mindset. This section will describe how the authors use a combination of management theory and theory of social anthropology.

The theoretical approach used by Team Bispevika, was based on a concept the Chief

Transformation Officer (CTO) developed which was branded "Team- and performance leadership" (see the section of case description).

This management approach was based on literature covering different aspects of both team and individual performance where alignments of both collective and individual goals is necessary for an organization to perform (Katzenbach and Smith, 1993; Wheelan 2013). The theory also emphasizes the need for team's leadership to master the skills to both set the right collective goals and break them down to relevant performance indicators for the individual team member so all the different tasks which need to interact to reach a required level of interdependence are all accounted for. If a group wants to become a real team, the members must be mutually dependent on each other (Bateson 1985; Fyhn 2009). Furthermore, another requirement is that the team members are mutually responsible for reaching their common goal. In other words, the ambition and goal of the collective performance must be so difficult to reach that nobody can do it by themselves (Greenberg & Baron, 2008; Bang & Middelfart 2014; Bakli 2016).

Another approach supplementing the above-mentioned literature is that of a more evolutionary approach to human cooperation where trust and openness is the base for successful communication, optimizing cooperation and teamwork. The true indicator for a successful team is here measured in the team's ability and capacity to revitalize its organization and sustain and transform to meet new challenges over time (Grennes 1999; Kahneman 2011; Taleb 2007).

A third strain of theory derives from military research on team dynamics, where collaboration in complex settings and the ability adapt to overcome extraordinary hardships is not only a goal, but a necessity (Alberts et al. 2001).

These three strains of theory were merged setting up the organization model and the team's performance structure during fall 2017. During the development of the organization during 2018, old school theory from classical anthropological literature where engaged in the work with the project culture. With this, concepts such as *rituals* (Turner 1969), *storytelling* and *mythology* (Eliade 1975), *taboo* (Douglas 1984), *participation* (Levy-Brühl 1978) and *identity* (Wenger 1998), where in traduced. This theoretical approach was introduced in order to develop a culture for high performance, but in the daily language of the project team, this tended to be called "mindset". The concept, mindset ended up connoting the ambitions of the culture building, thus this term is also used in the present paper.

THE CASE BISPEVIKA

The Bispevika project is one of the most ambitious and largest construction projects in Norway and aims at changing the collaborative patterns of the industry. For both Client and Contractor this is a transformation journey where the common scope of both parties is expressed in four main goals (Klagegg et al 2019).:

1. Bispevika shall become the most attractive part of the City of Oslo
2. Create the best place to live, and have the most pleased users
3. Create at least 40% more value than comparable construction projects
4. Change the collaborative patterns of the Construction Industry

To be able to reach such ambitious goals, the project owner, OSU, invited the largest construction companies to suggest how to reach performance levels beyond what is currently considered best practice in the industry the contractor, The AF Group, put together a small team of 4-6 persons that won the position as contractor, and the two parties defined the goals together. The project was set up in 2016 and is planned for completion in 2021. The business scope of the project for the Contractor is approximately €1 Billion (Klakegg et al 2019). When the AF group had won the competition, they had to put together a temporary organization – not only a project team as such - that could match these ambitions. The organization has grown gradually from the first 4-6 people in the team for conceptualizing the challenge from the client into the winning answer, 25 in the fall off 2017 and doubling to about 50 people in the winter of 2019. This being the construction industry with its fragmented value chain, the extended organization of Team Bispevika, counts 200 – 500 more people with a high number of partners and subcontractors.

After gradually getting to know the people representing the client, the leaders of Team Bispevika grew more and more curios of why the AF team won the job, competing against far more experienced house-building teams from competitors. After being asked directly by the key-persons in Team Bispevika, Rolf Thorsen, the CEO of OSU, and his colleagues, have answered this question in numerous settings, and the answer remains the same; "Top management commitment, an innovative approach for increasing value and above all a daredevil mindset matching our ambitions".

APPLICATION OF THEORY IN BISPEVIKA

Above the authors described the merge of two different theoretical approaches, where Team Bispevika first used management theory, industry proven experience and skills to master the building of a performance culture.

This was the a priori theoretical way Team Bispevika was set up to be able to perform extraordinary as a real team, where the goal was to deliberately create a performance culture. This was a process of fall 2017, a joint effort led by the leadership team of Team Bispevika, spearheaded by the CTO and the concept of Team- and performance leadership. This concept was developed by the CTO over several years setting up a project governance model and building "High Performance Teams" for over 25 large projects in the construction industry. The concept has three main goals. First it is to simplify complexity making it easier for the project team to cope with reality. Second it is to create a high-performance team. Third, it is to align collective and individual goals and increase individual accountability and give the employee an attractive learning and career opportunity. (see table 1. for a structured overview of the concept).

Table 1. Team- and performance leadership.

Goal	Simplify the complex	High performance teams	Alignment of goals. Employee training and individual accountability

Explanation of goals	Create best possible preconditions- businesswise and organizational – for performance and to reach the goal of the project	Create a real team which reach the common goals of the project	Create a sense of trust and individual capability to master tasks. Increase individual accountability and performance. Articulate an individual training and career plan. Increase attractivity to stay on/attract new talent.
Prepare	Risk analysis and evaluation of the needs of the project in terms of business/contract preconditions, technology. Map the milestones and phases. Make plan for execution.	Analysis of resources to meet capacity and capability requirements. Recruitment of team. Organize the team as a network of specialists. Process leadership/coaching	Map the performance potential of the team using a psychological tool called “Jugend type index”. Express tasks needed to reach goals. Design the right governance model.
Do	Teach key personnel the need of goal alignment. Show them how to express ambitions and set goals. Involve – and make top management accountable. Team recruitment. Collaborative process with client and other external partners.	Team kick off workshop. Create a common goal and ambition to become a real team. Coach the team in understanding the potential of the team and each individual and how to create common trust. Define meeting structure and map critical communication hardships.	Define individual tasks. Set individual goals. Self-evaluation. Make personal goal-plan with colleagues and leader. Check that all personal goals gives mutual responsibility and common goal alignment.
Follow up	Strategic partner with the top management and	Evaluate team performance at a	Individually

	project management. Process leader of meetings, workshops, client meeting. Evaluation and performance assessment. Evaluation of the project for scalable learning.	regular basis at each milestone. Identify treats and prioritize. Fix troubles. Team workshops. Individual coaching.	Monthly check in the team meeting. "Am I on track?" In the annual employee/career-plan meeting" with the management. Training plan/education
Accountability/ Responsibility	Top management and project management are measured in terms of both quantitative and qualitative indicators.	Top management, project leader and individual.	Individual employee Project manager Top management

.

In a posteriori perspective the term mindset emerged gradually to describe the special sense and feeling of a collective commitment to be all inn to accomplish the ambitions for Team Bispevika, all for one, one for all. This was not deliberately a part of the branding strategy of the leadership team.

Another a posteriori experience was the introduction of a social anthropologist, part of research consortium called KSS, companies in the construction industry cooperating with different researchers from NTNU. Here the CTO was introduced to classic theory and terms of social anthropology for the study of cultural phenomenon such as rituals, mythology, storytelling, taboo, participation and identity. All though this was not entirely unknown matter for the key persons in the leadership team and the CTO, they had not a priori incorporated these cultural tools in the design for becoming a true performance culture, only the above-mentioned tools from management theory.

Henceforth form start of 2018, all collective moments such as meetings, presentations, performance assessments and such was a part of deliberate leadership design where management theory was merged with classical theory on culture creating not only a notion of a special team – but the genesis of a myth. This increased the ability of the leadership team to a priori create the transformation of Team Bispevika to become the most innovative bunch in the construction industry. At least within their own company. This was the start of opening up the black box of the mindset to create a performance culture.

Regarding mindset, the CTO, approached the terms of his classic training in moral philosophy, and discussed the meaning of the term within the team. Here they defined it as a state of mind in which the motivation or intention of what you do, determines whether the action itself can be determined good or bad, regardless of the outcome. We will not go into an ontology and per se discussion of moral philosophy here, but the authors think this is an interesting observation on how this specific culture embraces and encourages people to try new things – without being punished. According to the approach, there is only one thing you can do wrong, and that is to not ask for help.

One thing is to create a performance culture, furthermore an innovative mindset that is fueled by a collective sense of being able to reach extraordinary ambitions. Another thing is to be able to sustain that mindset maintain the belief in 40% more value creation.

During the spring and the summer of 2018, the team grew gradually. Many of the team is very young and inexperienced and the ones that are experienced are mostly not used to work in big and complex projects.

In addition to this Team Bispevika has implemented a complex planning system called Last Planner with corresponding new digital tools and extreme ambitions on behalf of all partners and sub-contractors as well (Klakegg et all, 2019). Not to mention that Team Bispevika has not only one project scope going on, but three. One for the Northern part with a traditional business model, one for the Southern part where Team Bispevika is developing a new collaborative business model with OSU, and third, a on focus for integrating all these new things learned so Team Bispevika can accelerate the transformation of the construction industry.

One year after the first team kick-off, it was by October time for the second, preparing the team for the next stage. By this time the organization had doubled in size and the project entered new phases adding more and more complexity, tasks and communication challenges making it more difficult to reach the required performance level. The first kick-off in 2017 had focused on "project-governance", the second focused on self-management and individual accountability and the need to re-invest in maintaining the unique mindset and culture.

The leadership group recognized a growing need to clarify structure and transparency for the team by focusing on organization development which consisted of four elements; organization charts, individual description of role and responsibility, work/role instruction and a personal goal plan.

In many terms this was precisely the same implementation of the "Team- and performance leadership" concept again, but this time also with the a priori design integrating the theory and new insights learned from social anthropology and how the phenomenon of mindset had manifested itself. The leaders were now aware of the importance of the effect of creating a myth linking individual and group in a collective collaborative where individual performance was crucial for the collective outcome.

In addition to this the CTO hired a consultant firm which has developed their own tool for mapping the state of the team/company culture. This company is called Alfa & Omega, and they call their mapping tool "The Culture Solitaire". (https://www.alfaomega.no/).

This analysis confirmed a common view of the culture as open, innovative, experimental, ambitious and with high levels of trust, but a need for more structure, clarity of tasks and the need to run a more "tight ship". The tool also showed that all team members also wanted the same output; a winning team where everybody helps their colleagues and a culture of collective learning, experimenting and where high performance is expected. Above all this confirmed the goal of the second kick-off and nearly all went home with a up to date personal plan empowered to perform extraordinary, where all structure needed where integrated in a robust organizational design, implemented with a priori leadership design, executed as planned.

In the weeks following the second kick-off the leadership team was very focused on collaborating with their client OSU to develop a new business model and let the different teams within Team Bispevika focus on their specific tasks. Interviews were conducted with team members to see how things had developed since the second kick- off. Over all the feedback from the team members where positive regarding the state of the mindset and performance culture, but an urging need to follow up, and re-focus on the individual need seemed to be emerging again for pointing out and mapping individual and collective path, despite a success of the executing the second kick-off in a a priori way.

DISCUSSION

So here we are, in the winter of 2019, 18 months after the organization of Team Bispevika was launched.

The need to re-visit the cultural work recognized by the leaders. In collaboration with the social anthropologist the leaders developed a survey to map the current state of the mindset and performance culture. This survey was presented at a team meeting, digitally sent to all right there and all where encouraged to respond to the survey as fast as possible. Here it was made sure that it was an anonymous way of producing knowledge on the current state of the performance level and the cultural aspects of Team Bispevika.These team meetings are held about every 6 th week, giving information of the current state of the project, leadership focus and on the organization as such.

As mentioned above the authors will discuss only the most important practical implications based on the results of the survey in this paper. These discussions will be given as a feedback to the leader team, so they can use these insights to improve their own leadership in practice. If and how they do that will also be a part of the authors further research.

One of the most interesting findings was that 93% said that “I contribute to reach our goals”, while 43% meant that “we contribute to reach our goals”. Another finding was that 70 % said that their own tasks and performance were aligned with the 4 main goals of the team. A third was that 90% said that they ask for help from the leaders and their colleges. A fourth was that 83% said that the personal goal plan was a good tool for improving their own performance.

In the discussions with the team leaders before the survey was sent out, the leaders meant that a majority of the team members did *not* lead themselves effectively. In contrast to this is the findings when the authors asked how many people that in fact had the possibility to self management and also do that in practice. Here the team members responded respectively 88% on the first question and 92% on the second. On the other hand, the leaders in advance felt that they coached and to a high degree was present as good managers and helped the individual team member to increase daily performance and to succeed with the tasks in the job. Here 58% did not agree at all with the leaders and no team member gave full score on this topic. In addition to this the authors could see from the comments (where the team member could write in what they meant) that many wanted more feedback, more training and better on boarding (the team has grown gradually so only 40% of the team members have participated from the start of the project and 17% had not been on any kind of team building).

The preliminary findings of this discussion show that the leaders of Team Bispevika have managed to design and implement a structure that align the goals of the individual with the common goals of the project. Given the considerable changes in team size and tasks over a 18 months span this could indicate that Team Bispevika meet many important aspects of building a high performance team. It also seems as if the team members them selves mean that they function well in their roles doing their own tasks.

On the other hand, the same people think that a much smaller degree of their collogues contribute to reach the same common goals. Further they also say that the leaders could improve on following up the individual goal plan in a better way, although a vast majority of the people have a goal plan which they have made together with their leader.

This survey will be important in several terms. First for the team members. It will show the that the team leaders take the cultural aspects seriously and are willing to re-invest again to map the state of the culture. It will also show the willingness of the leaders to get direct feedback from the organization on how the current state will give transparent knowledge on both mindset and level of performance.

Second, the leaders will have knowledge – based on research -, not feelings, on where and how to act to improve team performance. The authors think that this can be a good example on how organizations can improve performance in real time – making collaboration between the construction industry and research more relevant for increasing productivity on a short-term basis in a specific context.

Third, the authors will also further research the term mindset as such, asking the team members on how they feel about different aspects of this matter.

Forth, it will give the authors a unique chance of researching and investigating on not only a large and long-term running project in the construction industry, but also the chance to develop generic knowledge which is relevant for other transformative processes.

This story is also a case of action research, combing both management theory, social anthropology with insights and skills of experienced leaders. This can result in a more nuanced research design, able to tackle real world challenges, adding value by developing better a priory strategies for creating and sustaining the needed mindset and performance levels required of a culture that must change all the time. (Klakegg et al., 2019). It is a matter of being able to disrupt or be disrupted. There is also a growing general recognition of the importance of mindset and culture as x-factor for succeeding in organizational shifts from hierarchy to a collaborative network-based model.

In terms of practical contribution the findings of all aspects of this research – not only the survey - can boost the performance of the project organization by helping the leaders in Team Bispevika increase their own knowledge in mindset and culture. This awareness should also develop the quality of how they in practical manage their own team and coach the team members in a more effective way, increasing both individual and collective performance. The contribution in generic terms should be relevant for all kind of organizations, not only temporary such as projects, where the motivation to change is driven by the need to stay competitive and in the end, not be put out of business by external disruption due to changes in the value chain. Innovation in many terms means the ability to change, not only once, but continuously. This is why you need a robust culture which can perform under pressure and actually make it possible to avoid disruption by being able to learn and change and sustain innovation over time.

In theoretical terms the authors hope the combination of two theoretical approaches combined with industry proven experiences leaders will contribute to a more nuanced discussion on why culture and mindset need to be integrated with management theory (Klakegg et al 2019). The case study is a unique opportunity as a laboratory for developing knowledge on culture and team performance. Here the authors will further investigate how mindset as a phenomenon can be of significance to help organizations succeed with collaboration and innovation over time.

The findings in this paper is off course limited by that the case study itself. This is a story of an organization that still is writing and re-writing its history as it evolving as a cultural phenomenon, impacting both inside and outside Team Bispevika. In many terms this case study is a real-time laboratory of the emerging and evolvement of a culture.

CONCLUSION

This case study shows that collaboration between researchers and industry proven leaders can be fruitful. It also tells us that a multidisciplinary approach is necessary in order to understand the impact extraordinary ambitions as a motivating factor for transformation. It also indicates the need to find new approaches in order to actually create a culture able to handle a transformative setting. It also gives indications to why one must revisit – all the time – and investigate the context and preconditions for learning, giving a better chance of actually create a performance culture, not once, but always. This requires not only repeated investments in terms of money, but also in transparency and accountability on behalf of the leaders.

The study further shows that systematic work on collective mindset is possible and it is possible to grasp the "slippery" phenomenon called culture. Exact implications from Bispevika: strong collective mindset, ability to learn and transform rapidly and the necessity to re-invest in building strong teams to reach extraordinary performance level.

There is still a need for further research in order to unlock "the black box" of performance culture. This calls for in dept studies over time of cultural development in temporary organizations such as construction projects. The next step for the authors will be to further analyze the findings of the survey, explore the phenomenon of mindset, share the insights in the extended network of Team Bispevika's industry clusters. The authors will also discuss and get feedback at the IGLC conference of 2019 and follow the development in the story of Team Bispevika where the ambition of the authors is to wright an article which in more depth can cover the aspects of mindset, organizational culture and disruptive performance.

REFERENCES

Agarwal, Rajat. Chandrasekaran, Sridhar, Mukund. 2016: *Imagening construction's digital future.* McKinsey Insights Report. McKinsey&Company.

Alberts, David S. David S ; Garstka, John J ; Hayes, Richard E ; Signori, David A. 2001: *Understanding Information Age Warfare.* Washington D.C. CCRP

Bang, H. & Middelfart, T.N. 2012: *Effektive ledergrupper.* Oslo, Gyldendal Akademisk.

Bakli, G. L. 2016: *Goal setting Contractor's Project Teams.* Master thesis, NMBU.

Bateson, Gregory. 1985 [1972]: *Steps to an ecology of mind. Collected essays in anthropology, psychiatry, evolution, and epistemology.* Ballantine Books. New York.

Bygg 21, 2015. *Neste steg.* Bygg 21.

Douglas, Mary. 1984: Purity *and danger: an analysis of concepts of pollution and taboo*. London: Ark Paperbacks.

Eliade, Mircea. 1975: *Myth and Reality*. New York: Harper & Row Publishers.

Fyhn, Håkon. 2009: “Kreativ tverrfaglighet”. I *Kreativ tverrfaglighet, teori og praksis*. Red. H. Fyhn. Trondheim: Tapir Akademisk Forlag.

Gadamer, H. G. (1975) "Hermeneutics and Social Science". *Philosophy Social Criticism / Cultural Hermeneutics*. 2 (4): 307–316.

Greenberg, J., & Baron, R.A. 2008: *Behavior in organizations.* New Jersey, Pearson Educational International.

Grennes, Carl Erik. 1999: *Kommunikasjon i organisasjoner.* Abstrakt Forslag A/S. Holy, Ladislav. 1983: “Theory, method and the research process.” I *Ethnographic Research, A Guide to a General Conduct.* Red. R. F. Ellen. London: Academic Press, Harcourt Braise Javanovich, Publishers.

Kahnemann, Daniel. 2011: *Thinking fast and slow.* Farrar, Straus and Giroux.

Katzenbach, Jon R and, Smkith, Douglas. K. 2010: *The wisdoms of teams: Creating the High- Performance Organization.* Harvard Business Review Press.

Klagegg, Ole Jonny, Lars Kristian Hunn, Per Fridtjof Larssen. 2019: *Bispevka Project – Research for constructing a collaborative value chain.* Emerald reach publishing services.

Levy-Brühl, Lucien. 1978: *The Notebook on Primitive Mentality*. Oversatt av P. Rivière. London: Harper & Row Publishers.

McNiff, Jean & Whitehead, Jack. 2002: *Action Research: Principles and Practice*. Cambridge: Cambridge University Press.

Rashasingham, Kamalan. 2019: *Digitisation in the construction industry.* Master thesis University of Oslo.

Taleb, Nassim Nicholas. 2007: *The Black Swan: The Impact of the Highly Improbable.* Random House Allan Lane.

Turner, Victor. 1969: *The Ritual Process, Structure and anti Structure*. Aldine. Chicago.

Watson, C. W. (Red.) 1999: *Being There. Fieldwork in Anthropology*. London: Pluto Press.

Wheelan, Susan A. 2013: *Creating effective teams.* Sage Publications.

Wenger, Etienne. 1998: *Communities of Practice; Learning, Meaning and Identity*. New York: Cambridge University Press.

Poshdar, M., Gonzalez, V.A., Antunes, R., Ghodrati, N., Katebi, M., Valasiuk, S., Alqudah, H., and Talebi, S. (2019). "Diffusion of Lean Construction in Small to Medium-Sized Enterprises of Housing Sector." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 383–392. DOI: https://doi.org/10.24928/2019/0257. Available at: <www.iglc.net>.

DIFFUSION OF LEAN CONSTRUCTION IN SMALL TO MEDIUM-SIZED ENTERPRISES OF HOUSING SECTOR

Mani Poshdar[1], Vicente A. Gonzalez[2], Ricardo Antunes[3], Nariman Ghodrati[4], Milad Katebi[5], Stanislau Valasiuk[6], Hamzah Alqudah[7], and Saeed Talebi[8]

ABSTRACT

The construction sector is known for its deficient productivity level compared to other sectors such as manufacturing. Lean approach, however, presents a promising option given its proven ability to improve the performance in other sectors. This study investigates the diffusion level of lean construction among the small to medium size enterprises (SMEs) by conducting a telephone survey in the Auckland region of New Zealand. The survey involved 100 enterprises active in the housing sector. The results indicated the rate of diffusion at three stages of a simplified innovation diffusion model including the knowledge exposure, decision analysis and implementation. The results are attributed to three main elements including the characteristics of SMEs as social units, the time required to attract adopters, and the level and type of communication must be used to reach the potential adopters. The study identified five main questions on the enablers and barriers of diffusion of lean construction to be addressed in future research.

KEYWORDS

Benefits realization, action learning/research, trust, diffusion, SMEs in housing.

INTRODUCTION

In New Zealand, the construction sector operates near capacity being incapable of attending the current demand (Pacifecon N. Z. ltd 2018). Despite such a high demand from the market

[1] Lecturer, Built Envir. Engrg. Dept., Auckland Univ. of Technology, Auckland, New Zealand, mani.poshdar@aut.ac.nz

[2] Senior Lecturer, Civil and Envir. Engrg. Dept., Univ. of Auckland, Auckland, New Zealand, v.gonzalez@auckland.ac.nz

[3] Civil and Envir. Engrg. Dept., Univ. of Auckland, Auckland, New Zealand, rsan640@aucklanduni.ac.nz

[4] Lecturer, Built Envir. Engrg. Dept., Auckland Univ. of Technology, Auckland, New Zealand, nariman.ghodrati@aut.ac.nz

[5] PhD student, Built Envir. Engrg. Dept., Auckland Univ. of Technology, Auckland, New Zealand, milad.katebi@aut.ac.nz

[6] Built Envir. Engrg. Dept., Auckland Univ. of Technology, Auckland, New Zealand, sttasv@gmail.com

[7] PhD candidate, Built Envir. Engrg. Dept., Auckland Univ. of Technology, Auckland, New Zealand, hamzah.alqudah@aut.ac.nz

[8] Lecturer, School of Art, Design and Architecture, Univ. of Huddersfield, UK, S.Talebi@hud.ac.uk

the industry even shows financial loses (Herald 2018). The construction sector heads as the least productive industry in the country since the 90s with no sign of improvement in the past forty years (Curtis 2018). This deficient productivity is combined with other issues notorious to the sector including the failure to attract professionals (Ministry of Business and Employment 2017), poor plan reliability (Harris 2017), and substandard quality (Gordon and Curtis 2018). Lean construction has proven its ability to offer significant improvements in similar circumstances across several areas such as cost structure, job satisfaction, plan reliability, quality, and productivity (Sacks et al. 2010; Gao and Low 2014; O. AlSehaimi et al. 2014; Poshdar 2015). Despite lean construction has shown presence in New Zealand; little is known about its level of acceptance by the small to medium-sized enterprises (SME) that form the skeleton of the country's construction industry (Fida 2008).

This study intended to find out and elaborate on the state of diffusion of lean construction among SMEs active in the Auckland region of New Zealand. The city has been forecasted to deliver 41% of all building and construction activity of the country from 2017 to the end of 2022 (Ministry of Business, Innovation and Employment (MBIE) 2017). The results provide a clear image of the dissemination of lean construction among SMEs, which enables initiate and design actions to increase lean adoption.

SMES AND LEAN CONSTRUCTION: A LITERATURE REVIEW

The importance of SMEs is well identified worldwide because of their significant contributions to satisfying various socio-economic objectives, such as higher growth of employment, output, promotion of exports and fostering entrepreneurship (Singh 2011). Despite the consensus on the importance of SMEs, no universal agreement exists about their size in particular. This study adheres to the definition provided by New Zealand Statistics, where SMEs are defined as a unit that consists of between 0 to 49 full-time employees. These enterprises make 95% of companies in the global market, which produce more than 50% of the economic value (Fida 2008). In Organisation for Economic Co-operation Development (2017) countries, SMEs account for 99% of all enterprises and contribute to 70% of jobs on average.

In construction, the majority of the active companies are from the SMEs category. According to New Zealand Statistics, SMEs constitute 76% of the active companies that employ about 68% of the total workforce in the industry (New Zealand Statistics 2018). A majority of SMEs involve in the housing sector (Ghodrati et al. 2018). In New Zealand, this sector accounted for almost 70% of the construction value (Ministry of Business, Innovation and Employment (MBIE) 2017). The significance of SMEs in the construction industry is increasing, especially in developed countries, where large companies (generally main contractors) tend to outsource construction activities (Farmer 2016). The restricted size of SMEs, however, imposes a significant limitation on their abilities to access financial and human resources (Egbelakin et al. 2018; Ghodrati et al. 2018). SMEs are also known as being typically owner-operated. In this structure, the management and operational layers merge to create a simple organizational structure (Alquda et al. 2018). In general, managers in SMEs are more independent; use multitasking, highly personalized, and operate in a particular area (New Zealand Government 2006; Darcy et al. 2014; Inan and Bititci 2015; Ghodrati et al. 2018; Tezel et al. 2018; Yadav et al. 2019). It gives SMEs unique characteristics that are put in contrast to those of large enterprises in Table 1.

Table 1: Large versus small to medium size enterprises (SMEs)

Attribute	Large	SME
Organizational Structure	Hierarchical with several layers of management	Flat with few layers of management
Leadership	Involves strategic activities	Involves operational activities
Management Style	Participative	Empowered supervision that commands and controls
Operational Improvement	Is often introduced with a holistic perspective	Is introduced with a partial and fragmentary prospect
Human Resource	Involves continuous training and staff development	Training and staff development is ad-hoc
Networking approach	Extensive and structured external networking	Limited and unstructured external networking
Innovation	Derived by R&D	Derived by clusters and networking

The simple organizational structure and the flexible production process of SMEs provide a unique ability to implement lean construction. The increasing presence and the number of SMEs involved in the construction sector highlight the imminent need for understanding the issues around the diffusion of lean construction to SMEs.

AN INNOVATION DIFFUSION MODEL

Lean construction strives for a new delivery system that can be applied to any construction development with a particular focus on the complex, uncertain, and quick types of projects (Howell 1999). It fits well into the definition of innovation that refers to a new invention, tool, system or approach intending to change an existing situation, providing an enhanced solution to a problem, and improving the overall performance of the product (Hoffmann et al. 2007; Rogers 2010). Therefore, when the users adopt lean construction as their project delivery system, they are anticipated to pass through the stages drew on the diffusion of innovation theory. The theory has been developed by Rogers (1962) to explain how a new product gains momentum and spreads over time in society. This study divided the process into the three main following steps (Figure 46):

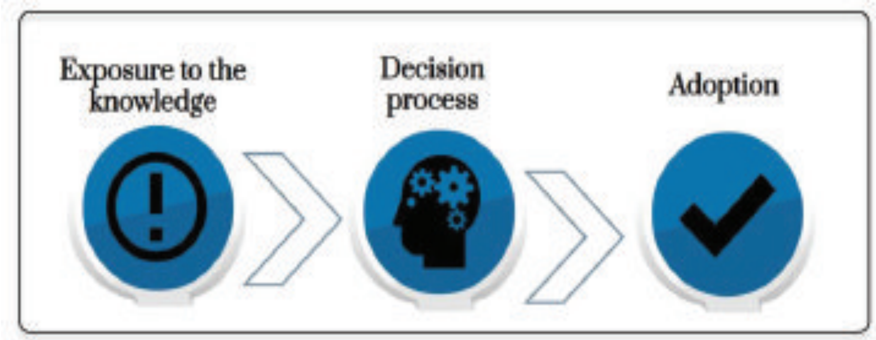


Figure 46: A simplified diffusion model

1) Exposure to the knowledge - users become aware of the existence of the innovation, with restricted knowledge about the details. It commences when the users become exposed to the initial information about the novelty (Rogers 2010). They may find this information in a passive behavior and by an accidental exposure (Coleman et al. 1957), or when a dissatisfaction creates a need, and the users develop a tendency towards self-exposure (Hassinger 1959). Accordingly, the types of knowledge transferred in this step include awareness- knowledge, where the user finds out about the existence of the innovation; how-to knowledge, where the user gets the information necessary to use the innovation properly; and principles knowledge, where the user deals with the functioning principles underlying the way the innovation works (Rogers 2010).
2) Decision process – the users form a favorable or unfavorable attitude towards the innovation (persuasion) and may engage in activities that lead to adopt or reject the innovation. At the persuasion stage, the users become more psychologically involved with the innovation; therefore they actively seek information about the new idea. This information involves relative advantage, compatibility, and complexity associated with the idea. The new information leads to developing a general perception about innovation. In most cases, the users put the innovation on trial on a small scale before making their final decision about adopting or rejecting the novelty (Rogers 2010; Berry and Berry 2018).
3) Adoption – The users put the innovation into use on a large scale and confirm the innovation in the face of conflicting messages arise during implementation. The user may face some problems in the operation when the innovation is implemented. The move from the decision process to the adoption step involves a shift from a mental process to practical behavior. Innovation can be institutionalized and routinized into the ongoing practice if it could pass this last stage successfully (Rogers et al. 2009; Rogers 2010).

RESEARCH METHOD

The research was designed based on a post-positivism methodology. Accordingly, a quantitative approach was undertaken to obtain an interpretation of diffusion of lean construction to SMEs in Auckland, New Zealand concerning the simplified diffusion model in Figure 46. A telephone survey method enabled the researchers to maintain an immediate interaction with the respondents, and quick data processing and handling at later stages. This method also provided a high level of anonymity for the respondents, who wished to hold their opinions in confidentiality. It could facilitate accuracy in responses.

Sample selection

The study used cluster sampling practice, in which seven residential construction sites were selected as the indicative clusters of construction companies working in the Auckland region. A simple random technique was applied to take two of the construction sites to the further stages of the study. The full list of the subcontractors working within the two selected clusters was obtained from the site managers. The list included the name of companies, type of work they were performing, their phone number, and the contact person. A few information was missing from the list that was retrieved from the internet.

Sample Size and the response rate

One hundred and thirty companies were listed from the two clusters used for the sampling purpose. The survey was stopped as soon as 100 responses were collected. This size was obtained based on the guidelines provided by Creswell (2014) called data analysis spiral. It suggests an inductive process in several rounds during which the data are organized, conceptually reviewed, classified and synthesized.

Data Collection

The data were collected between May and August 2018. Since the telephone survey could interrupt the personal time of the respondents, the interview sessions were designed to take no longer than 10 minutes.

The respondents were requested to answer the following three questions:

1. Please, indicate the size of your company.
2. Has your company ever faced/ been involved with the lean construction topic at any level?
3. Has your company ever practised the use of lean construction in any of its projects?

The first question ensured that the surveyed company is within an SME category. The next two questions investigated the position of the company in relation to the simplified diffusion model (Figure 46).

DISCUSSIONS

The analysis of the Respondents' profile

The profile of the respondents was studied based on the frequency of the type of work they were delivering in the projects in order to demonstrate the demographics of the sample studied. They were found to be involved in a broad range of works with a relative balance in the frequency observed. Nine activities recorded with a frequency between 4% top 11%. Figure 47 provides a summary of these activities along with their observed frequency. In this figure, the responses with a rate of fewer than 4% were grouped as the *other*. These responses included activities such as surveying, scaffolding, stair construction, membrane installation, and waterproofing.

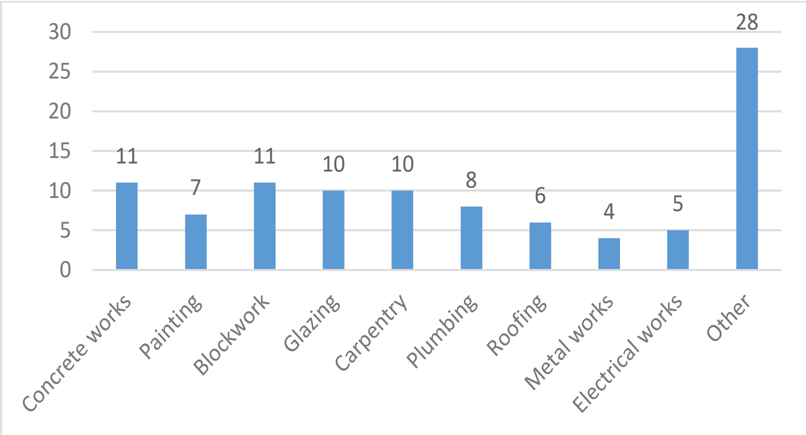


Figure 47: The type of works and the observed frequency

The knowledge and implementation levels observed

Twenty companies (20%) identified that they had been exposed to the lean construction idea at some points in their past. Three companies (3%) were actively using lean construction system. Also, one company (1%) had used the lean construction system in the past with a discontinuation decision. They associated this decision with the fundamental changes that occurred in the company's managerial team and strategy. Given the differences between the observed rates for the companies with exposure to the lean construction idea and those were implementing the system, the simplified diffusion model (Figure 46) showed a 17% drop in the decision process step.

COMMENTARY ON THE PATTERN OBSERVED

We discuss three main elements that can affect the observed pattern in the diffusion level of lean construction among SMEs based on a comparative synthesis of the body of knowledge developed in other fields of science:

1. The characteristics of SMEs as the social unit

A typical construction project can represent a social system comprising of a set of interrelated SME units. This system is known for its cultural resistance to change (Sadler 2011). Such a system often uses patterned arrangements of the units as its primary structure, e.g. the nine common types of works observed in this study represent a recurring pattern that gives stability and regularity to the projects. This arrangement affects the social and communication structure of these individual units that may facilitate or impede the diffusion of lean construction as an innovation in the main system.

System norms

Norms refer to the behavior patterns established in the units of the social system (Rogers 2010). In construction, SMEs are typically structured around a fragmented work delivery, which can even cause clashes in defining their priorities (Abdullah et al. 2009) and escalating their lack of cooperation (Mossman 2009). They are also known for their meagre budget for subcontracting (Bashir et al. 2010), lack of skill, development ignorance, and computer illiteracy (Abdullah et al. 2009; Poshdar et al. 2018). The literature to date also indicates a tendency to use traditional management (Abdullah et al. 2009), lack of commitment, lack of ability to work in a group, lack of self-criticism, weak communication and transparency as other attributes ongoing in construction (Mossman 2009).

2. COMMUNICATION

Communication plays a significant role in the diffusion process of innovation (Rogers et al. 2009). The potential users confront two types of uncertainty facing an innovation: the first type relates to the suitability of the innovation to their requirements and the other type concerns about the consequences expected from implementing the innovation. Both types can be reduced by proper communication. The reduction in the uncertainty about the suitability of the innovation will impel the users to exert effort in order to learn about the innovation (Rogers 2010). It will sustain the persuasion phase in the decision making the process (Figure 46). To do so, Lean construction needs to clarify the following three main points to SMEs: What is lean construction? How does it work? And why does it work? In order to reduce the uncertainty about the consequences, the communications should involve innovation-evaluation information (Rogers 2010). It entails answering an inevitable question: What will be the advantages and disadvantages of implementing the innovation in the particular situation of the user?

The opinion leaders and change agents

Certain individuals play different roles in social systems when communicating the suitability and the implementation consequences of innovation. Opinion leaders serve as the group of individuals who can influence the attitudes of others informally in a desired way with relative frequency (Rogers 2010). In SMEs, the managers can play this role, given their importance in defining the strategic orientation of the enterprise. The literature, however, demonstrates a lack of commitment and support from the top managers (Bashir et al. 2010), coupled with the lack of training and experience for other members, which disrupt a change in the mindsets (Mossman 2009).

In such situations, the presence of a change agent may help to direct the decision process of the enterprise towards the desired orientation. A change agent, however, is typically more competent than his clients technically. It can pose a severe problem in the effectiveness of communicating lean construction as an innovation. As a principle of human communication, the degree to which pairs of individuals who interact are similar in certain attributes, such as beliefs, education, and social status represents the main factor in facilitating the transfer of the ideas. A heterophilous pairs of the change agent and the potential user can effectively interact if they could build a level of empathy (Rogers 2010).

The channels

A communication channel is a way by which messages are passed from one individual to another. The transfer can take place using the mass media, social media, or interpersonal channels.

The results of various diffusion investigations, however, show that most people depend upon a subjective evaluation conveyed to them from other similar individuals who have previously adopted the innovation (Rogers 2010). This dependence on the communicated experience of near-peers suggests that the interpersonal channels can significantly partake in the persuasion and confirmation phases of diffusion.

3. TIME AND THE ADOPTION RATE

A cumulative frequency over time plot of the number of adopters typically forms an S-shaped curve (Rogers 2010). It starts with a few adopters known as the innovators; followed by a climb in the number of adopters (involved with the early adopters and the early majority, respectively). Afterwards, the trajectory of the rate begins to level off, as the late majority adopt. Finally, the S-shaped curve reaches its asymptote, when laggards decide to enter into the adoption phase. The results of this study indicate that the lean construction idea has found its early adopters among SMEs, and needs to make sure about engaging the early majority type of adopters in the near future.

CONCLUSION

This paper studied the state of diffusion of the lean construction system as an innovation among SMEs which are known as the backbone of the construction industry in the majority of the countries. It was found that while 20% of the companies had been exposed to the knowledge about lean construction, only 3% were actively using this system. It was discussed that a strong link could be spotted between the level of involvement demonstrated by the SMEs as the social units of the projects and their cultural norms. The norm is formed around the current practices that arrange the units in a fixed pattern in projects to gain stability and regularity. It poses a significant impediment to their extensive involvement in adopting lean construction. To break this pattern, an in-depth understanding of the decision mechanism that drives changes in an SME seems to be necessary. It entails identifying effective people to be targeted and the communication channels to be established with the organization. The paper also classified time as one of the main players in getting the changes ongoing and increasing the rate of the adopters. In the light of the findings a number of research questions can be established: (1) What are the roles of different actors within the construction industry to leverage the introduction of Lean Construction as a disruptive innovation within the SME sector in construction?; (2) What are the reasons for the observed drop between the rate of the SMEs that were exposed to the lean construction knowledge and those are implementing it?; (3) Are there other innovation initiatives that faced similar patterns of the innovation-decision process?; (4) What are the likely drivers of innovation that can optimize the innovation-decision of Lean Construction within the SME sector in construction?; (5) What are the roles of innovators such as universities, professional bodies, industry champions, government to promote Lean Construction within the SMEs sector in construction?

The next step of the research will conduct another round of data collection regarding the lean diffusion state among SMEs. It will involve questions to enhance our understanding of the lean practices in SMEs and to clarify the current state of the three main elements of the diffusion model within these enterprises. An analysis of the responses can support answering the main questions about the drivers of lean diffusion.

REFERENCES

Abdullah, S., Abdul-Razak, A., A.Abubakar, and Mohammad, I. S. (2009). "Towards producing best practice in the Malaysian construction industry: the barriers in implementing the Lean Construction Approach." *Faulty of Engineering and Geoinformation science, Universiti Teknologi, Malaysia*.

Alquda, H., Poshdar, M., Rotimi, J. O., and Oyewobi, L. O. "Determinants of construction organisations' performance: a systematic literature review." *Proc., 42nd Australian Universities Building Education Association (AUBEA)*.

Bashir, A. M., Suresh, S., Proverbs, D. G., and Gameson, R. (2010). "Barriers towards the sustainable implementation of lean construction in the United Kingdom construction organisations." *In ARCOM doctoral workshop*, pg 1.

Berry, F. S., and Berry, W. D. (2018). "Innovation and Diusion Models in Policy Research." *Theories of the policy process*, Routledge, 263-308.

Coleman, J., Katz, E., and Menzel, H. (1957). "The diffusion of an innovation among physicians." *Sociometry*, 20(4), 253-270.

Creswell, J. W. (2014). *A concise introduction to mixed methods research*, Sage Publications.

Curtis, M. (2018). "Productivity in the Construction Industry 2017." 26-26.

Darcy, C., Hill, J., McCabe, T., and McGovern, P. (2014). "A consideration of organisational sustainability in the SME context: A resource-based view and composite model." *European Journal of Training and Development*, 38(5), 398-414.

Egbelakin, T., Poshdar, M., Walsh, K. Q., Ingham, J., Johnston, D., Becker, J., Mbachu, J., and Rasheed, E. (2018). "Preparedness of small to medium-sized enterprises to earthquake disaster: Napier and Dunedin case studies." *Bulletin of the New Zealand Society for Earthquake Engineering*, 51(4).

Farmer, M. (2016). "The farmer review of the UK construction labour model." *Construction Leadership Council*.

Fida, B. (2008). "The Role of Small and Medium Enterprises (SMEs) in Economic Development." *Enterprise Development, Free Online Library*.

Gao, S., and Low, S. P. (2014). "The Toyota Way model: an alternative framework for lean construction." *Total Quality Management & Business Excellence*, 25(5-6), 664-682.

Ghodrati, N., Yiu, T. W., Wilkinson, S., and Shahbazpour, M. (2018). "A new approach to predict safety outcomes in the construction industry." *Safety science*, 109, 86-94.

Gordon, G., and Curtis, M. (2018). "Building-quality issues : A literature review."

Harris, C. (2017). "Poor project management blamed for construction budget blowouts."

Hassinger, E. (1959). "Stages in the adoption process." *Rural sociology*, 24(1), 52.

Herald, N. Z. (2018). "Construction industry in urgent meeting with government ministers over sector problems."

Hoffmann, V., Probst, K., and Christinck, A. (2007). "Farmers and researchers: How can collaborative advantages be created in participatory research and technology development?" *Agriculture and human values*, 24(3), 355-368.

Howell, G. A. (1999). "What is lean construction." *Proc., 7th Ann. Conf. of the Int'l. Group for Lean Construction*.

Inan, G. G., and Bititci, U. S. (2015). "Understanding organizational capabilities and dynamic capabilities in the context of micro enterprises: a research agenda." *Procedia-Social and Behavioral Sciences*, 210, 310-319.

Ministry of Business, I., and Employment (2017). "Future demand for construction workers."

Ministry of Business, Innovation and Employment (MBIE) (2017). "National construction pipeline report 2017." Ministry of Business, Innovation and Employment, Wellington, New Zealand.

Mossman, A. (2009). "Why isn't the UK construction industry going lean with gusto?" *Lean Construction Journal*.

New Zealand Government (2006). *Small and Medium Businesses in New Zealand: Report of the Small Business Advisory Group*, Small Business Advisory Group.

New Zealand Statistics (2018). "New Zealand Business Demography Statistics: At February 2017." Retrieved.

O. AlSehaimi, A., Tzortzopoulos Fazenda, P., and Koskela, L. (2014). "Improving construction management practice with the Last Planner System: a case study." *Engineering, Construction and Architectural Management*, 21(1), 51-64.

Organisation for Economic Co-operation Development "Enhancing the Contributions of SMEs in a Global and Digitalised Economy." *Proc., Meeting of the OECD Council at Ministerial Level, Paris*, 2017.

Pacifecon N. Z. ltd (2018). "Guide to the National Construction Pipeline Report."

Poshdar, M. (2015). "An Advanced Framework to Manage Uncertainty and Buffers in Construction." PhD, The University of Auckland, The University of Auckland.

Poshdar, M., Gonzalez, V. A., and Kasiviswanathan, B. (2018). "Buffer Management in Construction - A New Zealand Study." *26th Annual Conference of the International. Group for Lean Construction (IGLC)*, V. A. Gonzalez, ed.Chennai, India, 818–828.

Rogers, E. (1962). "Diffusion of innovations. New York: Free Press."

Rogers, E., Singhal, A., and Quinlan, M. (2009). "Diffusion of Innovations." *An Integrated Approach to Communication Theory and Research*, D. Stacks, and M. Salwen, eds., Routledge, NY, 418-434.

Rogers, E. M. (2010). *Diffusion of innovations*, Simon and Schuster.

Sacks, R., Radosavljevic, M., and Barak, R. (2010). "Requirements for building information modeling based lean production management systems for construction." *Automation in construction*, 19(5), 641-655.

Sadler, L. (2011). "The adaptation and implementation of lean production in the New Zealand construction industry."

Singh, R. K. (2011). "Developing the framework for coordination in supply chain of SMEs." *Business Process Management Journal*, 17(4), 619-638.

Tezel, A., Koskela, L., and Aziz, Z. (2018). "Current condition and future directions for lean construction in highways projects: A small and medium-sized enterprises (SMEs) perspective." *International Journal of project management*, 36(2), 267-286.

Yadav, V., Jain, R., Mittal, M. L., Panwar, A., and Sharma, M. K. (2019). "An appraisal on barriers to implement lean in SMEs." *Journal of Manufacturing Technology Management*, 30(1), 195-212.

Skaar, J (2019). "The Power of Lean Principles" In: Proc. *27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 393–404. DOI: https://doi.org/10.24928/2019/0201. Available at: <www.iglc.net>.

THE POWER OF LEAN PRINCIPLES

John Skaar[1]

ABSTRACT

This article supports previous publications on the importance of lean principles as guidelines (Liker, 2004) or as challengers when developing systems and frameworks (Ballard, Hammond, & Nickerson, 2009) and even methods and tools (Santos, 1999). It seems that the principles have taken the position of being a significant part of lean thinking, meaning a knowledge that lean personnel should acquire. This article wants to support and emphasise the importance of lean principles as *rules of living* but believes in taking the power of the lean principles one step further. If a lean organisation, project or leader explicitly confronts each other with the principles, this empowers the individuals being challenged and may create an outcome that closely links the employee's know-how to the process. Using lean principles as the main message to be understood, they may pull in tools, methods, frameworks or systems to answer these principles. This paper reports from research that explores the effect of pushing lean principles as the direct challenger on employees. Skilled workers at construction sites are the receiver of both general principles but mainly rephrased into more operational language.

KEYWORDS

Principles, philosophy, continuous improvement, action research, waste.

INTRODUCTION

"A principle describes the pathway to transform existing reality through the basic idea set by a concept"(Santos, 1999), this definition is used throughout this paper and shows the close link a lean principle has to a lean concept.

Lean leaders should apply, understand and use lean principles daily to increase their probability to succeed with lean implementation (Emiliani & Emiliani, 2013). There are several papers within IGLC;

- Addressing the strategic issues of lean construction and the importance of organisational awareness towards lean principles (Almeida & Salazar, 2003; Neto, 2002),
- Make principles a strategic toll/managerial method (Bertelsen & Bonke, 2011)
- Addresses the need for tailoring the principles based on what type of situation in which they are used (Ballard et al., 2009; Ballard & Howell, 1998).

[1] Assistant Professor, Faculty of Engineering and Science, Department of Engineering Sciences, Univ. of Agder, Norway, + 47 919 09 313, john.skaar@uia.no

- Papers are presenting the lean principles as suitable in measuring lean conformance (Diekmann, Balonick, Krewedl, & Troendle, 2003) and structure implementation of lean (Picchi & Granja, 2004).
- Bertelsen and Koskela advise how to operationalise TFV theory (Bertelsen & Koskela, 2002)

There is also research addressing additional potential in implementing the lean principles in organisations (Coetzee, Van Der Merwe, & Van Dyk, 2016).

This paper builds on these papers and wants to support the importance of leader's ownership of the principles but also wants to express a warning if a leader's conviction results in pushing the proclaimed lean tools and methods towards the employees.

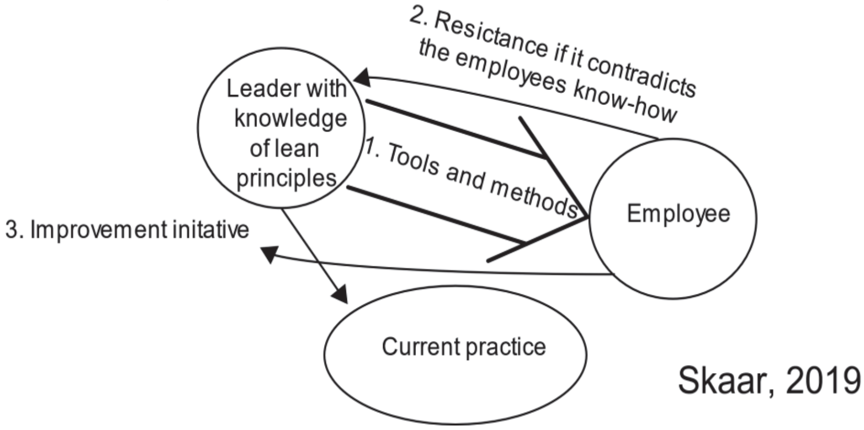


Figure 48 A leader with a lean mindset, pushes tools and methods on employees, may unintentionally submit the mean as the goal.

The reason for this warning is threefold:

1. The employee may not understand that the tool and method presented is just a mean toward a goal, and not the goal itself. Misinterpretation of the purpose might make the organisation more vulnerable to changes and needed system adjustments and negatively affect how an organisation both implement and measures the status of lean, especially if lean thinking is lacking among management (Howell & Ballard, 1998).
2. A situation may occur where the tool and method presented by the leader shouldn't be prioritised for implementation because more prevailed problems exist in the current practice. The leaders lack of know-how can both discharge the leader's recognition and/or hurt the current practice. A point is underpinned by research supporting that a lean leader should be process-oriented, rather than result-oriented (Liker, 2004; Liker & Convis, 2012; Rother, 2010). Are many lean leaders result-oriented in their eagerness to have tools and methods implemented, rather than being patient enough to have sufficient feedback loops with their employees?
3. If the employee resists the change *(Porwal, Fernández-Solís, Lavy, & Rybkowski, 2010)* required from the leader, may or may not be a result of reasoned conflict with the current know-how. Nevertheless, it should be taken seriously as respect for the employee's experience and situation (Liker, 2004).

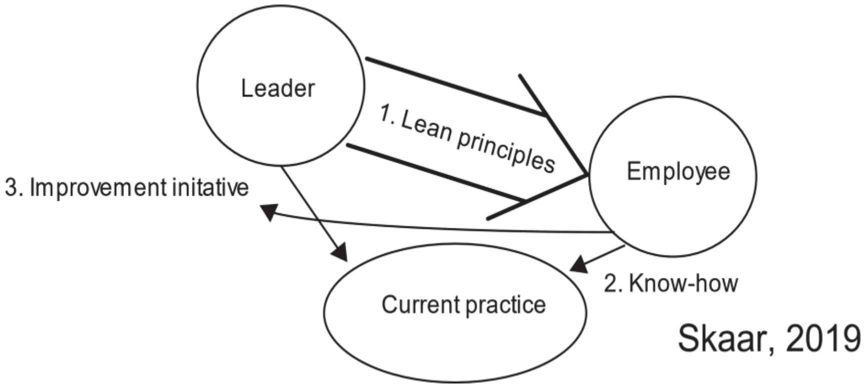


Figure 49 A lean leader pushing the principles towards the employee, may enable the employee to understand the lean mindset directly.

The reasoning behind using principles directly can also be summoned threefold:

1. A lean principle may spur lean thinking on its own, and consequently, the employee will be able to adapt their behaviour according to lean in changing and new contexts. In other words, enabling the employee to develop a lean mindset on their own (Howell & Ballard, 1998).
2. A leader may avoid pushing a wrong or have the wrong timing of a solution if the employee gets the first opportunity to initiate countermeasures to a problem (Harford, 2011). With a present leader, the improvement initiatives can be discussed in order to make sure it complies with tactical and strategic decisions and organisational standards (Liker & Convis, 2012).
3. Making the principles to be the spoken carriers of the lean culture, might empower the whole organisation to have a more innovative, flexible and agile approach to lean.

   A point grounded in the effect of trust building (Smith, Rybkowski, Bergman, & Shepley, 2014) and empowerment (Harley, 1995).

Literature has shown the importance of lean leaders to understand lean thinking (Howell & Ballard, 1998), but why stop with the leaders? In a project-based industry with many different actors, getting the leaders to think lean is a challenge; everyone else involved even so. But if the goal is to develop a lean mindset, why not challenge the employees with what has been created to present the core of lean thinking, namely the lean principles? This paper wants to explore the effect of exposing lean principles directly towards the employee, and we start with the skilled workers.

The reason for starting with the skilled worker is twofold;

1. Regarding the skilled worker as the value creators in production (Liker & Convis, 2012) and the rest of the organisation, if not directly creating value to the customer should serve the value creators (Goldratt, 2004). This way of seeing an organisation might be useful in reducing waste. This research adopts this view and puts the skilled worker as the starting point and "reverses" the research by going up the organisational line. Also inspired by the lean terms" Bottom-up" and “Go to Gemba” (Liker & Convis, 2012).

2. The research also builds on the assumption that the leaders in an organisation are more used to analytical processing in their line of work. It might be more challenging for the skilled worker to answer the lean principles, so an effect here might be more convincing.

METHODS

This paper's research view has a critical realism stand (Bhaskar, 2013). Thereby the epistemic fallacy (Bhaskar, 2013) is a core viewpoint. The epistemological (our study of knowledge) position might not be conceived to be relevant for practitioners and some academics but is essential for how we view the world and research, and thereby the methods the researchers use. Exploring fundamental views might lead to more in-depth knowledge also within lean construction as shown in previous work within Metaphysics (Our study of reality) of Koskela and Kagioglou (Koskela & Kagioglou, 2005, 2006).

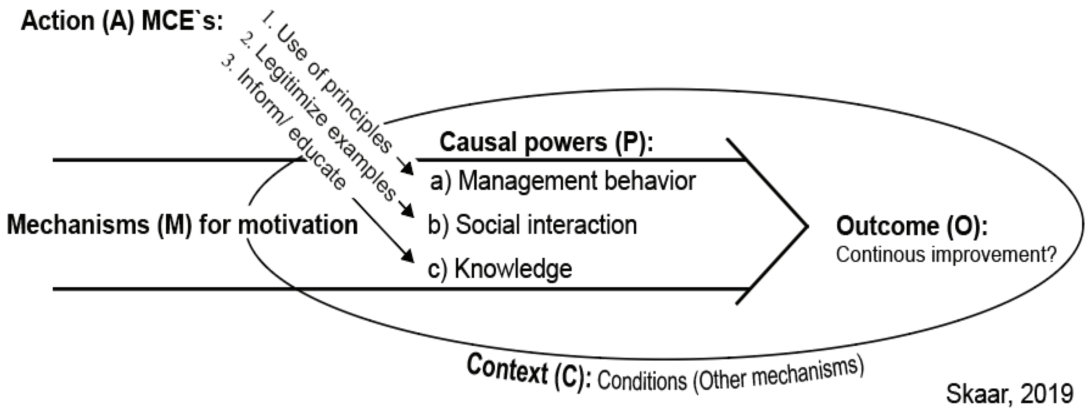


Figure 50 Methodology framework with stimulation of lean principles.

The underlying logic in figure 3 is from Ackroyd's Figure 6.1 "Realist explanation" in (Fleetwood & Ackroyd, 2004). The basis of this figure is that a critical realist imposes action (A) believed to affect an underlying mechanism (M) and seeks for causality linked to the outcome (O) (Fleetwood & Ackroyd, 2004). The study sees "motivation" as a **complex** mechanism, and we have defined motivation to "be moved to do something" (Ryan & Deci, 2000).

This paper link three assumed causal powers (P) to be central for the mechanism of motivation or challenges (Porwal et al., 2010) and the creation of positive outcome regarding improvement initiatives, namely;

1. **Management behaviour**: Challenge: Lack of leadership (Porwal et al., 2010). Countermeasure: 1.Use lean principles.
2. **Social interaction** Challenge: Organizational inertia & resistance to change (Porwal et al., 2010). Countermeasure: 2. Legitimize examples.
3. **Knowledge:** Challenge: Lack of training (Porwal et al., 2010), Countermeasure: 3. Inform/educate.

The researchers take an active role in testing and driving the principles in the project, so learnings from action-based research is relevant. The method has taken inspiration from

Lean Startup (Ries, 2011) literature, but instead of *Minimal Viable Products* (MVP), we named it *Minimal Causal Experiments* (MCE).

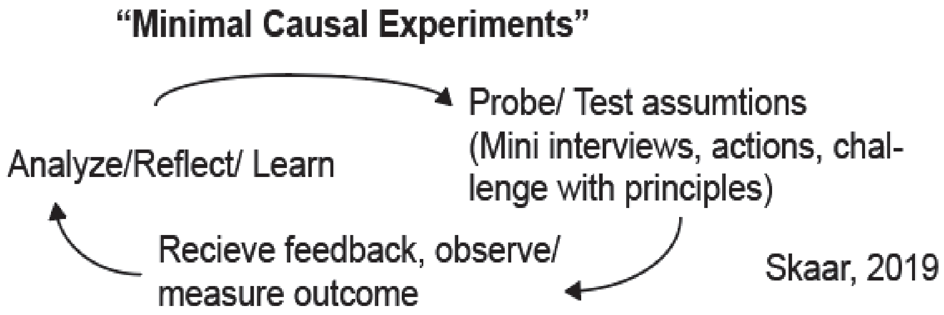


Figure 51 Inspired by Lean Startups "Minimal Viable Product" (MVP), the researchers conducted a learning loop named, "Minimal Causal Experiments" (MCE).

The loop visualised in figure 4 can be iterated many times during every encounter at the site. With the possibility to do a high pace of experiments, we can both gather information as from a traditional interview, but also directly educate, inspire and use principles in the field to spur the desired outcomes.

Alignment of interest between a research team and an organisation with lean ambitions gives unique possibilities to work together in a win-win situation. We learn from the obstacles and breakthroughs in the outcomes, and the organisations we research; get the improvements, more lean-educated personnel and hopefully a lean work mindset.

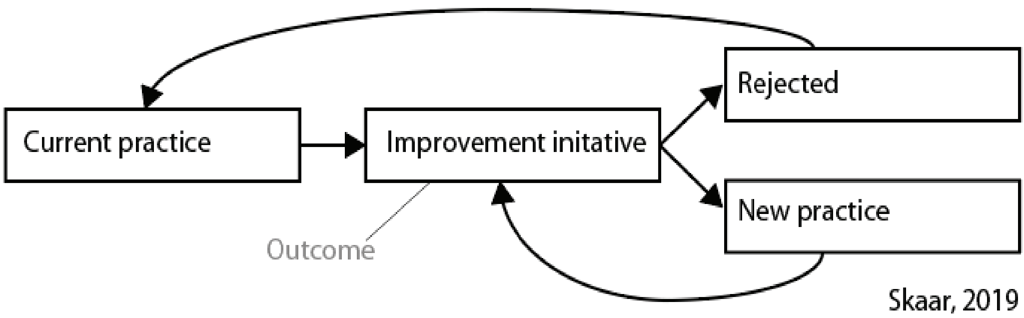


Figure 52 Any improvement initiative equals a desirable outcome

In short, we seek a deeper understanding of the actions giving tendencies in the mechanisms, the causal powers and the conditions spurring continuous improvement. Specifically, this paper seeks an understanding of whether a lean principle-based approach can be related to the preferred outcome.

This paper does not probe to distinguish between whether a person is intrinsic or extrinsically motivated (Ryan & Deci, 2000), though we note reflections and ask for their type of motivation. The research links findings to different models of social interaction and learning. The research relates the observation toward Kolbs (Holman, Pavlica, & Thorpe, 1997; Kolb, 1984), Illeris (Kalsaas, 2012), Bhaskar (Bhaskar, 2013) and Wilber (Bhaskar, Esbjörn-Hargens, Hedlund, & Hartwig, 2015) but the collected data is still insufficient for claiming contribution to these areas.

There are four construction projects involved with different case studies (Easton, 2010), supported by three master thesis and one bachelor thesis, with a total of 8 students, all linked to the start of a PhD study done by the author. This paper refers mainly to 3 of the projects where the project management actively stated and used the rephrased principles in their organisation.

FINDINGS AND DISCUSSION

The research focused on rephrased principles supporting flow, note that the rephrased principles only supports part of the potential within the more general principle. The list therefore not to be considered exhaustively.

General principle	The rephrased principles asked directly to the skilled workers.
Create Flow	• **"Reduce (your) movement"** [1,2] • **"Everything should have its place"** [1] • **"Everything should be mobile"** [2] • **"Everything on wheels"** [2] • **"Never go empty handed"** [1] • **"One piece flow"** [3]

The notation 1-3 behind the principles show how they were distributed over 3 individual projects. In the fourth project, the principles were not expressed to the skilled workers.

Examples of observations done with some of the rephrased principles follows:

CHALLENGING WITH "EVERYTHING ON WHEELS".

The observations below, are done by the author in a previous project that had weekly management rounds emphasising the principle "everything on wheels", and gave inspiration to the effect of rephrased principles;

1. One reaction was that the principle triggered solutions that gave easy moving of storage and workplaces from different locations and reduced unproductive time leaving and entering new areas (equality to SMED in production).
2. Another effect observed was that the workstation is rigged closer to the worker when doing work tasks; this seems to reduce the internal movement within the task process.
3. It also reduced the time spent clearing the area if another trade needed the space it occupied.
4. There were indications that a side effect of this principle was that employees kept the pathways tidy, motivated by increasing the mobility of the trolleys.
5. After a while, a "project culture" trying to answer the principle started to arise. It was indications that they repeatedly had to be nurtured by concise management that gave signals that they were not to abandon these principles; hence it became an expectation for everyone in the project.

Figure 53 Examples from a project that challenged with the principle "everything on wheels". Picture 1 Both workstation and part storage, picture 2 Larger trolleys used for electrical tubes, metal stud and mouldings. Picture 3. More standard solution. (Photo: J.S)

Challenging with “reduce movement." and "everything should have its place."

One of the projects in the research emphasised the two rephrased principles "everything should have its place." and "reduce movement." The management on the project added "never walk empty-handed." A selected team leader was quick to understand the intention of principle-based improvements. The management conducted a mixed leadership by giving orders to effectuate results and a more challenging/ stimulating approach. Some examples of the results are below:

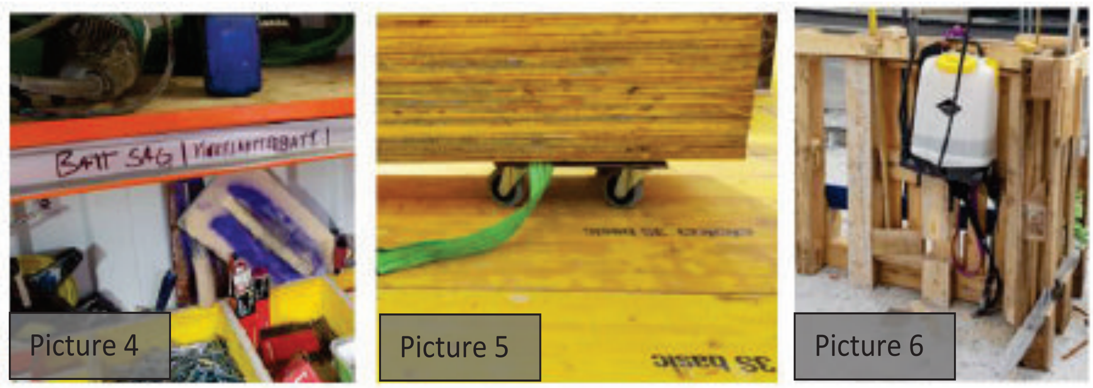


Figure 54 Picture 4: Inside a tool container, picture 5: A transport trolley and picture 6: A portable tool station. (Photo: J.Skaar)

Picture 4: The tool containers became an example, where continuous iterations took place within the containers but where the practice also spread to other teams.

Picture 5: A transport trolley was made to reduce the walking distance from primary storage to a moving workplace. But this became an example were further improvements to the trolley was acknowledged, but not effectuated.

Picture 6: A tool rack, as an answer to both principles, but at the same time an example of simplified solutions that still needed improvements to reach mandatory HSE standards.

A SUMMARY OF FINDINGS WITH DISCUSSION

After conducting a series of rapid interviews on randomly selected skilled workers, as a part of the “MCE approach”, the following observations came as a result:

- Almost all workers reported that they had heard about the “campaign”.
- It seems that rephrased principles are easy to understand.
- Many senior workers are already using “waste reduction” as a way of thinking, but even though they acknowledge a potential towards perfection, they seem satisfied with their current perception.
- Young workers need more exemplification than many senior workers, but at the same time, they appear to be more open to several iterations, with a possible link to that their actual improvement potential is more considerable for them also.
- After the first improvement initiatives, there is an indication that the creativity stops, there are therefore indications that many rephrased principles must be available to generate continuous improvement and the leaders need to follow-up progress and initiatives carefully.
- Around 50% of the improvement suggestions were suggestions outside the worker's area of direct influence.
- Work tasks with low frequency, are less motivational to improve than tasks done more frequently.

Some workers expressed a hostile or indifferent attitude against the use of principles. As a result, we did several "MCE" iterations around these attitudes to find the source of the attitudes expressed. Some of the findings follows:

1. Some of the hostile attituded was traced down to a "change in rules": As a part of "everything should have its place", all site containers had received their own "tagging colour", so that "yellow tagged tools, belongs to the yellow container". One of the teams reported that this had become a problem from them since their newly arrived container lacked necessary tools and when they tried to take equipment from others, they started to stress them more than usual.

In our opinion this is a positive effect, as in the Japanese sea, “lowering the water, to reveal the rocks”. The problem with their lack of tools became an issue, instead of hiding it by just taking from other containers and cause ripple effects in unproductive search for equipment.

2. A negative attitude could also be traced down to misunderstandings on the actual use of principles. One interpretation conceived the principle to be an order to "tidy their containers". When confronted with the information that the principles were meant to challenge and try to reduce their movements, one first reaction was "isn't movement good for our health?" Our respond made us reflect on the importance of emphasising that it is waste movements we want to reduce, not necessarily the the total amount.

Our reflection then became threefold. The information about how to think, differ from person to person, so management rounds might be an effective method to adjust some interpretations along the way. The intention of the principle is not always understood even if it produces some positive outcome. And finally, emphasising that the goal is for them to become more efficient without "running faster" is still relevant.

3. Some of the workers already use a way of thinking in their line of work comparable to the lean rephrased principles. Observing some smart working routines, made the need for an effective way to spread good ideas evident.

We observe that the first iterations with a rephrased principle often felt natural for the worker to do. We then observed more resistance when trying to improve the solution from the first iteration. The researchers reflected on that it's when you do several iterations, the less obvious potential of continuous improvement reveals itself. Being persistence within one lean principle may teach the scrutinises of lean.

LIMITATIONS AND FURTHER RESEARCH

The number of projects, interviews and "Minimal Causal Experiments" (MCE) are still low to draw strong causal links from the action. The use of MCE generates an active role as a researcher, that even talks on behalf of the management. A researcher that speaks on behalf of a manager alters a lot of the conditions in the situation we want to simulate. We defend the researcher's active role by the fact that it still is a more genuine situation than an answer on a survey. To get stronger tendencies, we believe we need to continue the fieldwork.

Focusing on only a few of all the lean principles, may limit the picture since it does not contain all aspects of improvement and hence give wrong prioritizations. Using a method for prioritising the most paramount principle are in order.

For further research, we are especially interested in seeking if positive feedback and recognition of a good attempt of improvement stimulate the repetitiveness of improvement initiatives. The use and form of visualisation in spreading new practices and supporting the process is also an exciting topic. At the same time, we have many different rephrased principles to test.

Regarding framework and methodology, can MCE rounds be useful both for researchers and managers to learn and educate the organisation on the use of principle-based management? How are our MCE rounds, inspired by Lean Startup (Ries, 2011), compared to methods reportedly used by management in Toyota like the "Ohno circle" (Liker & Convis, 2012) and "Toyota Kata" (Rother, 2010)?

This research is starting on an operational level to understand more about the mechanisms and actions to stimulate the powers for the desirable outcome and continue the approach up through the tactical level and up to strategic level. To be able to find a suiting lean framework for management in construction, it is natural to look towards Hoshin Kanri (Liker & Convis, 2012), but at the same time, this research wants to challenge it with more active use of lean principles and see how and where digitalisation can support the framework. The effects of a framework like this are still to be tested.

If lean tools and methods are pulled in from the use of principles, rather than pushed and whether the intrinsic motivation increases is still an assumption that needs more data to find stronger tendencies of causality. We hope that further research can create a much more self-driven culture on improvements after exposing projects more consistently with lean principles.

The case study has been conducted in Norway, a country where skilled workers are known for being independent and have a high level of training and education. The respect for skilled workers in Norway is also high, so the general culture on Norwegian construction sites is a part of the context.

CONCLUSION

We find causalities that challenging skilled workers directly with principles create motivation for the use of principles. Our initial assumption that rephrased principles give more direct outcome than general principles are also strengthened in this research. Rephrased principles have a shorter *lifespan,* in the sense that they are more specified. Rephrased principles need either be bundled or be replaced by other principles at a higher frequency than more general principles to reach over the same area of potential.

From the research, we can see tendencies that the skilled workers translate the rephrased principles into their working situation, with limited need for explaining. They often need some guidance to translate the more general lean principles, but the advantage of these is that they are less specific, and hence can be used in more situations. Still, it's a tendency that the level of motivation is stronger with the rephrased principles, so at least as an introduction to active use of lean principles, rephrased principles are an interesting mean.

REFERENCES

Almeida, J. C., & Salazar, G. F. (2003, 2003/01/01). Strategic Issues in Lean Construction. Paper presented at the 11th Annual Conference of the International Group for Lean Construction, Virginia, USA.

Ballard, G., Hammond, J., & Nickerson, R. (2009, 2009/07/15). Production Control Principles. Paper presented at the 17th Annual Conference of the International Group for Lean Construction, Taipei, Taiwan.

Ballard, G., & Howell, G. (1998, 1998/08/13). What Kind of Production Is Construction? Paper presented at the 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil.

Bertelsen, S., & Bonke, S. (2011, 2011/07/13). Transformation–Flow–Value as a Strategic Tool in Project Production. Paper presented at the 19th Annual Conference of the International Group for Lean Construction, Lima, Peru.

Bertelsen, S., & Koskela, L. (2002, 2002/08/06). Managing the Three Aspects of Production in Construction. Paper presented at the 10th Annual Conference of the International Group for Lean Construction, Gramado, Brazil.

Bhaskar, R. (2013). A Realist Theory of Science: Taylor & Francis.

Bhaskar, R., Esbjörn-Hargens, S., Hedlund, N., & Hartwig, M. (2015). Metatheory for the Twenty-First Century: Critical Realism and Integral Theory in Dialogue: Taylor & Francis.

Coetzee, R., Van Der Merwe, K., & Van Dyk, L. (2016). Lean implementation strategies: how are the Toyota way principles addressed? South African Journal of Industrial

Engineering, 27(3), 79-91. doi:10.7166/27-3-1641
Diekmann, J. E., Balonick, J., Krewedl, M., & Troendle, L. (2003, 2003/01/01). Measuring Lean Conformance. Paper presented at the 11th Annual Conference of the International Group for Lean Construction, Virginia, USA.
Easton, G. (2010). Critical realism in case study research. Industrial Marketing Management, 39(1), 118-128. doi:https://doi.org/10.1016/j.indmarman.2008.06.004
Emiliani, M., & Emiliani, M. L. (2013). Music as a framework to better understand Lean leadership. Leadership & Organization Development Journal, 34(5).
Fleetwood, S., & Ackroyd, S. (2004). Critical realist applications in organisation and management studies. London: Routledge.
Goldratt, E. M. (2004). The goal : a process of ongoing improvement: Third revised edition, twentieth anniversary edition. Great Barrington, MA : North River Press, [2004] ©2004.
Harford, T. (2011). Adapt: Why Success Always Starts with Failure: Farrar, Straus and Giroux.
Harley, W. B. (1995). Eight critical principles of empowerment. Empowerment in Organizations, 3(1), 5-12. doi:10.1108/09684899510079771
Holman, D., Pavlica, K., & Thorpe, R. (1997). Rethinking Kolb's Theory of Experiential Learning in Management Education: The Contribution of Social Constructionism and Activity Theory. Management Learning, 28(2), 135-148. doi:10.1177/1350507697282003
Howell, G., & Ballard, G. (1998, 1998/08/13). Implementing Lean Construction: Understanding and Action. Paper presented at the 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil.
Kalsaas, B. T. (2012). The Last Planner System Style of Planning: Its Basis in Learning Theory. Journal of Engineering, Project, and Production Management, 2(2), 88-100. doi:10.32738/jeppm.201207.0005
Kolb, D. A. (1984). Experiential learning : experience as the source of learning and development. Englewood Cliffs, N.J: Prentice-Hall.
Koskela, L., & Kagioglou, M. (2005, 2005/07/19). On the Metaphysics of Production. Paper presented at the 13th Annual Conference of the International Group for Lean Construction, Sydney, Australia.
Koskela, L., & Kagioglou, M. (2006, 2006/01/01). On the Metaphysics of Management. Paper presented at the 14th Annual Conference of the International Group for Lean Construction, Santiago, Chile.
Liker, J. K. (2004). The Toyota way : 14 management principles from the world's greatest manufacturer: New York : McGraw-Hill, [2004] ©2004.
Liker, J. K., & Convis, G. L. (2012). The Toyota way to lean leadership : achieving and sustaining excellence through leadership development: Maidenhead : McGraw-Hill Professional.
Neto, J. d. P. B. (2002, 2002/08/06). The Relantionship Between Strategy and Lean Construction. Paper presented at the 10th Annual Conference of the International Group for Lean Construction, Gramado, Brazil.
Picchi, F. A., & Granja, A. D. (2004, 2004/08/03). Construction Sites: Using Lean Principles to Seek Broader Implementations. Paper presented at the 12th Annual

Conference of the International Group for Lean Construction, Helsingør, Denmark.
Porwal, V., Fernández-Solís, J., Lavy, S., & Rybkowski, Z. K. (2010, 2010/07/14). Last Planner System Implementation Challenges. Paper presented at the 18th Annual Conference of the International Group for Lean Construction, Haifa, Israel.
Ries, E. (2011). The lean startup : how today's entrepreneurs use continuous innovation to create radically successful businesses. New York: Crown Business.
Rother, M. (2010). Toyota kata : managing people for improvement, adaptiveness, and superior results. New York: McGraw Hill.
Ryan, R. M., & Deci, E. L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. Contemporary Educational Psychology, 25(1), 54-67. doi:https://doi.org/10.1006/ceps.1999.1020
Santos, A. (1999). Application of flow principles in the production management of construction sites. (PhD), University of Salford, Retrieved from http://usir.salford.ac.uk/2231/
Smith, J. P., Rybkowski, Z. K., Bergman, M., & Shepley, M. (2014, 2014/06/25). Trust-Builder: A First-Run Study on Active Trust-Building. Paper presented at the 22nd Annual Conference of the International Group for Lean Construction, Oslo, Norway.

Dlouhy J., Binninger M., and Haghsheno S. (2019). "Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 405–416. DOI: https://doi.org/10.24928/2019/0249 Available at: <www.iglc.net>

LESSONS LEARNED ON TEACHING CHOOSING BY ADVANTAGES

Paz Arroyo[1], Randi Christensen[2], Annett Schöttle[3], and David Long[4]

ABSTRACT

Decision-makers on construction projects are faced with complex, multidimensional challenges that require grounded, thoughtful decisions be made to further the project. This paper discusses a breadth of strategies for training construction teams to implement the Choosing By Advantages (CBA) decision-making method. These strategies are analyzed based on coaches' experiences and observations in terms of short and long-term learning outcomes. The unique circumstances of every construction project require that lean coaches draw from a variety of teaching techniques to tailor the learning process to the specific needs of trainees. For example, while some trainees can quickly learn the basics of CBA theory, they often struggle to implement CBA in a practical context if not provided with proper support. Coaching proves efficacious in enabling construction teams to both make and carry-out decisions, however, a long period of training (12-16 weeks) is often necessary for thorough implementation and expertise in CBA.

KEYWORDS

Learning, teaching, choosing by advantages, decision-making.

INTRODUCTION

CBA is a decision-making system developed by Jim Suhr that is based on four principles: (1) Decision-makers must learn and skillfully use sound methods, (2) Decisions must be based on the importance of advantages, (3) Decisions must be anchored to relevant facts, and (4) Different decisions call for different methods. This paper will focus on the first principle (Suhr 1999). CBA has gained more attention in the construction industry in recent years. This increase has been driven by demands for more collaborative project organizations and transparent decision-making processes; by the synergy of CBA with other agendas such as improving sustainability and safety; and by an increasing need to incorporate multiple factors into the decision-making process. However, as the construction industry simultaneously prioritizes delivery logics confined by tight schedules

1 DPR Quality Leader, San Francisco, CA, PazA@dpr.com, and Founder and Co-Director, CollabDecisions, www.collabdecisions.com.

2 Lean Manager, Lower Thames Crossing, COWI, UK, RMCH@cowi.com and Founder and Co-Director, CollabDecisions, www.collabdecisions.com.

3 Senior Consultant, Refine Projects AG, Stuttgart, Germany, annett.schoettle@refineprojects.com and Founder and Co-Director, CollabDecisions, www.collabdecisions.com.

4 Regional Lean Manager, Turner Construction Company, Oakland, CA., dalong@tcco.com.

and budgets there is a competing desire to maximize efficiency and timeliness in training processes. Decision-makers seek training protocols with minimal disruption of delivery, even at the expense of quality in education. It is therefore crucial for decision-makers and coaches to think critically about how to provide the most effective training based on the financial resources of the project. This paper compares the experiences of four CBA coaches working separately in different countries and analyzes the skill development of the teams based on the methods of training they received. The primary research question is: What are the benefits and shortcomings of each of the CBA training methods employed by the coaches studied in this paper? This will be evaluated by comparing different styles of training with the learner's subsequent ability to implement CBA. First, this paper will present relevant literature on human learning to contextualize the need for a range of training options. The research methods used to observe more than 30 CBA trainings will be explained and the accompanying data presented. Finally, the outcomes will be discussed, and conclusions drawn regarding how this research can facilitate other coaches and decision-makers in the industry in personalizing CBA trainings to every unique audience.

LITERATURE REVIEW ON LEARNING

LEARNING NEW PRACTICES

Each individual begins the learning process from their own context of prior knowledge and experience (Nonaka and Takeuchi 1995). Through this lens individuals negotiate new situations in relation to pre-formed expectations that serve as a filter for incoming mental stimuli, and thus deviations from expected occurrences garner more mental attention than do normative situations (Nørretranders 1991). Daniel Kahneman distinguishes between System 1 and System 2 mental processing to further elucidate how individuals process information; System 1 operates based on intuition and instinct, while System 2 allocates mental attention to occurrences and activities that are unusual or require complex computational thinking (Kahneman 2011). Simultaneously, according to the pragmatist John Dewey, when a situation does not comply with an individual's expectation their perception of the world is challenged (Elkjær 2000). The resulting conflict between the situation and expectation creates the potential for learning through critical reflection and increases the ability to respond to similar situations in the future (Christensen 2008). The integral role of expectations as the context for learning means that it is essential for teachers to consider what knowledge, experiences, and habits learners have already integrated in their perception of the world. However, even while the tension between expectation and reality opens new avenues for mental growth, Brown and Duguid (1991) point to the problem that "most learning theory, including that implicit in most training courses, tends to endorse the valuation of abstract knowledge over actual practice and as a result to separate learning from working and more significantly, learners from workers" (p. 41). The disconnect between theory and practice is a barrier for learners' ability to apply newly acquired knowledge either in a practical setting or even in more complex thought scenarios requiring analysis on the level of System 2 thinking (Kahneman 2011; Münster 2017). Thus, it is not only the individual perspective of the learner which is important, but also the approach of the coach, which impacts the ability of learners to apply the acquired knowledge or skills to a work situation. Moreover, learning is influenced by mood. Negative moods (e.g., confusion, resignation, frustration, arrogance, impatience, etc.), inhibit learning until they can be identified and navigated through. Other moods such as curiosity, patience, trust, wonder, confidence, and ambition can facilitate learning (Flores 2016). Sensitivity to the effects of mood in either disrupting or supporting the learning process suggests that learning itself is a skill defined by the ability to cultivate optimal learning environments and attitudes.

STAGES OF LEARNING AND EFFECTIVE WAYS OF TRAINING

Stuart and Hubert Dreyfus (1980) present a model of the mental activity involved in skill acquisition. They describe the stages from beginner, advanced beginner, competent, proficient, expert and master (see Table 1). After observing the learning processes of several professions, Dreyfus (1980) concludes that for an individual to successfully acquire new skills they must be willing to take risks, make mistakes, and be emotionally engaged. Practically speaking, this means accepting the joy of successes and accom-plishments as much as remorse over breakdowns and failures. Successful teachers and students are actively engaged in creating a mood that is conducive to learning. Different training settings will be more appropriate than others for the specific needs of the learners and requirements of the project - for example, a classroom approach will have a different impact on skill acquisition and development than a learning-by-doing approach.

Table 1: Dreyfus stages of learning.

Beginner	Follow rules, do not see context.
Advance Beginner	Task oriented, begins to recognize different situations.
Competent	Experienced in standard practices. Start to see patterns and principles.
Proficient	Developed intuitions on what needs to be done.
Expert	Intuition well developed. known how to act on different contexts.
Master	Subconscious Expertise. Can generate knowledge from anomalies.

RESEARCH METHOD AND DATA COLLECTION

This paper uses Design Science Research (DSR) to evaluate evidence of learning and gain knowledge to inform best practices (Van Aken 2004). Different CBA training methods were studied to understand the effects of each and to determine the circumstances for which each alternative is best suited. The following three criteria were defined for the purpose of the analysis:

- Ability of the team to make a CBA decision with an external facilitator
- Ability of the team to make a CBA decision without an external facilitator
- Ability of the team to teach CBA to other members who did not participate in the training

For the purpose of the study "ability" refers to the participants adherence to CBA principles, use of CBA language, and resistance to digressions back to previous practices. The study acknowledges that learning CBA is not a straightforward process, nor can it typically be completed in the course of a single training session. In describing the outcomes of each type of training the study refers to the Dreyfus stages of learning to evaluate skills acquired. These evaluations are based on the coaches' observations; feedback received during the training in the form of evaluations, comments, and questions; and subsequent conversations with participants, including requests for more support in applying CBA. During some of the trainings analyzed, coaches were able to directly observe participants applying CBA on projects and therefore judge the practical ability of the participants as a result of training. Recognizing the risk that coaches are biased towards the quality of their own performance, group critique and retrospective feedback sessions were regularly held to assess performance. The specific process of gathering evidence and data is further described for each training below. Table 2 identifies the seven training alternatives evaluated (A-H) as well as the number of trainings facilitated by each coach (C1 to C4).

TRAINING ALTERNATIVES AND EVALUATIONS

The following trainings were designed and implemented to coach construction industry practitioners in employing CBA. This section describes each alternative in detail.

ALTERNATIVE A - COACHING ONE DECISION

Often coaches are hired to help projects grapple with a single critical decision. For example, assistance was sought in choosing a ceiling material for a commercial building (see Arroyo et al. 2015) and in choosing a project architect and general contractor for a capital project. In these cases, coaches briefly presented CBA to decision-makers (30 to 60 minutes) and discussed how it might be implemented in the specific context of the project. Due to time constraints the presentation did not include practical examples or a systematic introduction to CBA. Further coaching and support were sometimes available after the presentation. The provided support varied from 4-40 hours of coaching depending on the initial basis of understanding with regard to the factors, criteria, and attributes of the decision with which the decision-makers began; the complexity of the decision in question; and the amount of data that stakeholders had gathered prior to training. In several cases decisions were delayed because more data was required or because new stakeholders had to be included in the decision-making process. The process was also fraught as practitioners unfamiliar with CBA were asked to diverge from habitual methods; several times participants proposed weighting a variety of factors rather than identifying advantages, or tried to include cost as a factor rather than a constraint, both of which are antithetical to the CBA method.

Table 2: Overview of training alternatives

	Training alternatives	C1	C2	C3	C4
A	– 30 to 60 minutes explanation of CBA and then facilitate a team decision supported by a coach (from 1 to 5 days). – Internally for a project, including different stakeholders.	4	1	0	2
B	– 30 to 60 minutes explanation of CBA and then facilitate a series of team decision supported by a coach for 10-12 weeks. – Internally for a project.	2	0	0	1
C	– Remote training 2 hours per week for 12 weeks, in addition to coach support for several decisions. – Internally for a project.	1	0	0	0
D	– Face to face training 2 hour per week for 10 weeks (1-hour training and 1-hour coaching on practical examples form the project), plus minimum 2 CBA decisions with trained facilitator as coach. – Internally for a project.	0	1	0	0
E	– 1-day CBA workshop. – Mixed project teams and companies. Usually sponsored by an organization or universities.	5	0	0	3
F	– 2-day CBA workshop. – Mixed project teams and companies.	1	0	0	0
G	– ½ day CBA workshop with practical training on user examples – Same company, different countries, departments and mgmt. levels.	0	0	13	0
H	– 1-day training as part of a CBA train the trainer certification process. – Same company, different countries, departments and mgmt. levels.	0	0	1	0

ALTERNATIVE B - COACHING SEVERAL DECISIONS

Coaches also respond to requests to help projects with several decisions, such as choosing the interior design, MEP design, and landscape design of a capital project for an IT company in the U.S. (Arroyo and Long 2018); or choosing the location, layout, structural system materials, and schematic design of a commercial building in Chile. In these cases, in addition to a brief CBA introduction (as in Alternative A), coaches had the opportunity to introduce CBA in different practical contexts and participants gained more exposure to the method by making decisions together. After making several decisions (4-20) using CBA practitioners had both learned the theory and had the chance to integrate that knowledge, leading to a greater understanding of why CBA focuses specifically on the importance of advantages involved in decisions. Practitioners began to take initiative in the decision-making process by, for example, identifying alternatives without being prompted by the coach, investigating factors and criterion, and coming to meetings with pre-prepared lists of attributes. In most cases, by the end of the third to sixth decision made with the CBA coach, practitioners had developed skills that would qualify them as "advanced beginners" to "competent".

ALTERNATIVE C - FORMAL TRAINING

In some cases, companies seek formal training for their employees or project participants. In one instance, the hired coach developed a training program for 10 team members, working for a U.K. highway tunnel project (Highway England) to be educated in facilitating CBA; 12 weekly 2-Hour sessions were conducted remotely. This extended training format allowed for in-depth study of CBA concepts, vocabulary, principles, and methods. Participants read relevant literature on the topic and completed learning exercises and homework tasks. The structure allowed participants to think through different application contexts, ask questions, and learn from their peers as well as from their coaches. After completing the training, students' knowledge of CBA varied from "advanced beginner" to "proficient." Several participants applied CBA to personal and work-related decisions and reported their successes back to the coach.

ALTERNATIVE D - FORMAL TRAINING AND COACHING

After receiving formal training (see Alternative C) the UK highway tunnel project (Highway England) adopted a systematic approach to CBA and adapted CBA tools to the specific needs of the team. This initial adoption of CBA motivated a request for further training, and a coach was hired to teach a second group of 15 project team members. As in Alternative C, the training was a mix of theory, practical exercises, discussions based on real cases from the project, homework, readings, and tests. Trainees also made real project decisions using CBA with support from one or two coaches. According to the coach, after this training participants skills varied from "competent" to "expert" in terms of them to support and lead decisions made with CBA. All trainees participated in a community of practice to coordinate, share and further develop their skills. Discussions in this group have revealed that multi-disciplinary training in CBA combining theory, practice and discussion supported a thorough understanding of CBA and the skill to facilitate workshops and apply CBA techniques to other settings.

ALTERNATIVE E - 1 DAY OPEN WORKSHOP

Conferences and universities have employed CBA coaches to facilitate single-day educational workshops. For example, coaches led presentations at IGLC 2014 in Norway, P2SL-LCI Lean Design Forum 2019 in California, University of Tallinn in Estonia in 2018, and LCI – Canada in 2017 and 2018. The audiences for these trainings represented multiple companies and stakeholders (e.g. owner representatives, architects, engineers, researchers, students) from different backgrounds and project experiences. Workshops aimed to provide an overview of CBA vocabulary, principles, and methods, and included role play exercises to practice skills introduced by the coach. After these workshops, participants' skill level in CBA typically ranged from "beginner" to "advanced beginner." While presentations motivated participants to further their learning or introduce elements of CBA in their work, they often struggled to implement CBA among professionals who were unfamiliar with the concepts and practices. Reliable assessments of the outcomes of these workshops are limited, however, following the workshop at LCI-Canada in 2018 coaches 1 and 4 had the opportunity to meet with participants from the previous year. Only one of these participants was actively using CBA in their organization. Several reported not having implemented CBA, although they expressed intention to do so.

ALTERNATIVE F - 2 DAYS OPEN WORKSHOP

In some cases, such as AGC Michigan in 2018, coaches were asked to lead a 2-day CBA workshop. As in Alternative E, participants came from a range of companies and with a variety of professional expertise. In addition to the curriculum of a single-day workshop, coaches discussed preference curves, provided more examples of CBA in practice within a variety of contexts, and drew connections between CBA and other lean management principles. Following a two-day workshop practitioners' skill level typically ranged from "beginner" to "advanced beginner", but in the coach's assessment these trainees saw more possibilities for CBA applications than those in Alternative E. After the training at AGC Michigan, a small number of participants requested that coaches support their implementation of CBA in subsequent decisions, demonstrating some level of commitment to applying the skills they acquired during the workshop.

ALTERNATIVE G - ½ DAY WORKSHOPS FOR ONE COMPANY

Coaches have also provided half-day workshops for specific companies. For example, 13 half-day workshops have been conducted as part of a CBA rollout at Daimler AG (see Schöttle et al. 2019). One workshop was facilitated in Mannheim in October 2018, one in Dubai in November 2018, four in Melbourne in December 2018, three in Beijing in January 2019, and four in Bengaluru in February 2019. Participants were beginners who had no prior knowledge of CBA and represented different departments and different management levels. Workshops were individualized to provide practical examples based on participants' needs. Both Two-list and Tabular methods were introduced and explained. CBA tabular exercises were initially to be based on pre-loaded examples by the participants, however the submissions did not contain the required information to develop an example, so pre-existing examples were used. Based on their reflections regarding the practical tabular exercise, participants understood the benefits of using CBA, but also recognized that more training and support would be necessary to implement CBA in their own work. The coach classified participants as "beginners" or "advanced beginners" after engagement in the workshop.

ALTERNATIVE H – "TRAIN THE TRAINER" WORKSHOP FOR ONE COMPANY

Coaches are also hired to train individuals in CBA facilitation using a "Train the Trainer" curriculum approach. For example, subsequent to the training at Daimler (see Alternative G), a group was identified to participate in a "Train the Trainer" certification program consisting of a 1-day kick-off workshop, a Study Action Group (SAG) reading and facilitation exercise, facilitation of a CBA training session, and coaching of a team to reach an important decision using CBA (see Schöttle et al. 2019). The 1-day kick-off workshop consisted of theory, practical exercises, a test, and guidance about how to facilitate CBA. The first group consisted of 15 participants from different countries, departments, and management levels. Some had previously attended a CBA workshop (see Alternative G), while others had no prior knowledge of CBA. Based on the test result, participants struggled with the precise CBA language, the principles, and the role of money in the CBA method. However, after completing the SAG, participants did have a better understanding of CBA than in Alternative G and after the entire "Train the Trainer" process the participants could be classified as "competent" to "proficient."

FINDINGS SUMMARY

Based on observations from separate training situations in several countries, the authors have distilled the main findings regarding the efficacy of a variety of methods for teaching CBA (see Table 3). Table 3 shows the several training and coaching alternatives discussed in this paper, all of which were designed to develop participants' skill in making decisions using CBA principles. All alternatives demonstrated that participants showed potential for decision-making using CBA with the support of a facilitator, however, the level of skill acquisition varied. Skill was best developed when a project team received a combination of formal training and coaching that was grounded in their specific project needs. Workshops provided an opportunity to introduce CBA, begin skill development, and inspire further learning, but participants did not demonstrate significant implementation of CBA in their own work following these trainings.

Table 3: Overview of the findings

Alter-nativ e	Ability to decide with facilitator	Ability of the team to make a CBA decision without external facilitator	Ability of the team to teach CBA to other member that were not part of the training
A	Likely, but requires a lot of time to get the team around to understand what information they need.	Not likely. Participants tend to go back to weight factors and attributes however they have slightly more awareness on the importance of the advantages.	Probably a practitioner can explain a decision, but not likely to train others.
B	Likely, but requires a lot of time to get the team around to understand what information they need. Time for following decisions decreases.	Probably at the end of the course, they can lead decisions, but depend on the level of engagement during coached decisions.	Probably at the end of the training, some participants can train new members.
C	Very likely, by the end of the training most practitioners have experienced a decision made with CBA.	Very probable at the end of the training, in fact many did.	Probably at the end of the training, most participants can train new members.
D	Very likely, by the end of the training all practitioners have experienced several decisions made with CBA.	Very probable as the training include them to co-facilitate decisions, and coach observed them.	Probably at the end of the training, most participants can train new members.
E	Uncertain, it is hard to assess whether a student will be able to follow CBA principles even with a facilitator.	Not likely. But some cases have been documented.	Not likely. But some cases have been documented.
F	Likely, participants have the chance make several decisions on the training, they will be able to apply CBA with a facilitator.	Not likely, participants do not necessarily can frame and lead the decision, especially for weighting advantages.	Not likely.
G	Likely, by the end of the ½ training participants have experienced a decision made with CBA in groups with the help of the facilitator.	Not likely. One person started to use CBA after the workshop. Others want to and will participate in a follow-up to learn more about the method.	Not at all. More examples and theoretical background knowledge necessary.
H	Likely, by the end of the 1-day training participants have experienced a decision made with CBA in groups with the help of the facilitator and have the chance of solve question in the SAG.	Not likely.	Not likely, but a few participants who attended several G trainings before were able.

DISCUSSION

In the domain of project delivery, decision logic is accepted to be linear and thus decision-makers have been rewarded for making decisions quickly, in isolation, and often disconnected from true customer value. Decision-makers used to this logic find it difficult to change their mindset to learn to make decisions collaboratively and based on the importance of advantages rather than by weighting, rating, and calculating, or listing pros and cons. Furthermore, CBA relies on staging the context of the elements of the decision, which is a level of preparation that few are accustomed to. The democratic and collaborative nature of the CBA process equally values the assessments of people at all levels within the organization. In certain organizations this dynamic can appear threatening to upper management, but it is also why CBA is more readily accepted in a lean organization. When applying CBA, practitioners often experience frustration and breakdowns on:

- **Vocabulary:** Practitioners need time to integrate CBA terminology into their professional vocabulary. Until they become proficient and the vocabulary comes to mind intuitively, it takes a significant effort on the part of the trainee to employ new CBA terms in practice.
- **Weighing advantages:** Practitioners tend to regress back to weighting factors in decisions and struggle to understand that when using CBA decisions are made based on the importance of advantages. It can be difficult for beginners to understand the importance of advantages, and to weight them.
- **Viewing cost as a factor:** Beginner practitioners habitually include cost as a factor in decision-making and struggle to trust CBA's approach of separating value from cost. They struggle even further when asked to recognize cost as a constraint.
- **Choosing the paramount advantage:** It can be difficult for a team to come to consensus when determining the single most important element in decision-making. Beginners especially struggle to view matters objectively and consider multiple perspectives. Many get frustrated and defensive; coaches play an essential role in helping them see differently.
- **Preference Curve:** For a beginner it is confusing to understand the preference curves when scaling the importance of advantages. They tend to struggle with the concept that, within a particular factor, if no alternative offers an advantage then the factor is irrelevant. This is particularly true when quantitative data is involved.
- **Argumentation:** Many beginners struggle with the use of ethos (appeal to authority or credibility), logos (appeal to logic), and pathos (appeal to emotion) in the argumentation component of CBA (Arroyo et al. 2014). Being more conscious of these strategies, as well as using legal procedure principles, can enable teams to realize a more equitable decision-making process (Koskela et al. 2018).

Decision makers should consider the needs of the project or organization, the desired competence level of the learners, and the context of the learning environment before deciding on the type and extent of the training. Projects that need support in making a particular decision might benefit from a short introduction to CBA followed by individualized coaching (Alternative A). Others might need support with several decisions (Alternative B and G), or only want an introduction to the method and its potential before committing to more systematic training and implementation (Alternative C, D, and H). Systematic training within the work environment is the most extensive training option and offers the strongest outcomes. Learning is best achieved by integrating CBA in daily practices and routines such that theory is directly anchored to practice. Conducting workshops outside of specific workplace environments (Alternatives E and F) may be effective in providing some inspiration, but is unlikely to lead to significant behavioral or methodological changes. Implementing CBA after an introductory workshop would require considerable self-study and self-discipline, and many attendees who participated alone or as a small group would likely struggle to integrate the knowledge into a larger organization. The findings thereby show a clear connection between experiential learning and the ability to apply the acquired knowledge independently.

CONCLUSIONS

Short training sessions and coaching a team for a single decision can allow a team to move forward with a particular decision, however this level of education is unlikely to result in the team's ability to utilize CBA without support. Alternatives B, C, D, G, and H, in which coaching, and training is organization-specific, and several practitioners are learning together in a practical environment, offer the best opportunity to develop advanced skills and the ability to implement CBA without a facilitator. In particular, Alternatives D and H, where formal training and coaching is provided over 12-16 weeks, offer the most promising opportunities for developing expertise. A successful training has to facilitate experiential learning, familiarize trainees with CBA language, and address initial resistance to the CBA method.

This research was limited by the imprecision in tracking and measuring the impact of each training alternative, given a lack of opportunities for following up with most training participants. This is particularly true of Alternatives A, E, and F. However, all coaches have received feedback from some participants. Furthermore, the results of this paper could potentially be transferred to other types of lean training e.g. training of The Last Planner System, providing an opportunity for further research.

REFERENCES

Arroyo, P., Ballard, G., and Tommelein, I. D. (2014). "Choosing by advantages and rhetoric in building design: Relationship and potential synergies." *In Proc. 22nd Ann. Conf. of the Int'l Group for Lean Construction*, Oslo, Norway, 391-408.

Arroyo, P., Tommelein, I. D., and Ballard, G. (2015). "Selecting globally sustainable materials: a case study using choosing by advantages." *Journal of Construction Engineering and Management*, 142(2), 05015015.

Arroyo, P., and Long, D. (2018). "Collaborative Design Decisions" In: 2*6th Ann. Conf. of the Int. Group for Lean Construction,* Chennai, India, 463-472

Brown, J.S, and Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning and innovation. *Organization Science,* 2(1), 40-57.

Christensen, R. (2008). *Development Practically Speaking, Learning processes in the Danish Construction Industry*. PhD Thesis, Aalborg University.

Dreyfus, S.E., and Dreyfus, H.L. (1980). A five-stage model of the mental activities involved in directed skill acquisition. *California Univ. Berkeley Operations Research Center*, No. ORC-80-2. Berkeley, CA.

Elkjær, B. (2000). The Continuity of Action and Thinking in Learning: Re-visiting John Dewey. *Outlines, Critical Social Studies*, 2, 85–101.

Flores, G.P. (2016*). Learning to Learn and the Navigation of Moods: The Meta-skill for the Acquisition of Skills*. Pluralistic Networks Publishing.

Kahneman, D. (2011). *Thinking, Fast and Slow*. Penguin Books.

Koskela, L., Arroyo, P., and Ballard, G. (2018). "Designing as a Court of Law." In:, 2*6th Ann. Conf. of the Int. Group for Lean Construction,* Chennai, India, 614-624.

Münster, M. (2017). "Jytte fra Marketing er desværre gået for i dag, Sådan bruger du adfærdsdesign til at skabe forandringer i den virkelige verden (How to use behavioural design to create changes in the real world. In Danish). ISBN 0799702243581, Gyldendal A/S.

Nonaka, I., and Takeuchi, H. (1995). *The knowledge creating company.* Oxford University Press.

Nørretranders, T. (1991). *Mærk Verden, En beretning om bevidsthed*. Gyldendal.

Schöttle, A., Gigler, L.M., and Mingle, B. (2019). "From concept development to implementation: Choosing by advantages across an organization." In Proc. 27th Annual *Conf. of the Int'l Group for Lean Construction*, Dublin, Ireland.

Suhr, J. (1999). *The choosing by advantages decisionmaking system*. Quorum, Westport.

Van Aken, J.E. (2004). "Management Research Based on the Paradigm of the Design Sciences: The Quest for Field-Tested and Grounded Technological Rules." *Journal of Management Studies,* 41(2), 219–246.

Dlouhy J., Binninger M., and Haghsheno S. (2019). "Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 405–416. DOI: https://doi.org/10.24928/2019/0249 Available at: <www.iglc.net>

STREAM 7: ABOUT TAKT TIME PLANNING

Lehtovaara, J., Mustonen, I., Peuronen, P., Seppänen, O., and Peltokorpi, A. (2019). "Implementing Takt Planning and Takt Control into Residential Construction" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 417–428. DOI: https://doi.org/10.24928/2019/0118. Available at: <www.iglc.net>.

IMPLEMENTING TAKT PLANNING AND TAKT CONTROL INTO RESIDENTIAL CONSTRUCTION

Joonas Lehtovaara[1], Iina Mustonen[2], Petteri Peuronen[3], Olli Seppänen[4] , and Antti Peltokorpi[5]

ABSTRACT

This study addresses the suitability of takt planning and takt control (TPTC) for the interior phase in residential construction projects. The purpose is to gain understanding on how to best implement TPTC in residential construction.

The study was conducted as a qualitative case study, by investigating TPTC implementation for the interior phase in a residential construction project in Finland. The initial motivation for takt implementation was to achieve better flow efficiency and radically shortened production duration. The analysis was based on 14 interviews, site observation, data from digital control tools and workshops, and aimed to identify lessons learned as well as required future development actions in TPTC implementation.

The findings indicate that TPTC is well suitable for the interior phase and even in the first pilot project it substantially reduced the project duration. However, certain barriers, as well as enablers, were identified in both planning and control phases, which can be adopted as a basis for continuous development. For example, more detailed planning of wagons and tighter collaboration between all the project participants should be considered. The study represents the category of applied research and has implications for achieving the full potential of takt planning and control in the future.

KEYWORDS

Takt planning, takt control, lean construction, residential construction

---

1 Doctoral Candidate, Department of Civil Engineering, Aalto University, Finland, joonas.lehtovaara@aalto.fi

2 Site Engineer, Fira Oy, Finland, iina.mustonen@fira.fi

3 Production Engineer, Fira Oy, Finland, petteri.peuronen@fira.fi

4 Professor of Practice, Department of Civil Engineering, Aalto University, Finland, Olli.seppanen@aalto.fi

5 Assistant Professor, Department of Civil Engineering, Aalto University, Finland, antti.peltokorpi@aalto.fi

INTRODUCTION

Production planning and control are key contributors to successful and flow-efficient construction projects (e.g., Koskela 1992). During the last two decades, the Lean Construction community has invested considerable effort to develop tools and systems for more efficient production planning and control, and several case studies have been reported where lean methods were employed to successfully improve the construction workflow. Especially the implementation of collaborative planning methods such as Last Planner System (LPS, Ballard 2000) and the shift from activity-based to location-based management (LBMS, Kenley & Seppänen 2010) have shown their potential in improving flow efficiency. Recently, production planning and control methods *Takt Time Planning* (TTP) and *Takt Planning and Control* (TPTC) have received attention within the Lean Construction community. TTP and TPTC have shown great potential in radically decreasing production durations, and for example, Frandson et al. (2013) and Binninger et al. (2018) have documented 55% and 70% reductions, respectively, in durations by implementing takt production.

Takt is a lean concept, which refers to a constant production time in different work tasks. According to by Hopp & Spearman (2008), "*takt time is the unit of time within which a product must be produced in order to match the rate at which that product is needed*". In construction, takt practically means balancing the work tasks in order for them to proceed in the same beat, around the same unit of time. Takt in construction has been explored especially in California by Frandson & Tommelein (e.g. 2016, *defined as TTP, takt time production*), and in Germany, by Dlouhy & Binninger (e.g. 2016, *defined as TPTC, takt planning and takt control*). Although there are differences between the approaches, the basic principle of working around the balanced beat exists in both systems. Takt planning is based on identifying repetitive processes and sub-processes, after which production is optimized from the process perspective, and not from the product perspective which leads to sub-optimization (Dlouhy et al. 2016). Thus, the benefit of takt surfaces from its structured and methodological way of planning as well as daily control of the production, and therefore, achieving stability and continuous flow (Tommelein 2017). For clarity, we refer to both approaches as takt planning and takt control, TPTC.

As takt planning and control is by its nature suitable for highly repetitive work (Binninger et al. 2018), it would appear to be suited especially well for the interior phase of residential construction. However, little empirical research exists on TPTC implementation in residential construction projects. Also, only a few studies have documented the actual implementation and critical analysis of takt controlled cases (listed in Table 1). Documented cases cover mainly factory and hospital projects, while only Vatne & Drevland (2016) have observed the implementation and carried out critical analysis of takt planning in residential projects.

Therefore, it is necessary to examine ways in which TPTC could improve the flow efficiency and reduce production duration in residential construction. In addition, research is needed on investigating that are the methods used in other cases applicable to repetitive residential construction. The study aims to contribute to the mentioned research gaps by answering the following questions: *1) Is takt planning and control suitable for improving* *flow efficiency and shortening overall duration in the interior phase of a residential construction project?* and *2) which barriers, enablers and possible actions for development appear while implementing takt planning and control in residential construction?*

Table 1: Documented takt cases that include a detailed analysis of the implementation

Authors, year	Case and primary observations
Binninger et al. 2018	**Retail space renovation**: *Reduced production duration by 70%; extended planning and tight integration of participants required*
Etges et al. 2018	**Steel Mill**: *Good initial results, barriers consider mainly the resistance to change*
Dlouhy et al. 2016	**Large scale vehicle factory**: *Increased transparency, reduced production duration by 45%*
Mario & Howell, 2012	**Infrastructure project**: *Reduced waste (overproduction and wait), enhanced buffer control*
Frandson & Tommelein, 2016	**Hospital, interior phase**: *Takt planning shortened duration; require a more holistic approach to planning and strategic usage of buffers*
Frandson et al. 2013	**Hospital, exterior phase**: *Reduced production duration by 55%; obstacles regarding communication, commitment, and support*
Vatne and Drevland, 2016	**High-rise building with apartments and kindergarten**: *Reduced waste and duration, increased transparency but also obstacles including the tradition of working and revenue models*

RESEARCH METHOD

The research was conducted as a qualitative case study, focused on the interior phase of a construction project located in Helsinki, Finland. The data were primarily collected through semi-structured theme interviews, and in total, 14 interviews of the GC and trade partners' employees were conducted. Interviewees consisted of site managers, GC project personnel (such as procurement and design managers), as well as heads and workers of trades. Interview themes included technical details of planning, control, management, training and visualization, but also addressed social aspects, such of the involvement of stakeholders in the planning process, training of methods and tools, leadership, and overall satisfaction of implemented lean principles, processes and tools. Two of the interviews were conducted as group interviews, where the issues were analyzed with GC's site personnel. To triangulate the data collection and increase the reliability of the study (Patton 1999), data collection also included site visits, observation of project documentation as well as participation in production meetings. The observation addressed themes similar to those in the interviews. Site visits and meeting observations were conducted thorough the interior phase approximately once per week.

In addition to interviews and observation, some useful insights were also observed through digital monitoring tools which were piloted in the project by the GC (tools are introduced more thoroughly in case description). The implementation was done to gain quantitative data for further analysis of the production. However, as the interviews indicated that the quantitative data suffered from irregular tracking and poor utilization rate of tools, instead of conducting a thorough data analysis the tracking results were only used to support the qualitative observations.

The data were clustered according to the representative work stages, which were further analyzed through the 5-why root cause analysis. The 5-why analysis was chosen for its simplicity and efficiency and because it is exceptionally well suited to analyzing the production (Jabrouni et al. 2011). The analysis was conducted in order to understand the process on a deeper level and to connect the visible observations with root causes, which generally remain undiscovered during production. At the same time, recommendations for further process development were presented.

Furthermore, the observations and identified recommendations were synthesized by dividing them into two categories: **planning** (actions that need to be addressed before the production) and **control** (addressed during the production). The synthesis was conducted to provide a systematic way to learn and implement the actions in the future. Finally, conclusions were drawn regarding the actions that were seen to be the most critical for effective takt planning and takt control. The study was limited to the interior phase, and more specifically, to the work stages inside the apartments.

RESULTS AND ANALYSIS

CASE DESCRIPTION AND TAKT PLANNING

The studied case project is a seven-story residential building project located in Helsinki, Finland. The project was conducted through design-build delivery, orchestrated by the general contractor Fira, which was responsible for TPTC implementation. The building consists of 42 apartments, and their floor design varies from 31m2 studio apartments to 83m2 three-bedroom apartments. Also, floor designs vary in their shape and therefore are relatively challenging regarding repetitive planning. The production phase was preliminarily scheduled for 15 months, which provided a starting point for the takt planning.

The goal of the takt implementation pilot was to radically decrease the duration of the interior phase, without increasing costs or decreasing quality. The planning phase partially adapted the steps presented by Frandson et al. (2013): (1) *Gather information*, (2) *Define areas of work (zones),* (3) *Understand the trade sequence*, (4) *Understand the individual trade durations*, (5) *Balance the workflow* and (6) *Establish the production plan*. The planning phase consisted of two iterations. The first iteration was based on theoretical durations of the tasks combined with the main contractor's data and experience, whereas in the second iteration subcontractors were engaged through interviews and workshops. The main contractor attempted to include all the subcontractors in the planning, even though the decision to implement takt planning in the interior phase was done after most of the subcontractors were already contracted by the project.

A single apartment was determined as a takt area and was divided into two SSU's (standard space units): the bathroom and the rest of the apartment. The takt time was set as one day, which was justified to be reasonable for the given small, easy-to-visualize, repeatable takt areas and suitable for the goal of radically reducing production duration (Binninger et al. 2018). As an exception to one-day takt, wall levelling and painting were planned using a takt time of one week. Daily planning of the mentioned tasks would have required more thorough planning with the subcontractor and was set for improvement action for following projects. Some of the tasks were also divided for two days (batch size 0.5) and some contained multiple locations in same day (batch size > 1). The initial takt plan focused on the apartments, and the takt plan for the other functional areas such as storage and shared spaces were determined separately, which also functioned as backlog areas. After the second iteration, the production time for the interior phase was scheduled for 18 weeks. The estimated time saving through takt planning was ten weeks, a saving of approximately one third (35%) compared to the situation where the detailed planning would be done with traditional methods.

The schedule after the second iteration is presented in Figures 1 and 2. Figure 1 represents train 1, which includes apartment dry areas. Figure 2 represents train 2, which includes apartment bathrooms. In the study the interior phase is inspected through three stages, which are reflected in the different issues that were observed during the process, and which provide a tangible overview of the interior phase. *Early-stage production and ramp-up* includes painting and tasks before the painting, and include roughly the first six weeks of the 18-week phase. *Mid-stage production* considers tasks from ceiling equipment to floor laminate installation, spanning roughly six weeks. Last, *end-stage production and handover* roughly consists of the last six weeks of the interior phase.

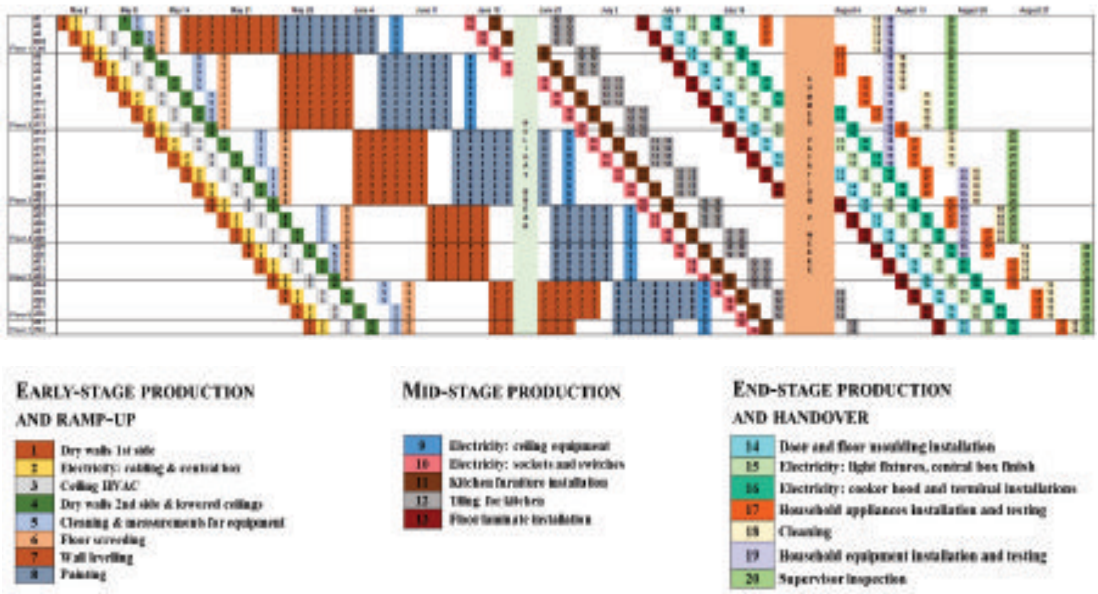


Figure 1 Takt schedule for the interior phase (train 1, dry areas in apartments)

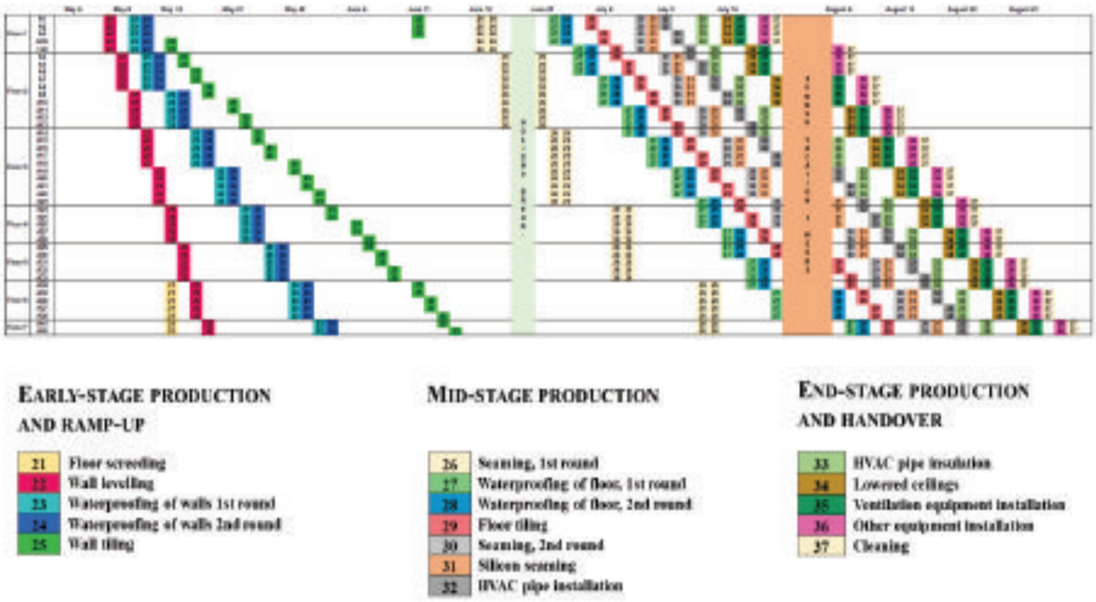


Figure 2 Takt schedule for the interior phase (train 2, bathrooms)

Plenty of effort was put in addressing the flow between the trains. Some of the tasks were possible to complete simultaneously in both locations, but some tasks, such as floor screeding, wall levelling and painting (tasks 6-8) required the usage of both spaces, which blocked the movement of the second train. This resulted in a three-week idle in bathroom train in May-June. Flow between the trains was found to be a problem also later in the control phase, where the avoidance of train clashes required significant amount of management effort.

The production was controlled through three weekly site meetings: 1) *the takt control meeting* which covered issues related to schedule; 2) *the contractor meeting* which covered issues related to technical issues; and 3) *the site manager meeting* which covered general contractor's internal issues. In addition to piloting TPTC, the main contractor also implemented several new digital project management and control tools for the interior phase. The most remarkable implementation was a new digital schedule planning and control tool *SiteDrive*, which allowed real-time inspection and control of the schedule through a mobile application. In addition, the production was tracked with the quality inspection tool *Congrid* and with indoor sensors which tracked drying, indoor conditions, and temperature in real time.

EARLY-STAGE PRODUCTION AND RAMP-UP

The interior phase was initialized as a so-called hard start, without any specific, slower ramp-up. It was soon realized that this caused various problems, the most remarkable one being the inadequate commitment of subcontractors towards takt. In addition, more time should have been reserved for inspecting the quality of the works in the first apartments, so the multiplication of defects could have been eliminated more effectively. As TPTC requires an entirely new approach to resource, task, and communication management, more preparation would have been required to engage every participant fully. Certain conflicts between the contracts and requirements for tightly controlled takt production made it also hard for the subcontractors to commit to the plan entirely. When the workers were paid based on piece rates, they tended to sub-optimize their own processes and leave work unfinished. Fully committing to the takt plan would have decreased their hourly payment. This problem emerged especially during drywall installation.

In addition to the need for a softer start and better engagement of subcontractors, four important enablers were identified in the early stage and ramp-up: 1) the logistic and material control plan should be addressed well before production begins, 2) takt planning should particularly focus on the specified critical tasks (such as drywalls, floor screeding and wall levelling works), 3) effective control of drying is essential for minimizing bottlenecks, and 4) the design solutions should support constructability and be finished before production begins. The latter lesson was especially realized in unsolved clashes between HVAC and architectural designs, which caused major disturbances in the early phase of production. Overall, the early-stage production suffered from several drawbacks that were not considered during the planning phase, which caused the first weeks of takt implementation to be quite chaotic. The interior phase was partially restarted between the early and mid-stages, which provided a fresh start for the next phase.

MID-STAGE PRODUCTION

After the ramp-up, several control actions were implemented to continue production with one-day takt. Tighter control provided clarification and transparency for the management as well as for the subcontractors, but at the same time, challenged all the actors to control their actions more aggressively. Tight one-day takt caused some stress for the subcontractors, and control actions caused slight fluctuations in resource alignment.

In mid-stage, the production control tended to slide towards weekly location-based control, which occurred in situations where sufficient control actions were not analyzed and planned beforehand. Although the slide to weekly control was prevented, it was realized that intensive one-day takt also required more intensive planning of control actions. More detailed planning of other functional spaces and backlog areas might have helped to achieve more proactive control. In addition, better visual guidance would have been useful to keep everyone on the site aware of the changes and control actions.

Slow concrete drying disturbed the flow in the mid-stage. This was especially noted in material-intensive tasks such as floor laminating, where disturbances in work flow caused unnecessary moving and re-storing of materials. The realized workflow of floor lamination is illustrated in Figure 3: the flow shape is significantly different than planned. Drying also affected the flow in the apartments, where the two trains clashed due of work rearrangements. Although the space for the trains was different, some work phases such as floor laminating and bathroom tiling prevented the work in the same apartment altogether. On the other hand, proactive actions and flexibility of HVAC and electricity subcontractors helped to avoid many other possible problems that could have otherwise hampered the flow. Their proactive operation demonstrated the importance of motivated subcontractors that are willing to work within tight takt controlled production.

Despite the challenges faced, the flow of the production was increased in the mid-stage. Compared to traditional location-based management, problems were quickly detected and solved, which effectively prevented possible cascading delays effectively. In addition, information gained from real-time tracking tools enabled a proactive and transparent way of control, and for example, the drying of concrete was addressed in real time.

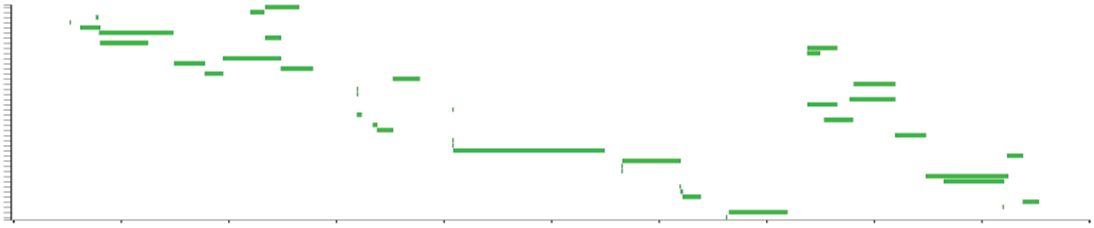


Figure 3 Illustration of realized workflow of floor lamination (from SiteDrive data)

END-STAGE PRODUCTION AND HANDOVER

Even though the middle-stage production progressed well, the production continued to slide towards the traditional weekly-based control in the end-stage. On the other hand, the actual benefits of TPTC were well-understood only at the end-stage of the interior phase. The active control of production eased the pressure during the end-stage, while most of the emerging problems were already detected and solved. In addition, the implemented digital scheduling tool allowed to look back on the realized actions, which also helped the subcontractors to gain insights and development ideas of their own performance.

The learning curve during the interior phase was steep from the viewpoint of both takt control and planning. Analysis of the lessons learned during the late production and handover allowed site management and subcontractors, but also actors involved in planning, procurement, and design operations to understand more deeply the requirements for effective TPTC. Overall, most of the actors were able to realize the potential, but also the demands of effective takt production. It is crucial to have a softer start and a detailed planning phase, where all the actors should gain an overall view of the requirements but also benefits of TPTC before the beginning of production.

DISCUSSION AND RECOMMENDATIONS

Although several items for development were observed, the implementation of takt planning and control was a success from the viewpoint of the general contractor and subcontractors. The cycle time of the internal construction phase was reduced radically by two months (nearly 30%), with only a slight increase in directs costs and no compromise with quality. As also noticed by Vatne and Drevland (2016), TPTC made it easy to spot errors and continuously steer the production proactively. While detecting and correcting errors daily is stressful, it helps to avoid cascading delays and overall improves the flow. In addition to various lessons learned, improved transparency during production and the potential of implemented digital tools indicated that TPTC is worth implementing in the future projects as well. Project personnel estimated that a 50% duration reduction should be possible in the future, while also improving quality and reducing costs. The analyzed and synthesized barriers are presented in Tables 2 and 3, together with the recommended enablers and actions.

Table 2: The most significant barriers, enablers, and actions connected to takt planning

Category	The most significant barriers	Recommended enablers and actions
Design operations	Unique and unfinished design solutions were the root cause of several bottlenecks	*Proactive and co-creative design management; implementation of modular solutions*
Procurement operations	Subcontractors and material suppliers were not prepared for the intensive TPTC	*Ability to commit on TPTC should be addressed in the procurement process; more effective revenue models*
Takt planning	Logistic and material control plan, control of drying and specified critical tasks were not planned thoroughly before production	*Co-operation with other pre-production operations; control of drying; detailed planning of logistics and determined critical, early-stage tasks*
Previous production phases	Lack of link of structural phase schedule and interior phase takt reduced the overall flow	*Takt planning should extend from affecting the individual construction phase towards a holistic approach*

For more thorough preparation and planning of takt production, resources should be ensured for proactive co-operation with design operations, procurement, and trade partners. As also noted by Frandson et al. (2013), a much higher level of planning is required for effective takt. On the other hand, Binninger et al. (2018) state that even though an extended planning period increases the benefits, the planning time is always somewhat limited and therefore should also be optimized. Vatne and Drevland (2016) also suggest starting the planning earlier as well as involving craftsmen, which also resonate with the findings from this study. The focus of planning should also be more centered on detailed, daily-based logistics planning (also Vatne and Drevland, 2016), control of drying, which typically becomes the bottleneck in takt production (also Binninger et al. 2018), the determined critical early-stage tasks as well as previous or adjacent work phases. These notions agree with the findings of Frandson and Tommelein (2016) and of Binninger et al. (2018), as they suggest that the whole production systems should be balanced more holistically.

Moreover, design solutions should promote the best constructability, not only the lowest cost. In addition to proactive co-creation in the design phase, the implementation of modular solutions, especially the use of modular and prefabricated, bathrooms could streamline takt production (Chauhan et al. 2018). The implementation could lower the risks and increase the flow, while eliminating the second takt train and almost halving the number of work stages operated in a single apartment.

The subcontractor's ability to commit to takt production should be addressed already in the procurement process, as the subcontractor's ability to perform takt can be hard to determine while participating in takt-controlled production for the first time (also noted by Binninger et al. 2018). In addition, the contract model should address the revenue logic of the main contractor, the subcontractor, and the individual worker in a manner that the contract itself creates no major conflicts while performing takt production. Vatne and Drevland (2016) similarly argued that in order to gain full monetary benefits from using takt, the current pay-per-square-meter revenue logic is insufficient.

Table 3: The most significant barriers, enablers, and actions connected to takt control

Category	The most significant barriers	Recommended enablers and actions
Takt control	TPTC implementation was not fully addressed beforehand, while hard start was too intense	*Mutual understanding of takt production requirements should be ensured through intensive training and a softer start*
Manageme nt of trades and tools	Daily control was not fully addressed; advantages of new implemented tools not fully realized due to poor data quality	*Daily control and full awareness of every actor on the site is required; effective learning requires better mutual understanding*

For optimal takt control, smooth onboarding with a softer start and higher-quality training is needed. The necessity of proper training of takt is also raised by Frandson et al. (2013), as they mention that the communication of the production plan and implemented methods effectively is the number one challenge of successful takt. Although construction production is by its nature always partially reactive, the methods for control and adjustment should be examined with all the actors before the production. The preparation is especially important in one-day takt, which challenges the actors to steer their actions in a somewhat hectic pace. Otherwise, production easily skids towards the traditional ways of working.

In addition to effective onboarding, daily control and constant situational awareness should be enabled. Daily routines and steering actions require a change in mindset for both management and subcontractors, but are pertinent for controlling one-day takt effectively. Moreover, the possibilities of new digital tools such as more accurate tracking of work and possibility of efficient learning should be also emphasized through the production. Digital scheduling tools could provide the needed visual guidance, a more agile and transparent daily control mechanism as well as an opportunity for continuous improvement through analysis of the collected data, but only if implemented and trained properly.

CONCLUSIONS AND AVENUES FOR FUTURE RESEARCH

The objective of the study was to address the suitability of TPTC for the interior phase of a residential construction project, where the initial goal of the implementation was to enhance flow efficiency as well as to radically shorten production duration. The study offered several lessons learned for future implementations. Even though TPTC challenged the team to work in a completely new manner and required increased effort, TPTC reduced cycle time substantially while also increasing transparency. Most of the lessons learned were related to planning operations, and several barriers should be tackled collaboratively with all the participants. If all or even some of the barriers can be solved, takt control itself could focus more on improving the production flow, and not only reactive firefighting. Further, better onboarding and adoption of digital control tools could enable more efficient takt control, but also provide an opportunity for more efficient learning from the process. It can be concluded that TPTC is suitable for improving flow efficiency and reducing duration of the interior phase of a residential construction project. The findings are based on a single case study, so further research is required to generalize the results. The future research could include addressing long-term effects takt production over several projects, and more thorough comparison of different takt methods and implementation cases.

REFERENCES

Ballard, H. (2000). The last planner system of production control.
Binninger, M., Dlouhy, J., Müller, M., Schattmann, M., & Haghsheno, S. (2018). Short Takt Time in Construction – a Practical Study. Proceedings (IGLC 26). Chennai, India
Binninger, M., Dlouhy, J., Steuer, D., & Haghsheno, S. (2017). Adjustment Mechanisms for Demandoriented Optimisation in Takt Planning and Takt Control. Proceedings (IGLC 25). Heraklion, Greece
Chauhan, K., Peltokorpi, A., Seppänen, O., & Berghede, K. (2018). Combining Takt Planning With Prefabrication for Industrialized Construction. Proceedings (IGLC 26). Chennai, India
Dlouhy, J., Binninger, M., Oprach, S., & Haghsheno, S. (2016). Three-level method of Takt planning and Takt control–A new approach for designing production systems in construction. Proceedings (IGLC 24). Boston, USA.
Etges, B. M. B. da S., Pereira, B. B., & Silveira, T. J. S. da. (2018). A Lean Approach to Improve Productivity in a Coke Oven Refurbishment Project: A Case Study. Proceedings (IGLC 26). Chennai, India.
Frandson, A., Berghede, K., & Tommelein, I. D. (2013). Takt time planning for construction of exterior cladding. Proceedings (IGLC 21). Fortaleza, Brazil
Frandson, A. G., & Tommelein, I. D. (2016). Takt time planning of interiors on a Pre-Cast hospital project. Proceedings (IGLC 24). Boston, USA.
Hopp, W., & Spearman, M. (2008). Factory Physics. Vol. 2.
Jabrouni, H., Kamsu-Foguem, B., Geneste, L., & Vaysse, C. (2011). Continuous improvement through knowledge-guided analysis in experience feedback. Engineering Applications of Artificial Intelligence, 24(8), 1419–1431.
Kenley, R., & Seppänen, O. (2010). Location-based management for construction: Planning, scheduling and control. Routledge.
Koskela, L. (1992). Application of the new production philosophy to construction.
Mario, F. C., & Howell, G. (2012). Using Production System Design and Takt Time To Improve Project Performance. Proceedings (IGLC 20). San Diego, USA
Patton, M. Q. (1999). Enhancing the quality and credibility of qualitative analysis. Health Services Research, 34(5 Pt 2), 1189–1208.
Tommelein, I. D. (2017). Collaborative Takt Time Planning of Non-Repetitive Work. Proceedings (IGLC 25). Heraklion, Greece
Vatne, M. E., & Drevland, F. (2016). Practical Benefits of Using Takt Time Planning: A Case Study. Proceedings (IGLC 24). Boston, USA

Dlouhy J., Binninger M., and Haghsheno S. (2019). "Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 429–440. DOI: https://doi.org/10.24928/2019/0226. Available at: <www.iglc.net>

BUFFER MANAGEMENT IN TAKT PLANNING – AN OVERVIEW OT BUFFERS IN TAKT SYSTEMS

Janosch Dlouhy [1], Marco Binninger[2] and Shervin Haghsheno[3]

ABSTRACT

Takt Planning and Takt Control (TPTC) as a method for construction has the potential to reduce construction time in relation to normal scheduling without the increase of manpower. This leads to the question: what changes with the use of Takt planning? One theory is that Takt planning is using buffers more effectively than other schedule and planning methods. This paper provides an overview of the various buffers in Takt planning and describes how they can be used.

KEYWORDS

Lean construction, buffer management, buffer, takt, takt planning.

INTRODUCTION

Takt planning and Takt steering is approached differently in construction projects all over the world. A number of the different approaches resume time reduction of the whole construction time that is planned with Takt planning (Kaiser 2013; Frandson et al. 2013; Binninger et al. 2018). One theory is, that buffers are used differentely and special buffers can be reduced. This paper summarizes the analysis of over 100 takted construction projects. Takt Planning and Takt Control is described as a method in other papers (Dlouhy et al. 2016; Binninger et al. 2017)

THEORETICAL FOUNDATIONS

In order identify the buffers properly in a construction schedule, it is important to define the buffers in a paper. There are many unique characteristics of buffers. The use of buffers (Howell and Ballard 1998; Horman and Kenley 1998), the method of production in a production system (Tommelein 1998); (Tommelein and Weissenberger 1999) and the use of capacity buffers to increase performance (Horman 2001) has been well described.

[1] Lean Expert, BMW AG Munich, Germany, +49-721-695-245, janosch.dlouhy@kit.edu

[2] Research Fellow, Karlsruhe Institute of Technology, Germany, +49-721-608-44124, marco.binninger@kit.edu

[3] Professor, Karlsruhe Institute of Technology, Germany, +49-721-608-42646, shervin.haghsheno@kit.edu

Literature for a detailed classification and differentiation of buffers in Takt Planning, however, could not be found.

In order to summarize all possible buffers, this paper considers the entire time allotted for a construction project. All hours, days and weeks are correlated to a specific construction area. As an example of this: every one x one square-meter area is linked to a single hour or one day. This approach shows in which areas, which work is being performed and where there are potential gaps. Because of its easy comprehensibility, a simplified Takt Plan (like in Figure 1) will be used as the basis for further observations.

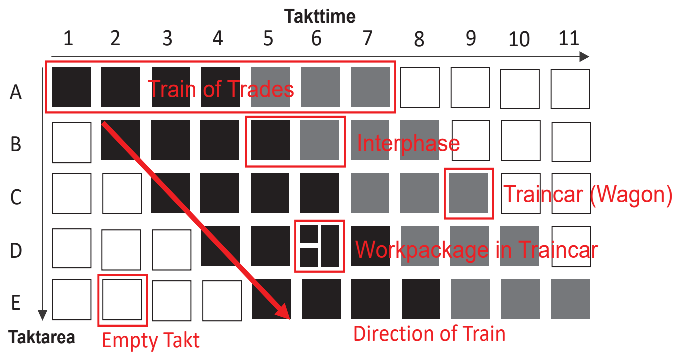


Figure 1: Takt Plan Pictogram

METHODICAL APPROACH

The buffer time represents a waiting time in a stable process, free of any external influences or hindrances, which equate to wastefulness. Nevertheless, buffers cannot be completely removed from a Takt plan. They must be properly dimensioned and located in a representative position (Poshdar et al., 2015, p.1). In non-stationary processes, such as the construction process, the use of moderate time buffers can increase the overall performance of the construction site processes (Sakamoto et al., 2002, p.11f.). More specifically, these buffers serve as factor of safety for budgeting costs, time scheduling, materials, storage, manpower and more. They can be used to compensate fluctuations or counteract resource shortages (see Alves and Tommelein 2004). Frandson et al. (2015, p.5) describes the formation of buffers through large areas of individual construction activities (lot sizes), in which schedule deviations are no longer visible.

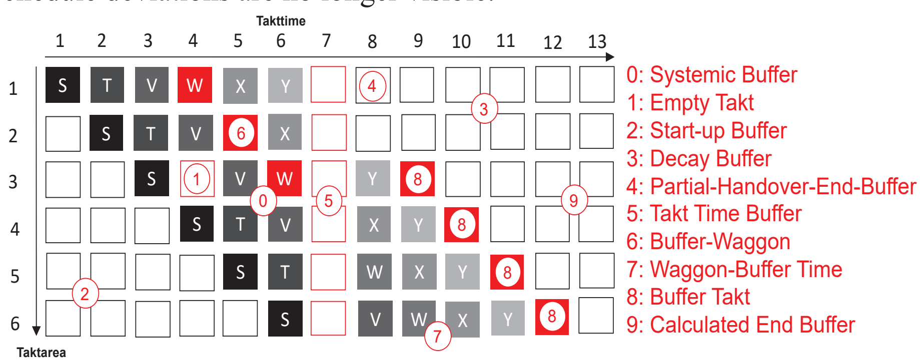


Figure 2: Types of Buffers

(0) The *Systemic Buffer* is an example of the weekend occurring at the end of each depicted calendar week. It is a buffer that the system naturally dictates, which does not have to be explicitly planned, but can be scheduled. At the scale of a daily Takt time, the buffer containing the weekend always occurs after 5 Takt times.

(1) The *Empty Takt* describes a Takt time in which no work is scheduled, yet Takt area is reserved. It can be planned or may occur unintentionally between individual wagons. Non-harmonized trades or overlooked restrictions may be responsible for this.

(2) *The Start-up Buffer* is the shift when starting Takt area after Takt area. It is a system dependent buffer that occurs based on the parameters of the system. It arises because the slope of the wagons has a limited extent (start-up curve). In principle, these areas are empty of value creation activity during the early Takts.

(3) The *Decay Buffer* is the counterpart of the start-up buffer. It is the result of the slope of the wagons in the trains ending in a pattern shifting the final wagon one Takt area further along the time scale, in relation to the offset at the beginning of the train. In principle, the area depicted represents empty, finished surfaces that no longer require subsequent work to be completed within them. Buffer types two and three are the largest single buffers in a project. They are not planned but are rather systemic. Reductions in this type of buffer have a high optimizing effect without causing the added value.

(4) The *Partial-Handover-End-Buffer* (PHEB) is the result of such an optimization. It is defined just as the total surface Decay Buffer, but only includes the triangle at the end of each cycle that shows a completed sub-project Area, that can be handed-over and where value creating activities can occur. In a Takt plan with 3 Takt areas, a partial-handover can occur 3 times after each completed train, creating in turn smaller partial handover buffers.

(5) A *Takt-time Buffer* affects a complete Takt time and can be either predictable (Christmas time, holidays or train stop) or might occur unplanned (weather conditions, strike or accident).

(6) A *Buffer Wagon* is the representation of a wagon in a trade train, in which no actual value creating process is undertaken. They are placed as placeholders for specific tasks or processes, such as the curing time, the replacement of machinery or the clearance of security areas. Buffer wagons can be placed at specific locations in the train's sequence.

(7) *Wagon-Buffer Time* defines the amount of buffer time within any given wagon. It is the difference between the floating buffer (Figure 16) and the amount of time required to perform the allotted tasks. After harmonization, any vacant time remaining in the wagon is considered to be a wagon-buffer. A wagon on a half-weekly cycle (2.5 days) might only be filled with 2 full days of work- the resulting Wagon-Buffer is a half day.

(8) The *Buffer Takt* is similar to the wagon-buffer in function, but varies in its location in the trade train. The Buffer Takt is placed at the end of a trade train sequence and is thereby no longer a part of the train. This type of buffer is often placed between two trains travelling consecutively in a single Takt area (e.g. between core and shell construction and the interior construction, or building construction and technical equipment installation.

(9) The *Calculated End Buffer* is the total cumulative time that can be saved from an optimized process flow. While this buffer may seem unnecessary at first glance, in reality

it is deliberately planned. It communicates a general reserve of time that is at the project's disposal and which can be used, if the project requires it. If there is no need for its usage, it can be accounted for as time gained. This makes it the most effective type of buffer. By deliberately transforming buffers into the calculated-end buffers, projects can effectively gain time for the construction. In the Takt planning process, it is therefore important to set this transformation as a goal.

RESULTS

LOT SIZE REDUCTION

In construction, the lot size represents the size of the work areas (Takt areas) per Takt (Shim 2011, p.930). The number of Takt cycle times corresponds directly to this. By dividing the lot in half (effectively doubling the number of Takt areas, each with an area that has now half), the number of Takt cycles doubles (although the actual time per Takt has now been halved). Smaller lot sizes allow for lower risk, generate lower costs and deliver more visible results faster (see Reinertsen 2009), (Nielsen and Thomassen 2004, p.1). Lot size reduction (LSR) makes it possible to shorten the total time of a production process, improve the flow, control compliance with the plan is easier and the site is more flexible and easier to control (Valente et al., 2013, p.1037). Several authors have published papers about the effectiveness of LSR (Tommelein et al., 1999), (Alves and Tommelein 2004), (Dlouhy et al., 2017, p.7ff.). The general principle has been explained in the publications or illustrated by examples with clear, uniform subdivisions of small units of gaps (e.g., hotel or housing). In isolated publications, as in Ward and McElwee (2007) or Dlouhy et al. (2017), this effect has also been applied to building structures that are not uniform and do not contain standard repetitive elements. These papers focus on projects, in which the smallest common denominator is not always clear- supermarkets (Ward and McElwee 2007, p.547), (Dlouhy et al. 2017, p.8) or the production properties considered here. The LSR makes it possible to present waiting times transparently, that is time in which no work takes place on a small area of the total project (Ward and McElwee 2007). For this purpose, tools for visualization, such as "Line of Balance" (LOB) or the Takt plan can be used. In Figure 3, the lot size reduction is shown schematically using a timing diagram. Number one shows a classic sequence of work processes (w, x, y, z) one behind the other with a large lot size (one clock range). In number two, the total work is divided into three smaller Takt areas. The sequence of work processes remains. In the third image, the work processes are sequenced with the smaller lot size. The result shows how this example reduces the initial twelve cycle times to six, which corresponds to a relative time reduction of 50%.

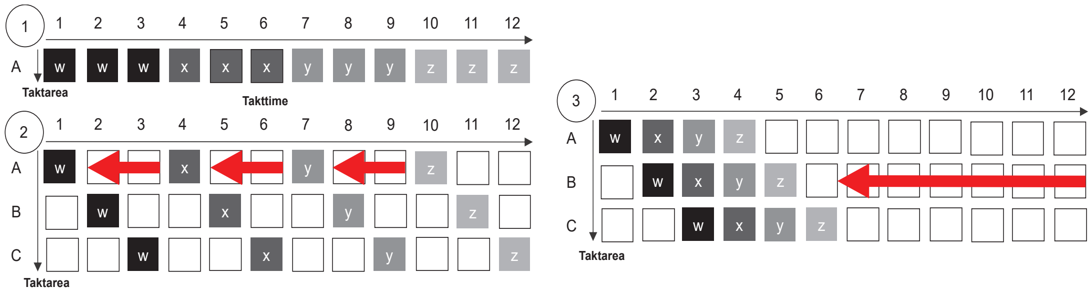


Figure 3: Lot size reduction effect

The actual reduction effect arises from the earlier beginning of the individual work contents. Actual working hours are not shortened. However, because of the earlier handover of the smaller Takt areas, subsequent work is able to be carried out much sooner. Although further divisions into smaller area units offer renewed optimization potential. These potentials are reduced with each subsequent application (decreasing marginal utility). Figure 4 shows the application of the lot size reduction in combination with Takt time reduction. In the first step, work is shown without overlap. Step 2 shows a typical example of a schedule with a 50% overlap of work. Number 3 visualizes the initial implementation of Takt planning. Number 4 shows a doubling number of Takt areas, and the resulting halving of Takt time (smaller areas require less time to accomplish work). Number 5 shows a further halving of Takt area and Takt cycle time. From the classic scheduling (number two) to the small lot size of Takt planning, the lead time is reduced from 25 to 7.25 weeks, which corresponds to a reduction of 71%.

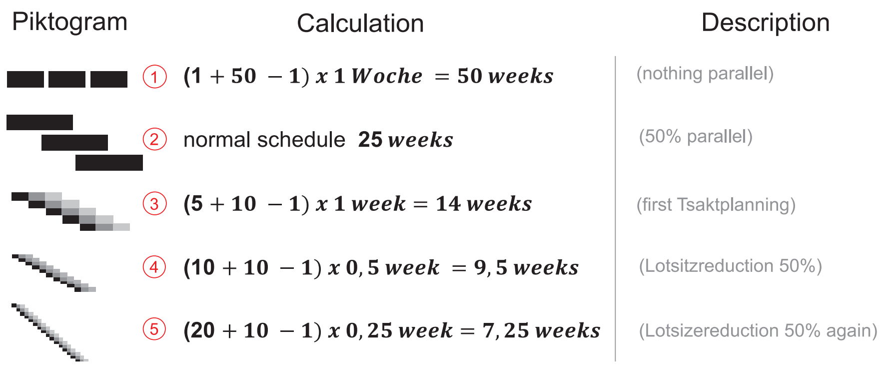


Figure 4:1 Effectiveness of lot size reduction in combination with Takt time reduction

Side Effects

A lot size reduction of 50% produces a Takt increase equivalent to the factor of four or 400%. This massive increase in Takt creates increased control effort. Additionally, the number of movements of the trades doubles due to the halved Takt time. This increase must remain manageable, while the system increases in complexity. The stability of the processes can be jeopardized as the reduction of the Takt time also reduces the reaction time. However, the added value per Takt cycle time is increased. Figure 5 illustrates this relationship with an example of a ten wagon train, where multiple Takt halving has been performed, in combination with area division.

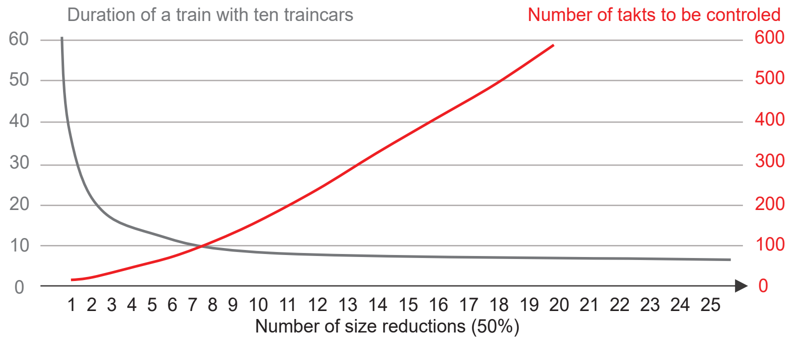


Figure 5: Reduction of total duration compared to the total number of Takts

PARALLELIZATION

In Takt planning, parallelization takes place by bundling work packages in a wagon. The various trades work simultaneously in the same area. Work, however, can only be carried out in parallel if sufficient processing units are available for its execution. Additionally, there can be no dependence to previously carried out regular work. Previous work package must be completed in order for the next to be allowed to begin. If a parallelization succeeds, the Takt times are reduced, which corresponds to an effective time gain.

The takting of train of trades produces the effect of parallelizing individual building process steps (e.g., work packages in core/shell, mechanical, finishing, etc.). Process steps usually consist of sub-processes, which in turn can be executed successively or in parallel. An example would be the decoupling of wagons and allowing parallel execution of work packages. This effect is summarized under *Wagonisation.*

The *Lot size reduction* (LSR) is another form of parallelization. By reducing the size of the Takt area (m²), individual work steps are cycled through earlier. The overlapping of time periods for the individual trades is also considerably parallelized. Work that has yet to be takted or scheduled (workable backlog) must be performed after the takted work has been completed. By completing these untakted work packages within the defined Takt periods, a higher level of parallelization is achieved. In order for this to work, excess time (buffers) in the wagons must be identified, which can then be used to finish the workable backlog. The various types of parallelization are depicted in figure 6. Number 1 shows Lot size reduction. 2 shows the wagonization of various work packages. 3 depicts two trains running in parallel. Number 4 shows the synchronization of work from the workable backlog into the Wagon Buffer-time.

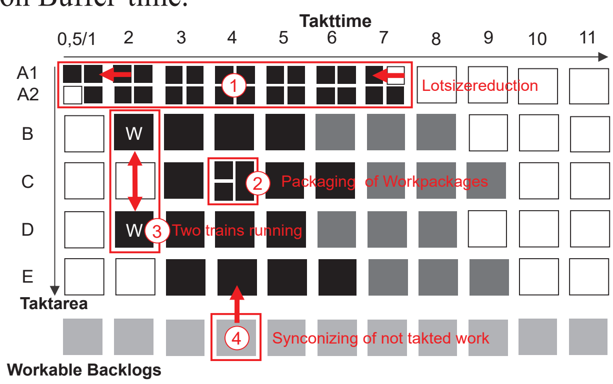


Figure 6: Parallelization-effect

Side Effects

The parallelization means that more work packages are completed simultaneously either in the same Takt area or Takt period. A high concentration of work, caused by high levels of parallelization, can lead to a disruption of individual work processes.

This concentration can lead to a disruption of the individual work, if the parallelization reaches a critical point. The coordination and control effort increase significantly with intensive use. The supply of material and resources must be guaranteed. The benefit of this extra effort, however, is great as the added value share per Takt increases.

Harmonization

Harmonization can take place within a wagon, within a train or even within a project with several trades. The harmonization of the wagons has the intended goal to produce a uniform distribution of the work contents. Through a balanced distribution of work, the trades can complete their work unhindered within their specific Takt area. This creates a continuous stream or flow of work.

The harmonization can be calculated and adjusted by manipulating the workforce and work content. Further mechanisms for adjustment include prefabrication or other classical acceleration measures (see Körtgen 2010, pp. 31f). The targeted use of buffers can also be used for harmonization. Figure 7 shows what time potentials can arise from the harmonization of trains. Each of the five trades is on site for the same amount of time in both scenarios, yet in the Takt plan example 4 Takt cycle (just about 29% of the total duration) can be saved. The Gantt chart (Graphic1), in which there is already a certain degree of parallelism (though independent from specific area) is transferred to the Takt plan, shown in graphic 2.

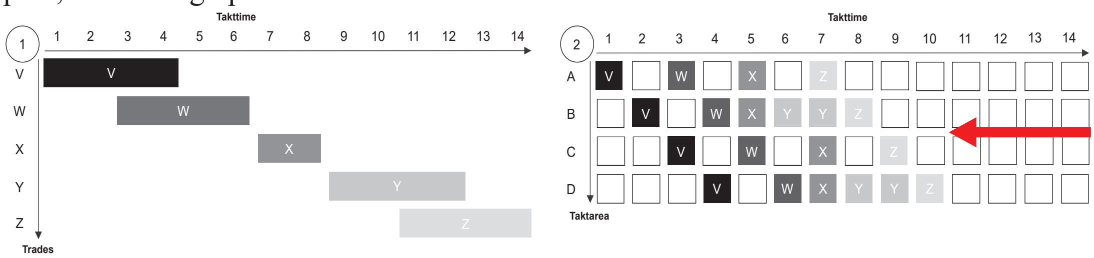


Figure 7: Harmonization-Effect

Side Effects

Improper harmonization inevitably leads to under- or overuse of workers. Underuse creates waiting times, alternate work, as well as requires increased control effort. Waiting times lead to the consumption of buffer times and alternate work can disturb the work of other trades. The overuse leads to a misconduct of the Takt targets. As a result, the work of the next car will be delayed in the next Takt cycle, resulting in disabilities in the workflow.

Flow-Based Repetition

The harmonization of the train of trades, with its work package wagons (railcars), allows work to proceed in a continuous cycle with regulated flow. This generates a steady stream of value creation for the construction project, not only for the individual trade, but for all trades together. The goal is to reduce waiting times for workers or machines and avoid accumulation of material or work in progress (Faloughi et al., 2015, p.164ff.).

The flow-based repetitive effect can be generated on construction sites and communicated transparently. Regardless of how many trades or work packages are located in a wagon, the trades move from Takt area to Takt area, throughout the project in a repetitive process (see also Figure 8). Even if the flow-repetition is not clearly visible, as in the second graphic of Figure 8, it is still possible to identify a repetition.

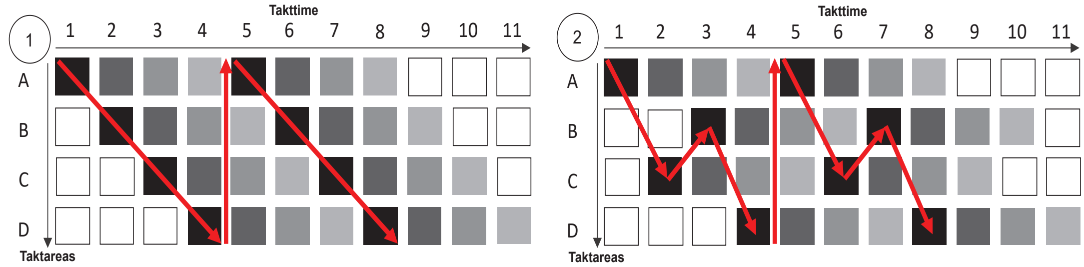


Figure 8: Flow-based Repetition

Side Effects

While repetition provides the benefit of learning from- and preparing for future Takts, it can also lead to an oversimplified routine for the workers. This can result in mental fatigue, especially at short Takt cycles.

WAGONISATION

The Wagonisation represents a kind of parallelization at the level of the trades. A wagon describes a receiving unit for work packages in a train of trades. It is a container defined by a single takt area in a single Takt time. It is defined by amount of time within one Takt cycle time. Work packages can be combined in these 'containers'. The work packages may have different relationships; they can either build upon one another or work side by side. Cumulative work is combined based on workload. Trades that can run side by side are harmonized individually. A wagon contains at least one work package (step 5 of the TTPTS), except when it is an empty buffer wagon (eg. drying times). If several work packages can be executed in parallel, in a specific Takt, these units can also be combined in one wagon. By allowing the trades to work together and individual wagons to be combined, the total completion time is reduced (as shown in Figure 9). In the example shown below, three Takts have been combined in illustration 2, thus generating 30% time saving compared to Figure 1.

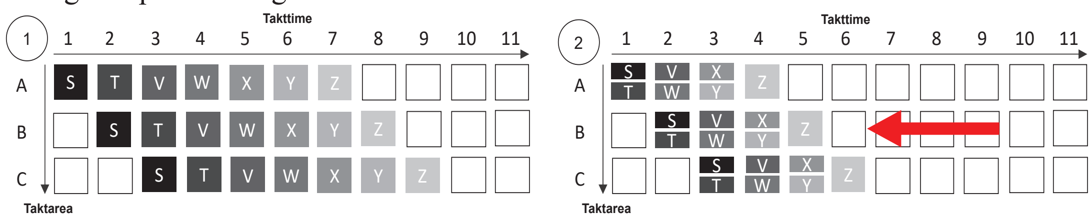


Figure 9: Wagonisation

Side Effects

Incorrect wagonisation may cause interferences between the trades working together, which may have an effect on their performance.

LONG LEAD MECHANISM

In the case of the long-runner mechanism, time-consuming process sequences are started at an early stage, which allows a maximum processing period until the end of the project. Although this effect often considered in construction projects, it is rarely described methodically. In order for this effect to be made transparent, location-based scheduling is required for the identification of the long-running processes.
As depicted in figure 10, this effect can ensure an optimized overall project duration. By prioritizing Takt area C, two cycle times or 22% of the total duration can be saved, as depicted in the second example.

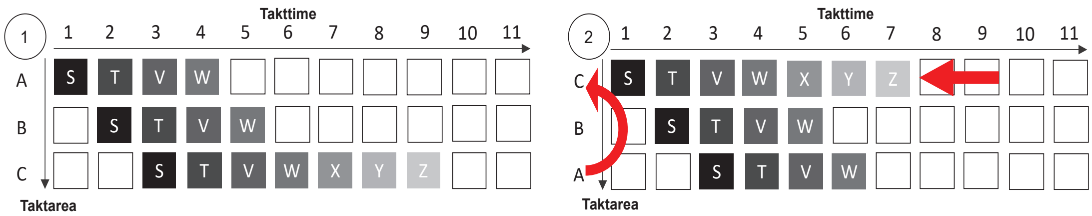


Figure 10: Long Running Process

In addition to the time advantage of prioritizing, long running processes and a customer-oriented planning of the construction processes, ensures the partial area prioritization goals of the client are delivered. For this purpose, the user or the client must be involved in determining which areas contain installations which require the longest construction time.

Side Effects

The prioritization of long running processes restricts the customer prioritization of areas and can lead to technical problems in the process.

ALL OVER USAGE OF BUFFERS IN TAKT PLANNING

The method and visualization of Takt planning shows a different usage of buffers like common scheduling. Buffers are mathematically designed. All other buffers get excluded. While projects are not stable in realisation than planning is, buffers are installed in the project time which makes them passive time that will be wasted if the buffer was not necessary. Also, Takt projects show volatility in realisation. For that reason, these additional buffers where installed behind the normal schedule to get an active buffer that could be used for any situation. With this approach, just buffers are used, which are needed and there is always an overview over the *calculated end buffer*. Figure 11 shows the visualization in a Takt schedule.

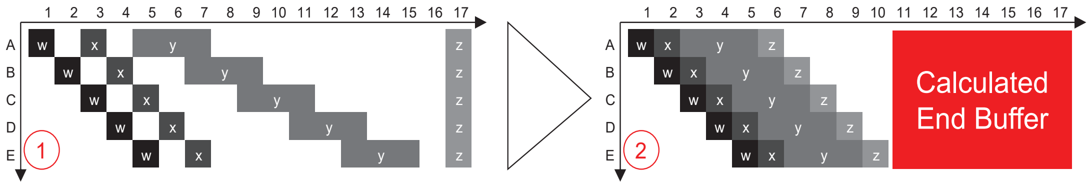


Figure 11: Using the *Calculated End Buffer* in scheduling

DISCUSSION AND CONCLUSION

Buffers are not just waste that can be eliminated; there is a correlation between the performance of a project and the use of buffers (Sakamoto et al., 2002, p.11f.). Through the visualization of buffers in a Takt schedule, the buffers become a part of the Takt process and integrated into a Takt area. Too many buffers within a project are waste. The paper shows an overview of all detected buffers during 100 projects and the different ways to optimize these buffers. With this foundation in buffer management for Takt planning, construction schedules could be more stable and efficient.

REFERENCES

Alves, Thais da C. L.; Tommelein, Iris D. (2004), „Simulation of Buffering and Batching Practices in the Interface Detailing-Fabrication-Installation of HVAC Ductwork“. In: *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*. Helsingør, Denmark.

Binninger, M., Dlouhy, J., and Haghsheno, S. (2017). “Technical Takt Planning and Takt Control in Construction.” *25th Annual Conference of the International Group for Lean Construction*, Heraklion, Greece, 605–612.

Binninger, M. , Dlouhy, J. , Müller, M. , Schattmann, M. & Haghsheno, S. (2018), 'Short Takt Time in Construction – a Practical Study' In:, *26th Annual Conference of the International Group for Lean Construction.* Chennai, India, 18-20 Jul 2018.

Dlouhy, J., Binninger, M., Oprach, S., and Haghsheno, S. (2016). “Three-Level Method of Takt Planning and Takt Control – a New Approach for Designing Production Systems in Construction.” *Proceedings of the 24th Annual Conference of the International Group for Lean Construction*, Boston, USA, 13-22.

Faloughi, Mazen; Linnik, Meeli; Murphy, Dan; u. a. (2015), „WIP Design in a Construction Project Using Takt Time Planning“. In: *Proceedings of the 23rd Annual Conference of the International Group for Lean Construction*., S. 163–172.

Frandson, A., Berghede, K., and Tommelein, I. D. (2013). “Takt Time Planning for Construction of Exterior Cladding.” *21th Annual Conference of the International Group for Lean Construction*, Fortaleza, Brazil, 527–536.

Frandson, Adam G.; Seppänen, Olli; Tommelein, Iris D.; u. a. (2015), „Comparison between Location Based Management and Takt Time Planning“. In: *23rd Annual Conference of the International Group for Lean Construction*. Perth, Australia, S. 3–12.

Horman, Michael; Kenley, Russell (1998), „Process Dynamics: Identifying a Strategy for the Deployment of Buffers in Building Projects“. In: *International Journal of Logistics Research and Applications*. 1 (3), S. 221–237, DOI: 10.1080/13675569808962049.

Horman, Michael J. (2001), „Modeling the Effects of Lean Capacity Strategies on Project Performance“. In: *Proceedings of the 9th Annual Conference of the International Group for Lean Construction*. Singapore, Singapore.

Howell, Greg; Ballard, Glenn (1998), „Implementing Lean Construction: Understanding and Action“. In: *Proceedings of the 6th Annual Conference of the International Group for Lean Construction (IGLC 6), Guaruja, SP*. Guaruja, Brasil.

Kaiser, J. (2013). *Lean Process Management in der operativen Bauabwicklung*. [Lean Process Management in operational execution of construction work] Schriftenreihe des Instituts für Baubetrieb, Inst. für Baubetrieb, Darmstadt.

Körtgen, Manfred (2010), Optimierungsansätze zur prozessorientierten Abwicklung komplexer Baumaßnahmen unter Einsatz neuer Informations- und Kommunikationssysteme. Kassel: Kassel Univ. Press (Schriftenreihe Bauwirtschaft 1, Forschung). — ISBN: 978-3-89958-929-0

Nielsen, Anni Schmidt; Thomassen, Mikkel Andreas (2004), „How to Reduce Batch Size“. In: *Proc., 12th Annual Conf. of the Int. Group for Lean Construction (IGLC-12).*

Poshdar, M.; González, V. A.; Belayutham, Sheila (2015), „An Inclusive Probabilistic Buffer Allocation Method“. In: *Proceedings of the 23rd Annual Conference of the International Group for Lean Construction*. Perth, Australia, S. 183–192.

Reinertsen, Donald G. (2009), *The Principles of Product Development Flow: Second Generation Lean Product Development*. 1. Aufl. Redondo Beach, Calif: Celeritas Publishing. — ISBN: 978-1-935401-00-1

Sakamoto, Masanobu; Horman, Michael J.; Thomas, H. Randolph (2002), „A Study of the Relationship between Buffers and Performance in Construction“. In: *Proceeding of the Tenth Annual Conference of the International Group for Lean Construction*. Gramado, Brazil.

Shim, Euysup (2011), „Impacts of matched batch sizes on time reduction in construction projects.“. In: *Proceedings of the 28th International Symposium on Automation and Robotics in Construction.*, S. 929–934.

Tommelein Iris D. (1998), „Pull-Driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique“. In: *Journal of Construction Engineering and Management*. 124 (4), S. 279–288, DOI: 10.1061/(ASCE)0733-9364(1998)124:4(279).

Tommelein, Iris D.; Weissenberger, Markus (1999), „More Just-in-Time: Location of Buffers in Structural Steel Supply and Construction Processes“. In: *Proceedings of the 7th Annual Conference of the International Group for Lean Construction.*, S. 109–120.

Valente, Caroline P.; Montenegro, Germano A.; Brito, Felipe L.; u. a. (2013), „Benefits of Batch Size Reduction: A Case Study in a Residential Project“. In: *Proceedings of the 21th Annual Conference of the International Group for Lean Construction.*, S. 1029–1038.

Ward, Steven A.; McElwee, Ward (2007), „Application of the Principle of Batch Size Reduction in Construction“. In: *15th Annual Conference of the International Group for Lean Construction.*, S. 539–548

Dlouhy J., Binninger M., and Haghsheno S. (2019). “Buffer Management in Takt Planning – An Overview of Buffers in Takt Systems.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 429–440. DOI: https://doi.org/10.24928/2019/0226. Available at: <www.iglc.net>

Blank

Schöttle, A., and Nesensohn, C. (2019). “The Beauty of a Phase-overlapping Last Planner System with Incorporated Takt.” In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 441–452. DOI: https://doi.org/10.24928/2019/0247. Available at: <www.iglc.net>.

THE BEAUTY OF A PHASE-OVERLAPPING LAST PLANNER SYSTEM WITH INCORPORATED TAKT

Annett Schöttle[1], and Claus Nesensohn[2]

ABSTRACT

The purpose of methods and tools is to serve the project team and add value within the project delivery. Therefore, the implemented production system should support the interaction of the project team, enabling team members to develop a common understanding, and to reach the required quality and production performance when carrying out their daily activities. This research concludes that the Last Planner System (LPS) aligns to the Toyota Production System (TPS) and its recognized management theory, which is a vehicle to integrate the minds + hands philosophy within projects from early design phase till handover. Our findings show that adopting the LPS as a production system helps to align and integrate the project participants. Takt is a work structuring tool that can be integrated into the LPS, if the product allows (repeatable areas). Thus, we recommend that the production system be designed based on the team’s needs and the product requests.

KEYWORDS

Lean construction, last planner system, minds + hands, takt, toyota production system.

INTRODUCTION

Although a large number of papers have been published regarding the Last Planner System (LPS) in the International Group for Lean Construction (IGLC) community, few papers have been published regarding takt time – only some regarding the combination of LPS and Takt-time planning. The LPS has been the major method used to implement Lean within construction projects for decades. Formerly introduced by Ballard and Howell more than 25 years ago as a system for production planning and control (Ballard 1993), its application has been reported for all kinds of projects within the Owner, Architectural, Engineering and Construction (OAEC) fields in the construction phase and for a few

1 Senior Consultant, Refine Projects AG, Schelmenwasenstraße 34, 70567 Stuttgart, Germany, +4915156561529, annett.schoettle@refineprojects.com, and Founder and Co-Director, CollabDecisions, www.collabdecisions.com.

2 CEO, Refine Projects AG, Schelmenwasenstraße 34, 70567 Stuttgart, Germany, +491799789624, claus.nesensohn@refineprojects.com, Professor, Lean Construction and Project Management, University of Applied Science Stuttgart.

projects within the design phase. However, no study has explored how the LPS as an overall production system, from early design phase until handover, defines the applied management philosophy whilst also incorporating the work structuring method takt time planning in dedicated areas. To explain the LPS from a production system context, this study uses the TPS and its management theory and philosophy. Therefore, the research questions the paper seeks to answer are:

- How does LPS function as a production system across the whole project and which role does takt play in the LPS?
- How to design a production system for all project phases?

The paper is structured as follows: First, the literature is reviewed for production systems, specifically the Toyota Production System (TPS) as management theory and the LPS together with the element of takt. Then the research methodology utilized to analyze the case study will be introduced, followed by the case study findings and the discussion of these findings in accordance to the literature. Finally, we will draw our conclusion and answer the research questions.

BACKGROUND BASED ON LITERATURE

TOYOTA PRODUCTION SYSTEM

The Toyota Production System (TPS) has been acknowledged to be truly remarkable in generating more value for the company's customers and employees than alternative management systems (Spear 1999). Krafcik (1998) highlighted a distinctive difference between the TPS and the Fordist Production System in the way that Toyota was the innovator, taking the minds + hands philosophy of the craftsmen era and merging it with work standardization and assembly line. The TPS thus showed that, if workers are given responsibility and a variety of tasks, they effectively engage their minds + hands within the production system. This was added through commitment, teamwork, empowerment and training of the shop floor workers to give them responsibility to steadily improve quality and performance (Krafcik 1998). The simple act of asking and integrating the people who carry out the work in order to identify what they needed to handle the variety in the production line made the difference (Seddon 2007). Johnston and Brennan (1996) underlined that the TPS stands for more than just a superior production system. Based on their work, Koskela (2001) found out that TPS is the better management theory, because it involves the following four functions: (1) Management as-organizing, (2) Management as-planning, (3) Management as-adhering and (4) Management as-learning. Seddon (2007) aligns with Koskela (2001) and summarizes that TPS is based on systems thinking that handles both the design and management of the work to have products with no defects and the best possible flow. This recognition is closely related to the application of collaborative production planning systems within the construction industry like the major lean construction (LC) method LPS.

LAST PLANNER SYSTEM AND TAKT TIME

The LPS is a production planning and control system that is based on the development of a network of commitments; it aims to improve workflow, reliability and predictability between different trades in the various phases of a construction project (Ballard and Howell, 1998; Ballard, 2000). This network of commitment is created through the conversation for action loop, also named the promise cycle, defined by Flores (2013) and is an important connection between TPS and LPS. This mind + hands philosophy empowers foremen/forewomen to make their own commitment regarding their daily and weekly tasks in order to deliver and improve their performance continuously (Shang and Low 2014). To do so, the LPS consists of seven key principles: (1) use pull planning to develop the different scheduling levels, (2) engage the Last Planners early on in the different scheduling phases to reduce uncertainty, (3) activities are planned and made-ready collaboratively by the Last Planners, (4) commitments are given by the Last Planners, (5) do not detail too far in the future, (6) the opportunity to say ‘no’ to attain a transparent and trustfully production plan, and (7) learn from mistakes by having short-cycle evaluation and planning meetings (see for example Ballard and Tommelein 2016).

In theory and practice there is an ongoing discussion about whether to implement LPS or Takt time. Frandson et al. (2014) point out that takt time is a work structuring method to simplify the lookahead process by focusing on standardization and clear batch size in order to “create a more stable environment for the LPS” (Frandson et al. 2014, p. 573). In comparison, the LPS “facilitates irregular work variances” (Frandson et al. 2014, p. 577) such as areas with non-repetitive work. Takt-time planning can be processed in six steps: (1) data gathering, (2) zone definition, (3) trade sequence generation, (4) individual trade duration, (5) workflow balancing and (6) production schedule finalization (Frandson et al. 2013). The development of a Milestone & Phase Plan (MPP) requires similar steps. The main difference exists in the granularity. In Takt Planning the degree of detailing the time duration is more intense in order to harmonize the resources through repetition. The MPP is based on the approach that, the further away the future is, the more unrealistic the plan (e.g. Mossmann 2013). Therefore, the MPP that builds the guideline for the six week lookahead (6WL) and the weekly workplan (WWP) is based on weekly durations and only done for a few months. Last Planners then detail and optimize their activities based on the MPP in the 6WL and the WWP during the LP meeting. This links back to the theory of management within the TPS and the mind + hands approach which is evident within the TPS too. Furthermore, there is a great opportunity in integrating takt time in the LPS for repetitive work.

RESEARCH METHOD

The authors used case study and action research to analyze the research questions. Case study research was used to investigate the particular issues in depth (Yin 2014). Therefore, 21 structured interviews were collected from design and construction teams across different trades and positions. Questions were asked regarding production system, Lean knowledge, target and milestone definition, decision-making, honesty and transparency, challenges, the working relationships, and degree of diffusion. The interviews were transcribed and, based on Mayring (2010), analyzed using the MAXQDA software package. Additionally, in a close-out workshop the project team did a reflection on the implemented production system in February 2019. Action research was used during the project to support the project team and act when issues occurred based on investigation (Dickens and Watkins, 1999). The authors were part of the project team and responsible for Lean implementation in the design and construction phases. The second author supported the design team for the first six months. The first author took over in June 2017, shortly before construction started, and supported the design team until December 2017 and the construction team until December 2018 (see Figure 1). The support included the facilitation of the weekly Last Planner meetings, called production evaluation and planning (PEP), and pull planning sessions for the MPP, as well as onboarding and training workshops. Thus, the action research during the project was based on discussions, meeting evaluation, plus delta evaluation, observation and findings during workshops.

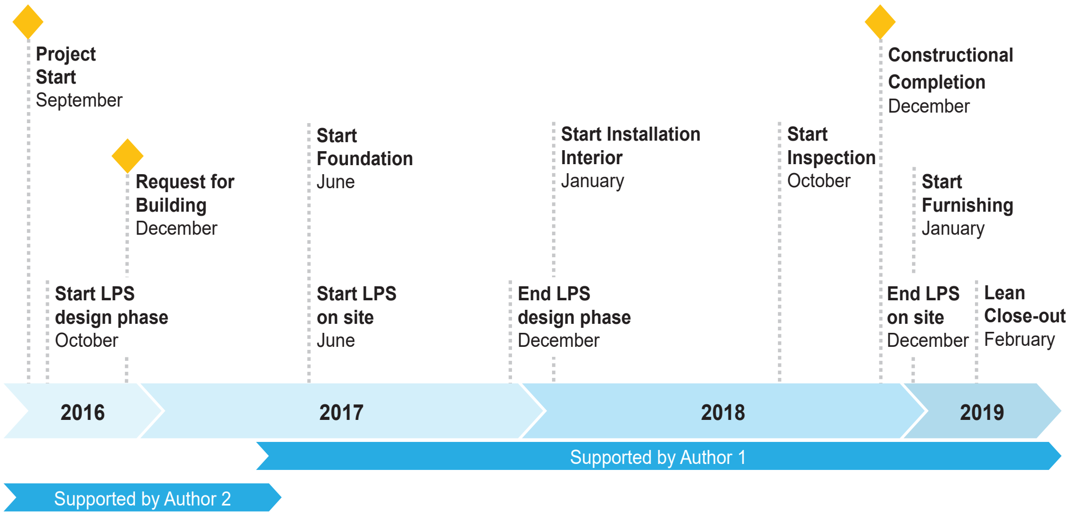


Figure 1: Project timeline with illustration of the Lean support

CASE STUDY

PROJECT INFORMATION

BMW Freimann is an office building of around 75,000 m^2 in the north of Munich that will accommodate 3,500 employees. The building has a length of 248 m and a width of 96 m (see Figure 2) and contains, besides the office facilities, a restaurant with 1,000 seats, a cafeteria, fitness centre and a shop.

The design team started in October 2016 and submitted the building permit in December 2016 (see Figure 1). The project team was contractually required to submit the building request within six weeks to achieve the permit on time. Furthermore, because of the short timeline until construction started and due to the request, the design team had to produce the preliminary design, detailed design and construction documents in parallel. The design team started detailing the design in January 2017. The construction phase was contractually fixed to 18 months and started with foundation work in June 2017. The shell contained prefabrications and was finished in May 2018. Installation of the interior started in January 2018. Inspection of the first office area started in October 2018. Constructional completion was finished in December 2018 and commissioning and inspection were completed in February 2019. The occupation of the building started in March 2019.

Figure 2: Project BMW Freimann (PORR Design & Engineering GmbH)

IMPLEMENTATION OF THE PRODUCTION SYSTEM

The LPS was applied from project start throughout the commissioning and handover phases. In the design phase, the main goal was to achieve the permit and produce the construction documents for the site on time. Construction documents were produced while construction was already ongoing. The design team was collocated in Vienna, while the site was in Munich. Thus, two weekly PEP meetings were carried out to coordinate the design and construction phases. Therefore, an Obeya-Room with all the visual management, trade sequence, MPP, 6WL and area overview was set up in Vienna and Munich. During the overlapping design and construction phases, the site pulled construction documents using milestones which the LP consultancies integrated in the 6WL of the design phase. With the start of the interior installation, the MPP was split into two major areas. Areas which contained specific functional areas like the basement and the first floor were developed in a usual LP pull scheduling session. Levels one to three consist of repeatable office space. Therefore, a sequence of the trades for a smallest common area was developed to integrate a takt into the MPP of the LPS (see Figure 3 and Table 1). To achieve a common understanding and to make them aware of the need for transparency and teamwork, new team members were systematically onboarded through a workshop and on-site explanation. It has to be noted that a project delivery with such a Lean approach and a consequent use of this from design and construction was new for all of the participants involved.

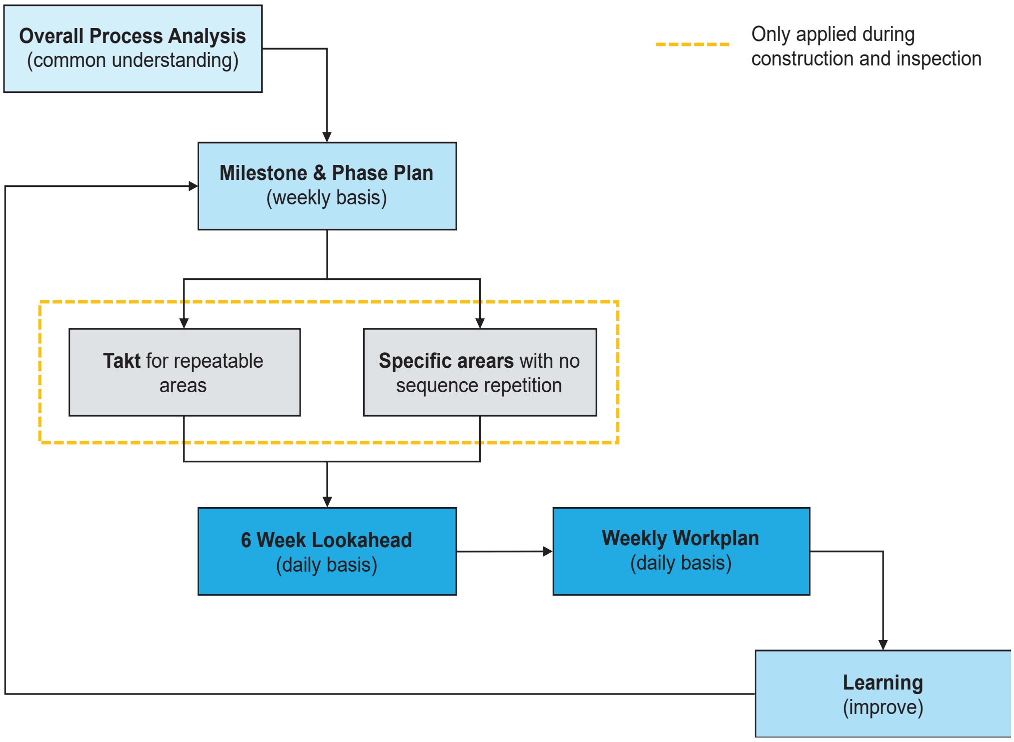


Figure 3: Integration of a Takt Plan for repeatable areas in the LPS

Table 1: Overview of the MPP during construction, commissioning, and inspection

Unique sequence	**Takt**
– Ground floor	– Shell
– Basement	– Interior office space 1. – 3. floor
– Roof	– Interior core area 1. – 3. floor
– Outside facilities	– Exterior (partly)
– Commissioning	– Inspection 1. – 3. floor

FINDINGS FROM THE INTERVIEWS AND OBSERVATIONS

To understand the implementation of the production system, it is important to be aware of the challenges the project team had to face. During the interviews the following main challenges were reported: aggressive project schedule, the new way of working regarding the executed project delivery system and the implementation of LPS and Building Information Modelling (BIM), coordination of interfaces especially during installation and completion, the cultural differences between Austria and Germany including the difference in wording, norms and regulations, and missing support from their own company. Additionally, with the start of the construction site in Munich, a natural break in the communication within the project team occurred due to the geographical distance and the non-reciprocal participation of the other PEP. The issue was solved by basing one person from the design team on site to answer questions quickly.

The analysis showed that the LPS and its structure and transparency as well as the disciplined execution of the weekly PEP meetings had improved communication and the common understanding within the project team. Furthermore, it was generally acknowledged that the clearly visualized production areas and the colour-coded sticky notes with the activities of the upcoming six weeks made it easy to coordinate, as long as people were honest and had all the information regarding their resources such as material and labour. This is evidence that the Obeya-Room delivers a great advantage to identify the issues and discuss problems effectively. Furthermore, the PEP meetings were received as a great element to connect everyone and enable a clear view of the activities of other team members as well as the overall process and the impact of changes. One interviewee mentioned that, without all this information, the communication among the trades would not have been engaged as deeply as required.

The production plan was continuously prioritized, adjusted and optimized. This was regularly performed as part of the self-organized collaboration of the LP within the PEP meetings and MPP sessions. Both LPS steps have been characterized as profound. It was not always possible to execute the takt that was integrated into the LPS as planned. With a focus on the MPP, there is clear evidence in the findings that a regular re-planning or adjustment is a requirement for both the specific areas and the takt areas. There were different reasons that triggered a re-planning as, for instance, that team needed to react to the difficulties in achieving the targeted milestones, so there was a need to optimize the production sequences of the areas or trades. One interviewee stated, *"There have been relatively many such kinds of improvisational needs and changes used against the original commitment, but, in the end, they have proved to be right."* Reasons for not keeping commitments were mainly the missing check of preliminary work, a lack of coordination between the trades, not having the right people in the meeting along with the lack of fully understanding the system, and missing information from their own company. Somewhat difficult were the shortage of resources, changes and additional requests for work.

For the design phase as well as for the overall project, it was incredibly relevant that people of all key trades such as: facade, MEP, dry construction and building automation and the general contractor had been involved early on within the design phase. Although it was not contractually recognized (no rewarding system, no multi-party agreement) and the tendering was carried out traditionally, the project can be classified as IPDisch, because of the early contractor involvement and the behavioural characteristics such as trust and open communication of an IPD project. It became clear that a Lean approach for project delivery can bridge traditional contracts towards the Lean philosophy and the level of collaboration connected to this. Some statements from the design team that support this view are:

> *"All in all, of course, including the construction site, this coordination, this regular one, which was now taking place intensively over the six weeks' lookahead, has helped the whole project and the whole team, construction site, planning, pretty well."*

> *"[Because we] were transparent to the construction site, and so was the construction site to us, we were able to react very well to [their sequence changes during building the shell] and we were also able to tell the construction site realistically if we could do it or not."*

Almost every interviewee (20 out of 21) felt that the overall production system was helpful. Most of the reported reasons for this are: reduced coordination effort, deep content, reducing the project managers' workload, as a basic medium for communication, a better thinking through the lookahead, transparency and open communication. Only one interviewee did not find the system helpful, mentioning that his project manager was setting unrealistic targets and did not listen to the Last Planners on site. A majority of the interviewees had used the production system not only within the project, but also for their own needs within the project and their company. The overall result of the project was, in the view of most interviewees, not possible without the LPS from design to commissioning.

DISCUSSION

From the production system view, the most important finding is the necessity to adjust and improve production schedules to meet the project targets. Although a takt was developed for the repeatable areas, due to the listed issues it was impossible to always follow the takt as planned:

- No error-free and no on-time delivery of construction documents
- Limited availability of resources in the market
- No early involvement of the trades that execute the work possible
- Shortage of subcontractor availability
- Shortage of labour
- Variable performance by the different work crews of a trade

- No availability or late delivery of material
- Late change orders by the client
- Delayed decision-making by the client

For example, because of the existing market constraints and the named challenges the MP system could not follow the takt at the beginning. The team then decided to change the sequence of the area and the installation moved forward. This proves that flexibility within the production system is mandatory. Thus, the LPS fulfils this requirement by enabling the project team to continuously adjust.

Additionally, all production systems need to consider the human factor (Seddon 2007). It is important to understand that project teams contain a highly psychological side, because a team consists of members with: (1) different personalities, (2) different attitudes and behaviours, (3) different languages, (4) different experience, (5) different learning speeds and (6) different expectations. Therefore, implementing the LPS is a cultural change and the diffusion degree might be low if the team members are using the system for the first time, because often the Last Planners are not empowered to make decisions and therefore not able to act in the project's best interests. Nevertheless, having a project team that is using Lean for the first time does not prevent you from achieving the set project targets successfully.

So, our research question, 'How does LPS function as a production system across the whole project and which role does takt plays in the LPS?', must be answered as follows: the LPS functioned very well as an overall production system across the whole project, because it was customized through every project phase based on the team's needs. The LPS helps to align and integrate the different project participants in creating a common production plan. Thus, LPS is a production system which triggers minds + hands thinking and a management theory to combine those TPS thoughts such as management as-organizing, management as-planning, management as-adhering and management as-learning (Seddon 2007). The element of takt did not really matter, since most of the people from the construction phase have used takt for their work for many years. Nevertheless, it is a good tool to structure the work of repeatable areas, if it is kept flexible and the sequence can be adjusted through learning. The second question, 'How to design a production system for all project phases?', has to be answered as follows: the production system has to be designed based on the team's needs and product request. It is crucial to have a production system that is able to engage people easily to collaborate within the team through visuals and structured communication. Therefore, the system requires flexibility for improvements, to achieve the geographical proximity of design and construction teams, supporting a common language and a common understanding, because "language is our primary for coordinating our activities" (Flores 2013, p. 20). Furthermore, it could be questioned if categorizing Lean into Lean Design and Construction could result in a mental break, especially when people are using a production system such as the LPS for the first time.

This is a perception, but it could help to use one term to align the design and construction phases after decades of separation.

CONCLUSIONS

This research showed that, for a project to succeed, the most relevant aspect is not what type of relational contract has been used, nor what kind of production planning system someone uses in design and in production, but it is important to design a production system which does span from design till handover and is serving as the marketplace for information, planning re-planning and communication. Moreover, the production system must serve as a link to create and foster team cohesiveness by understanding different perspectives. Overall, the study stressed that the most important factor for success is to achieve a production flow by integrating the knowledge of the LP in every phase. The production system needs to be flexible for improvements and to react if breakdowns occur. Furthermore, the engagement of people, the support from their company and honest conversations are relevant for success, and thus need to be considered. Finally, the team's openness to new ways of working is also important.

ACKNOWLEDGEMENTS

We would like to thank all interviewees from the project team for their contribution.

REFERENCES

Ballard, G. (1993). "Lean Construction and EPC Performance Improvement." In: L.F. Alarcón, ed. *Lean Construction*. Rotterdam, Netherlands: A.A. Balkema Publishers.

Ballard, G., and Howell, G. (1998). "What kind of production is construction?" In: *Proc. 6th Annual Conf. of the Int'l. Group for Lean Constr.* Guaruja, Brazil.

Ballard, G. (2000). *The Last Planner System of Production Control*. Ph.D. thesis, University of Birmingham, U.K.

Ballard, G., and Tommelein, I. (2016). "Current process benchmark for the last planner system." *Lean Construction Journal,* 89, 57-89.

Dickens, L., and Watkins, K., (1999). "Action Research: Rethinking Lewin." *Management Learning,* 30(2), 127-140.

Flores, F. (2013). *Conversations for Action and Collected Essays: Instilling a Culture of Commitment in Working Relationships*. CreateSpace Independent Publishing Platform.

Frandson, A., Berghede, K., and Tommelein, I. (2013). "Takt-time planning for construction of exterior cladding." In: Proc. 21st *Annual Conference of the International Group for Lean Construction.* Fortaleza, Brazil.

Frandson, A., Berghede, K., and Tommelein, I.D. (2014). "Takt-Time Planning and the Last Planner." In: *22nd Annual Conference of the International Group for Lean Construction.* Oslo, Norway.

Johnston, R.B., and Brennan, M. (1996) “Planning or Organizing: The Implications of Theories of Activity for Management of Operations.” Omega*, Int. J. Mgmt. Sc.,* 24(4), 367-384.

Koskela, L. (2001). “On New Footnotes to Shingo.” In: *Proc. 9th Annual Conf. of the Int’l. Group for Lean Constr.* Singapore.

Krafcik, J. (1988). “Triumph of the Lean Production System” *Sloan Management Review*. 30(1), 41-52.

Mayring, P. (2010). *Qualitative Inhaltsanalyse: Grundlagen und Techniken*. Vol. 11, Beltz, Weinheim.

Mossman, A. (2013). “Last Planner 5 + 1 crucial & collaborative conversations for predictable design & construction delivery.” *Researchgate*.

Seddon, J., and Caulkin, S. (2007). Systems thinking, lean production and action learning, *Action Learning: Research and Practice*. 4(1),9-24, 10.1080/14767330701231438.

Shang G., and Low, S.P. (2014). “The Toyota Way model: An alternative framework for lean construction.” *Total Quality Management & Business Excellence*, 25(5-6), 664-682, 10.1080/14783363.2013.820022.

Spear, S. (1999). *The Toyota Production System: An example of managing complex social/ technical systems: 5 rules for designing, operating, and improving activities, activity-connections, and flow-paths*. Ph.D. thesis, Harvard University.

Yin, R.K. (2014). *Case Study Research Design and Methods.* Sage, 5th ed. Los Angeles, CA

Schöttle, A., and Nesensohn, C. (2019). “The Beauty of a Phase-overlapping Last Planner System with Incorporated Takt.” In: Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.), Dublin, Ireland, pp. 441–452. DOI: https://doi.org/10.24928/2019/0247. Available at: <www.iglc.net>.

Blank

Andersen, L, and Fyhn, H. (2019): 'Organizational and Cultural Preconditions for Extending the Use of Takt-Time Planning.' In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 467–478. DOI: https://doi.org/10.24928/2019/0271. Available at: <www.iglc.net>.

CAN A TAKT PLAN EVER SURVIVE BEYOND THE FIRST CONTACT WITH THE TRADES ON-SITE?

Otto Alhava[1], Vili Rinne[2], Enni Laine[3] and Lauri Koskela[4]

ABSTRACT

This study takes a critical look at Takt planning and takt control (TPTC) by analysing a successful case project. In the study, the digital system architecture and collected data are used for providing a process break-down and analysis in terms of waste and potential root causes. The paper shows how vulnerable the TPTC is for disruptions caused by a lead waste, making-do/task diminishment, and ad-hoc tolerance management. Based on the digital footprint of the project, an explanation is given why good results in terms of money, customer satisfaction, time and quality were achieved even though the takt was practically lost towards the end of the project. The results indicate that the excellent outcome of the project was not based on TPTC and steep learning curve. Instead, the results were achieved by exploiting the real-time situation awareness provided by the digitalised smart site and disciplined use of applications, as well as by a pragmatic approach to planning and leading work on-site. The validity of the results is limited as the conclusions are drawn based on only one TPTC project.

KEYWORDS

Takt planning and takt control (TPTC), job sequencing, work in progress, making- do/task diminishment, tolerance management

INTRODUCTION

Takt Planning and Takt Control (TPTC) is booming in the construction industry, both in research and in the press. In the Finnish market, more than ten general contractors have already reported positive financial results gained with TPTC on construction projects. TPTC has also been tried out in FIRA Ltd, where two of the authors work. While the projects have been successful, the contribution of TPTC to the success is not immediately clear.

Graf von Moltke (1871), a Prussian field marshal and chief of staff of the Prussian Army, came into conclusion that no plan of operations extends with any certainty beyond the first contact with the main hostile force. Von Moltke would have been surprised about how precise his insight could have been a hundred and forty years later in the context of the construction industry. Based on the experience of the examined Takt project, the same weakness of exposing the pre-made plan with the reality also applies to the Takt plan and the first contact with the trades on-site. The TPTC is suggested to be the operating system of the construction industry combining

[1] CTO, Fira Group Oy, Vantaa, Finland, +358 400 792493, otto.alhava@fira.fi

[2] Production Engineer, Fira Oy, Vantaa, Finland, +358 44 3023471, vili.rinne@fira.fi

[3] PhD Candidate, Civil Engineering Department, Aalto University, enni.laine@aalto.fi

[4] Professor, School of Art, Design and Architecture, University of Huddersfield, Queen St, Huddersfield, West Yorkshire, HD1 3DU, United Kingdom. L.Koskela@hud.ac.uk

successfully Lean culture, continuous planning and multilevel communication (Dlouhy et al., 2018). However, the pathogens of low productivity seem still to be lying dormant in the system and waiting an opportunity to come to light as an error (Love et al., 2009)

In view of this situation, this study aims to understand in detail the difference between the planned schedule and actual implementation of the tasks on-site in TPTC project by using the digital footprint provided by the mobile applications. The objectives for the study are: 1) provide visualisation for the planned schedule and actual implementation of the tasks, 2) provide analysis for the efficiency of the TPTC implementation, 3) identify the needed improvements for the use of digital footprint in the future TPTC projects, and 4) identify improvements TPTC implementation.

When the data from a case project was analysed first time in detail, the number of changes in the schedule as well as the delta between the initial schedule and the actuals was staggering, especially as the case project itself was considered to be successful and the throughput time was reduced more than 30% compared to a reference project. Similarly, the data revealed waves of defects, which were flooding the production process and finally changing the proactive planning of tasks to reactive management for fixing work. These findings raised questions for finding the pathogens and their root causes, which must be eliminated from the process before applying TPTC or any other modern flow-based methodology for increasing the productivity. The data also raised the question of why the project was managed and implemented so successfully even though the tolerance management failed. Similarly, it is clear, that the vicious cycle of waste generating more waste was present also though the TPTC was used.

The analysis of the data and the following interviews of participants suggested that there were too many problems in daily work, which were caused by the relatively loose tolerances of the installation of prefabricated elements or the tolerances of precast elements themselves. If compared to the installation tolerances of the kitchen furniture, there is a mismatch, which should be taken care of before starting the Takt. These problems were not apparent at the beginning of Takt phase, but they appeared as the work progressed to later the stages, and previous tasks were checked. This continuous appearance of waste reminds the vicious cycle of waste as Ohno (1988) describes in his work with the Toyota Production System (TPS). Even more severe was the tolerance problem, which was caused by slow and erratic drying of in-situ casted areas in apartments, as the installation of the laminated floor had to be rescheduled for reaching the moisture requirements of concrete floors before covering installation.

In addition to problems with tolerances and subsequent delays in installation times, which were recorded as roadblocks by trade partners or as re-scheduled tasks by main contractor's foremen, there was another type of root cause for quality deviations present. Based on data and reported rework, the definition of "done" was neither clear for those who were finishing their work nor to those who were checking and accepting the task as finished. Last Planner System (LPS) is used for supporting the implementation of tasks toward the planned accomplishments. Even though the TPTC was implemented in the case project and the project was completed in time, the last four weeks were mostly spent in fixing and finishing tasks, which were already reported done. Clearly, the project, with a successful outcome, did not triumph because of the TPTC or due to fact that the LPS was not used properly as a part of the TPTC implementation.

RESEARCH METHOD

The site of the case project was digitised for providing connectivity to mobile devices and IoT sensors. The technical solution was developed based on experiences from the iCONS project (Zhao et al., 2018). The use of mobile applications provided a new source of data for the scientific work. Every transaction, change, assignment of the task in the scheduling app, inspection in the site by using the quality management app, or message in the site's Whatsup channel, leaved a trace to the event log of the particular system. This metadata was used during data mining and enrichment of data for this study, when the planned schedule, the actuals from the site and quality information were structured, merged, analysed and visualised. As depicted in Figure 1., all the applications used on-site created data and metadata in transactions and these data were collected to Fira's Open Data Platform (ODP). The metadata were used for providing visualisations used in this study. The data enrichment process was conducted in Fira's ODP by using the developed ontology of Takt production for combining data from Takt scheduling software, Fira SiteDrive and quality management software, Congrid and Congrid Lite. The developed ontology was essential in enriching the data for situation awareness tool, Fira InSite, as it provided the methods for visual interpretation of data in terms of business process, in the context TPTC.

Figure 1 Situation awareness and visualisation of IoT sensor data required integration of point solutions data streams to the platform (Fira Open Data Platform) for providing real-time situation awareness to participants (Fira Insite)

THE CASE PROJECT AND DATA ANALYSIS

The studied case project consists of an internal work of a seven store residential building located in a recently built area in Helsinki. The building itself represents typical urban housing design in Helsinki, with 42 apartments from studios to three-room apartments. The delivery of the project was made through a design and build contract, which allowed the main contractor, Fira, to change the production into TPTC in arelatively late stage of the project and to narrow the scope of TPTC to be used for internal works of the apartments only. The decision to start using the TPTC on the project was made during the erection of the frame as the procurement of the remaining work was not finished. Half of the contracts for indoor works were signed before the decision for TPTC was made, and therefore the contracts were not tailored for TPTC although the contracting model included a clause on the general contractor's responsibility for providing the possible disambiguation to schedule. Thus, in a sense, the TPTC schedule was forced into use.

The main contractor focused on training and learning from the beginning of the indoor phase and provided resources for the site in this respect. The project personnel of the main contractor included three unexperienced foremen, a senior site manager and an adept site engineer. The personnel of trade partners were randomly selected, and reflected variation in skills as typical to the industry. None of the participants had previous experience or understanding of the TPTC. As there was a potential risk of failure when a new method is taken into use for the first time, the main contractor decided to focus on internal work and limited the TPTC cover only the apartments whereas the stairways, the bomb shelter, storage rooms, the sauna area, and the common facilities, were not included in the Takt schedule.

From the beginning of the project, the main contractor provided software development resources for the project team, with ambitions to develop Takt control tools for Takt project management. The site manager, foremen and selected trade partners participated in development and testing, which was conducted in six sprints during the first four weeks of the interior works. the results were published for the project after each sprint as situation awareness dashboards and tools. According to interviews, the most relevant tools for the project were 1) the main situation awareness dashboard (Fira InSite: Main View) and conditions monitoring dashboard. The Main View, depicted in Figure 1, was developed for and used on daily meetings as well as in daily planning and its functionality was owned by the site manager, who made the development decisions during sprints and controlled the features taken to the user interface.

Additionally, numerous other views were developed, e.g., user activity matrix for monitoring the learning curve of users during training and especially in daily management, conditions monitoring view (temperature, humidity, air pressure in each apartment based on IoT sensors), access control activity for logging presence of individuals on site for security purposes. Together with dedicated software applications for scheduling and quality management, the situation awareness main view established its role and position as a daily site management tool. The following use cases were identified in interviews: 1) project routine meetings: weekly Takt meeting with trades, the main contractor's internal weekly meeting for foremen and site manager, biweekly project meeting (main contractor and trades), 2) the site manager planning and control tool for managing all trades and own foremen, and 3) foreman planning and control tool for managing specific contracted work. Altogether, the intensive and disciplined use of the applications enhanced the management and leadership, as the decisions were made based on facts instead opinions, as typical in decision making.

Figure 2. Situation awareness tool (Fira Insite), which was developed during the project for site manager and foremen for visualising the current status of tasks and roadblocks as reported by trades.

The use of real-time apps on-site also provided new features for daily management. As the scheduling app for trades provided a tool for allocating tasks in certain locations for a specific worker of a specific trade, the same app was used for reporting roadblocks, which were preventing worker from proceeding with the assigned task. This reciprocal channel was quickly tested and taken into use as the site manager realised the potential of receiving announcements from the site directly and immediately when the problem occurred in starting the task. The site manager gave a promise to the trade partners that every roadblock will be solved in four hours after reporting. Later, the site manager restricted the time to two hours, as it was essential, that the foremen of the main contractor reacted without anticipation to the alarms from the site.

ORIGINAL TAKT PLAN

From the first version of the Takt plan, the standard space unit was determined to be a single apartment even though the size of the apartment varies from one to three rooms and the floor plans of the same sized apartment were completely different depending on the location of the apartment. As depicted in Figure 3, the Takt schedule was a very straightforward and fluent flow of tasks in as-planned phase. Interviews revealed that there was only a very limited amount of dialogue with trade partners during the design of the Takt plan and the resulting schedule was merely given to trade partners as a contractual fact.

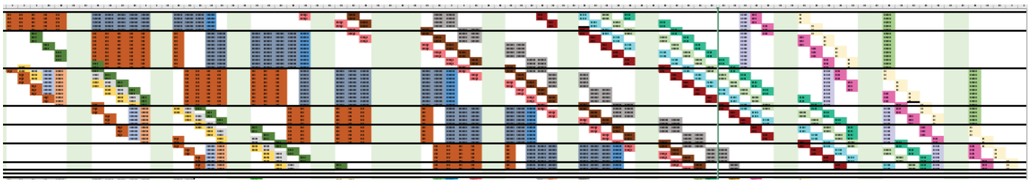


Figure 3 Original takt schedule was made in Excel and maintained manually in the site office. The method was found to be ineffective due to real-time and accessibility requirements of TPTC.

The production engineer used the methodology described by Frandson et al. (2013), for iteratively finding an optimal task order and minimising the throughput time. During the planning phase, logistics was not in focus, since movement of materials was mostly on the responsibility of trade partners.

MOBILE TAKT PLAN AND REQUIREMENT FOR SITUATION AWARENESS

Simultaneously with the manual Takt schedule, the project organisation started using Fira SiteDrive for maintaining the Takt plan and especially for allocating and updating the daily tasks for trade partners. The software also provided a mobile app to be used on site for trade partners' foremen and workers on site. The main contractor had also taken into use a quality management software, Congrid, which included a mobile app for quality inspections on-site and user interface for trade partners for receiving defect reports and tasks (Congrid Lite). The original intention was to introduce the apps and to have them to be used by every worker, but the utilisation rate was very low. The site manager made a decision that the use of apps was mandatory only for the main contractor's and the trades' foremen.

The main contractor was also developing a platform (Fira Open Data Platform) for integrating the data from point solution software and IoT on-site, to be used as raw data for data enrichment and business process analysis mandatory for providing situation awareness for participants. In Figure 3, the point solution software, use-cases and users are depicted for identifying the information flows and system architecture.

The use of mobile applications for the scheduling, resource allocation and quality management, SiteDrive and Congrid, formed the digital footprint to the data integration platform, which was used for collecting raw data for this study. The visualisations presented in this paper can be interpreted by using the legend and colour coding displayed in Figure 4.

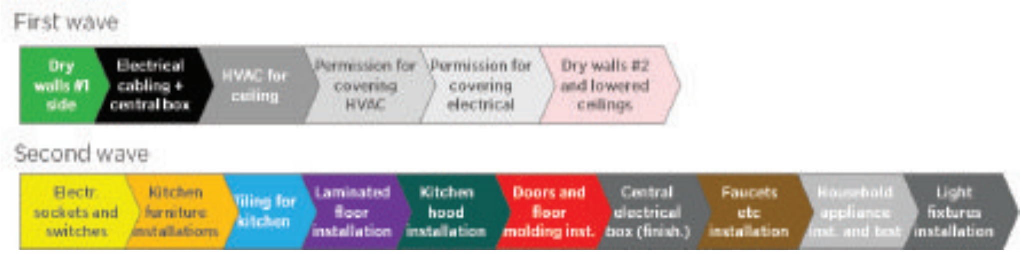


Figure 4. Work order of Takt schedule and colour coding for interpreting the Takt plan

The real nature of the whole Takt phase can be combined for visual inspection by adding the detected faults apartment by apartment to the as-build schedule. Firstly, the as-built schedule does not adhere to the original takt schedule. Instead, the duration of the completed tasks varies and the tasks are scattered into an order, which does not seem to follow any logic. Secondly, in Figure 5, the inspection rounds made by the foremen are added to the as-built schedule, indicating one or more faults detected per apartment. As the diagram shows, there were more than ten inspection rounds after the last reported completion of the last task. In twelve apartments, there were delivery problems with household appliances, and therefore the inspection date was delayed to the end of the project. When the faults are added to the same figure with as-build takt schedule, the actual progress of the project can be seen in same context. The amount of rework is now comparable with the takt schedule and deviations of task durations.

The data from the quality management tool reveals the number of faults in total at each phase of the project. Firstly, after the erection of the frame, there were 427 open faults, from which 366 were located to the apartments. The element installation trade made the levelling according to sub-contract, and the work was accepted. Unfortunately, more than 50 of these already fixed faults emerged at October in inspections, after the walls were finished and the laminated floors were installed. The reason for accepting faulty work was caused by misunderstood or misinterpreted tolerances. Similarly, all bathroom floors, which were cast in-situ, were re-plastered before installing the insulation due to inefficacious use of tolerances in contracts.

In the first week of July, the main contractor decided to restart the Takt procedure and implemented a thorough quality check to every apartment. The objective for the effort was to complete the situation awareness picture and to create two punch lists for all trades, one for tasks, which were blocking other tasks and second for standalone faults, i.e., faults which must be corrected, but there are not in priority. The number of faults in prioritised blocking fault list was relatively low, 155 pcs, 3 per apartment and the number of standalone faults was higher, 320 pcs. Faults were given to trades for fixing, although more than 1/4 of them could not be originated, and therefore the main contractor had to take care of them. None of the fixing work was scheduled to SiteDrive or elsewhere. Instead, the lists were sent by using Congrid to trades leaving the digital signature for faults.

The second wave of Takt production should have started with installations of the floor lamination. Due to unexpected drying times, the order had to be changed from the planned, and all related tasks, especially the door installations and moulding had to be rescheduled as the drying had to be speeded up by using ventilation, dryers and compartmentalisation. The installed real-time condition monitoring system made the drying process foreseeable, as there were sensors in each apartment providing accurate measurements on humidity and temperature, which were visualised to the project team by mobile app, Fira InSite. From a process perspective, the drying of the concrete required proactive measures as the weather and humidity at the seaside was not favourable for the operation (humidity was between 60-70% during working hours, temperature 25-33 C). The drying time was drastically reduced by using compartmentalisation in the apartments and dehumidifiers and air movers. Real-time monitoring of the conditions made it possible to the project team to take actions and control immediately whether the change in temperature and humidity was as planned.

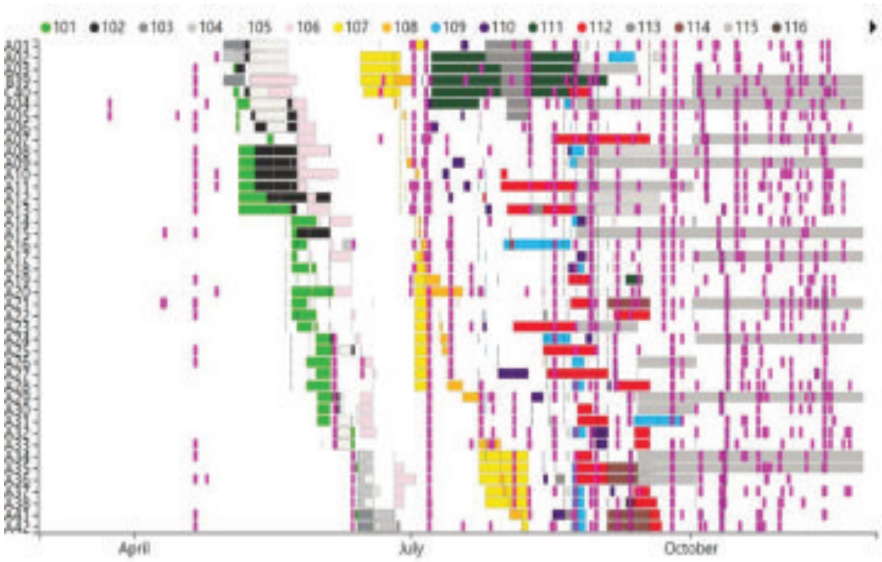


Figure 5. Actual tasks and their lengths in the Takt plan as reported on-site via SiteDrive app by foremen enriched with the data from quality control findings from Congrid

Based on data visualised in Figure 5, it is apparent that the Takt implementation in the case project was not producing results or benefits reported in Dlouhy et al. (2016) or Binninger et al. (2018). TPTC should specifically benefit the project when prefabrication and Takt planning are combined (Chauhan et al. 2018). TPTC should enhance the dialogue between participants and provide common understanding, which provides positive effects to the whole project (Dlouhy et al., 2018). The data provided by the quality inspections were used into the categorisation of sources of waste, as every fault was documented with pictures, a short written description, the location at the text, location in floorplan and the responsible trade partner.

The visualisation of the project cannot be fully understood or studied without a synthesis of individual phases. Figure 6 provides the first analysis for the Takt phase in the case project. Firstly, the main contractor tried to educate the trades for both using the Takt schedule and develop tools for efficient TPTC production (Ramp-up in Figure 6). Secondly, the main contractor managed to implement the TPTC for a short while (Takt production) and even (thirdly) thought there would be even more productive wave to come, and therefore a restart of Takt was planned and extra care for quality management was introduced (Restart). However, in the fourth phase, the tolerance problems surfaced (Tolerance Management), and as a result of them, the Takt plan was challenged. In the fifth phase, all the tasks in Takt were reported to be accomplished, but in reality, 2335 faults were detected, and the modus operandi of the project was changed from a proactive scheduling and resource allocation into reactive management of defect correction and punch lists (Quality Management).

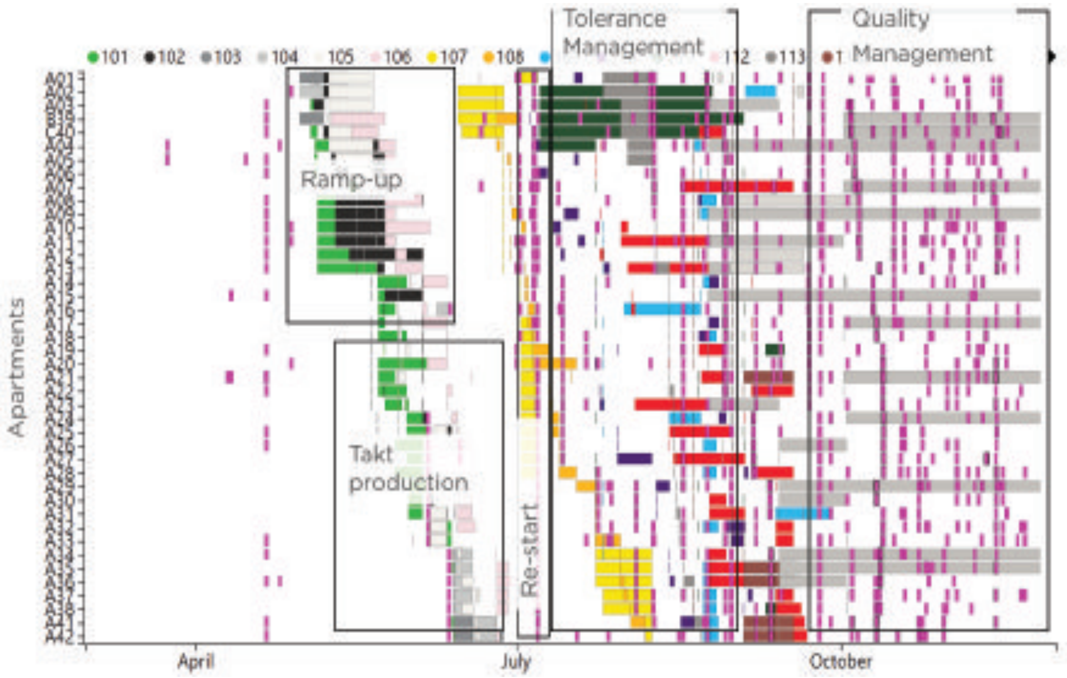


Figure 6. Suggested interpretation of phases moving the proactive TPTC implementation into reactive fault punch list management

Both tolerance and quality management phases can be examined by analysing the metadata from quality management software.

THE LEAD ROOT CAUSE FOR CHALLENGES IN PROJECT: AD- HOC TOLERANCE MANAGEMENT

In the case project, the first two weeks introduced problems with variation in required installation work hours of dry walls while the second wave of apartment construction work was seriously challenged by problems related to extended drying times. Both types of incidents required ad-hoc scheduling on-site, measuring the conditions per apartment continuously and adjusting the schedule accordingly. As can be seen from Figure 5., the Takt schedule and the cyclic order of work was heavily disturbed, and from the perspective of workers, the resulting working order was neither optimal nor easy to understand or remember. Instead, the lost regularity in order of work per floor required the foremen to continuously communicate changes and even interceptalready started tasks for enhancing the daily flow.

Based on data from quality management app, Congrid, the tolerance management problems caused by the mismatch of precasting/installation tolerances and furniture tolerances, are surfacing when doors, furniture, doors, and moulding installations. There were not visible in after first wave, wherein the total of 420 faults were reported. Instead, the tolerance problems surfaced after the last task was finished and the previous tasks were approved.

Tolerances and the management of tolerances in the construction industry have received too little attention (Milberg and Tommelein, 2004). Recently, Talebi et al. (2016) argue that tolerance problems not only cause defects but also create chains of waste. These defects are present in the case project, as the tolerances of both concrete elements and their installation cumulated errors, which together were so severe that the following tasks had to be postponed for extra plastering work. Similarly, the whole installation of laminated floors, installation of floor moulding and doors had to be rescheduled due to prolonged drying times as the on-situ cast floors didn't meet the tolerances.

Based on data, 22 faults out of 141 faults were caused by ad-hoc tolerance management and remained through all inspections and corrections. Based on results, the holistic and continuous process for tolerance management was not in place in case projects, and the root causes, which Talebi et al. (2016) provided, 1) lack of standardisation, 2) poor workmanship, 3) lack of state of the art, 4) incomplete drawings and 5) inefficacious standards on tolerances, were all present and affecting to the TPTC process.

LEAD WASTE IN THE PROJECT: MAKING-DO AND TASK DIMINISHMENT

According to data from the case project, the quality management phase took four weeks of a total of six months during which the TPTC was conducted. In essence, the throughput time could be reduced by one month if the vicious cycle of waste could be removed. For further projects and for ensuring the productivity, it is vital that the TPTC implementation is changed and therefore the root cause allowing the waste cycle must be found, isolated and removed from culture, habits and process.

Koskela et al. (2013) have raised the question of origin and nature of waste in construction based on the finding that seven waste originally presented by Ohno and Shingo may not be relevant as such in the construction process. Koskela (2004) introduced the eighth waste, making-do, as a neglected but most relevant source of waste for the construction industry. According to Koskela, making-do refers to starting a task without all standard inputs or execution of task even though the availability of at least one standard input is ceased. Patton (2008) adds the definition of task diminishment to categories of waste, as actual customer value of the product will be less than expected due to the sub-optimised implementation of the individual task. Koskela et al. (2013) underline the prevalence of both making-do and task diminishment as they both cause further waste as well as serve the same purpose of absorbing variability as inventories in other industries and especially in car manufacturing.

Based on the data in quality management tool (Congrid) in the project (picture of the fault, location in floor plan, a short description, date and time, and responsible trade partner) it was possible to categorise further the last set of reported quality deviations and isolate the making-do/task diminishment as a root cause from other incidents. Examples of typical making-do incidents in the project were kitchen furniture installations with partially incompatible parts (3 pcs). Similarly, examples of task diminishment were the installation of the bathroom without adjusting the doors, installation of moulding without proper tightening/adjustment for ensuring proper fitting of the moulding or installation of light fixture without ensuring the correct positioning of the fixture, or for focusing the light to working surface on the kitchen.

The quality management data reveals that seven of 42 apartments were handed over without faults. According to the project team, this result was considered to be better than the average on housing market. However, a thorough examination of data, including the results of customer complaints, the number of making-do/task diminishment faults was 45 out of a total of 141 faults. Keeping in mind that more than 2300 faults were fixed, but still, 45 faults remained in this category. The final 141 faults we categorised as an example case for finding making-do/task diminishment, and results showed that in the end of the project, the portion of making-do was 32% and task diminishment was 27%, while the rest was either damaged or other types of faults. One can assume, that the same apply to all faults, which were detected during the project, and therefore the making-do/task diminishment was the lead waste.

CONCLUSIONS

The data from transactions of the project reveal the true nature of the TPTC implementation in the case project. Instead of completing the tasks without faults, the flow of the construction process let the subsequent task to be started. Instead of halting the line and understanding the root cause of fault and removing it, the work progressed and repeated causing more faults to be corrected somewhere in the future. Instead of setting up the communication and learning curve characteristic to Lean implementation, the implementation of TPTC in the case project made the construction process, which by nature is creating faults and vicious cycle of waste, controllable and manageable for the main contractor. Nevertheless, the project was considered to be successful, as the throughput time was successfully reduced by 30%, and the targets concerning customer satisfaction, quality and the financials, were met. The challenge with drying times and the resulting need for daily changes to the weekly plan could have been disastrous, but thanks to the aid of digital tools, the change management was very efficient on-site. The common situation awareness made the decision making very fluent and effective as the required information for correct decisions was available in real-time and via mobile devices. The deviations in quality management and the delta between the original takt plan and actuals require further study and suggest that situation awareness in combination with real-time digital tools can turn a doomed project into a manageable one.

Takt production enhanced with digitalised scheduling and quality management applications provide an efficient tool for foremen and site manager by which the production team was able to complete the project even though the tolerance management problems were severe and lead waste constantly present. The production team, both the personnel of main contractor and trades, benefitted from the situation awareness information, and they were able to finalise the project in time by using TPTC as a tool for re-planning the order of tasks and assigning the tasks for a most efficient way to reduce the throughput time. The digital footprint of the project reveals that there is a significant potential for increasing productivity by removing the making-do/task diminishment as a lead waste of TPTC. However, the TPTC implementation was not successful as such and the project failed in implementing the LPS as a method for identifying and reducing the number of faults and quality problems during the project. The digital footprint was not adequate for supporting the project team for identifying the vicious cycle of waste. Further research must be conducted for data gathering, real-time analysis and further visualisation for providing valuable knowledge for TPTC teams and help them implementing the LPS and especially the make-ready planning as a part of TPTC project.

REFERENCES

Binninger, M., Dlouhy, J., Müller, M., Schattmann, M. and Haghsheno, S. (2018). “Short Takt Time in Construction – a Practical Study.” *Proc. of the 26th Ann. Conf. of the Int’l Group for Lean Construction*. Chennai, India

Chauhan, K., Peltokorpi, A., Seppänen, O. and Berghede, K. (2018). “Combining Takt Planning With Prefabrication for Industrialized Construction.” *Proc. of the 26th Ann. Conf. of the Int’l Group for Lean Construction*. Chennai, India

Dlouhy, J., Oprach, S. and Binninger, M. (2018). Using Taktplanning and Taktcontrol in Production Projects - Comparision of Construction and Equipment Phases. *Proc. of the 26th Ann. Conf. of the Int’l Group for Lean Construction*. Chennai, India

Frandson, A., Berghede, K. and Tommelein, I. D. (2013). “Takt time planning for construction of exterior cladding.” *Proc. of the 21st Ann. Conf. of the Int’l Group for Lean Construction*. Fortaleza, Brazil

Love, P., Edwards, D., Irani, Z., & Walker D. (2009). Project Pathogens: The Anatomy of Omission Errors in Construction and Resource Engineering Project. IEEE Transactions on Engineering Management, vol. 56, no. 3 August 2009

Milberg, C. and Tommelein, I. D. (2004). “Tolerance Mapping - Partition Wall Case Revisited.” *Proc. of the 12th Ann. Conf. of the Int’l Group for Lean Construction*. Helsingor, Denmark

Ohno, Taiichi. 1988. *Toyota production system*. Productivity Press, Cambridge, MA.

143 p.

Talebi, S., Koskela, L., Shelbourn, M. and Tzortzopoulos, P. (2016). “Critical Review of Tolerance Management in Construction.” *Proc. of the 24th Ann. Conf. of the Int’l Group for Lean Construction*. Boston, MA, USA.

Zhao, J., Olivieri, H., Seppänen, O., Peltokorpi, A., Badihi, B. & Lundström, P. (2018). Data Analysis on Applying Real Time Tracking in Production Control of Construction. 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). DOI: 10.1109/IEEM.2017.8289956.

von Moltke, H. (1871) Über Strategie. Cited from Militārische Werke (1890), Band 2, Teil 2. Mittler & Sohn Berl

Andersen, L, and Fyhn, H. (2019): ‘Organizational and Cultural Preconditions for Extending the Use of Takt-Time Planning.’ In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 467–478. DOI: https://doi.org/10.24928/2019/0271. Available at: <www.iglc.net>.

Andersen, L, and Fyhn, H. (2019): 'Organizational and Cultural Preconditions for Extending the Use of Takt-Time Planning.' In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 467–478. DOI: https://doi.org/10.24928/2019/0271. Available at: <www.iglc.net>.

ORGANISATIONAL AND CULTURAL PRECONDITIONS FOR EXTENDING THE USE OF TAKT-TIME PLANNING

Lars Andersen[1] and Håkon Fyhn[2]

ABSTRACT

This paper presents findings of a study about how to extend the use of Takt-time planning in construction projects. The study is based on analysis of two construction projects involving non-repetitive work that, after failing to use Takt-time planning, had to return to ordinary methods of production. To uncover causes to the problems, the research method Theory-building process tracing is used. Results show that extended use of Takt-time planning presupposes effective coordination in the projecting process and a proactive and well organised production control in the construction phase. It also presupposes high involvement of the craftsmen and crew-leaders in the Takt-time planning and production. The method of theory-building process tracing is transferred from political science and historical studies to construction projects. The research method offers a unit of hypothesis testing and cumulative practical theory development, which can be of general value for construction research. Although the validation of the present empirical results is thorough, based on interviews and workshops, the researchers own observations of the processes studied could have been more extensive.

KEYWORDS

Process tracing, takt-time planning, production control, culture, rationalism

INTRODUCTION

This paper reports the case studies of two construction projects involving non-repetitive work that failed to use Takt-time planning (TTP) and, as a result, had to revert to ordinary methods of production during the production phase of the projects. The two construction projects examined were organised by the same turnkey contractor who practises a variant of the Last Planner System (LPS) known as the Material Systemic approach (MSa), which was partly used in combination with TTP during the projects. One of the projects used integrated concurrent engineering (ICE) in the design and engineering process, whereas the other used a traditional sequential approach. Since both TTP (e.g., Frandson et al., 2014) and MSa (Andersen, 2018) are presented in previous papers, the following graphs only briefly describe the two methods.

[1]Lars Andersen. Research professor. NTNU – Norwegian University of Science and Technology. Trondheim. Norway. +047 92885305. Lars.Andersen@samfunn.ntnu.no

[2] Håkon Fyhn. Co-author. Senior researcher. NTNU – Norwegian University of Science and Technology. Trondheim. Norway. +047 91743561.

TP is a method for work structuring and flow (Frandson et al., 2014) that integrates the concept of the assembly line rooted in the manufacturing industry (e.g., Fordism and Toyotism) into construction processes. According to Dlouhy et al. (2018), TTP begins by dividing the object of the project (e.g., a building) into control areas (e.g., rooms or parts of floors) in order for production and the various trades involved to appropriately move forward from one control area to the next. The progression of trades through control areas can be conceived as a train with one trade in each wagon that stops in each control area for the given TTP period (e.g., one week). With tight coupling up of standardized tasks internally and between the control areas, the work structure enables flow with no idle time. The internal production control of TTP follows the logic of planned–percent–done in the LPS; however, the LPS places greater emphasis on proactive production control based on plans that are first detailed near execution and with obstacle analysis making the activities ready (sound) before execution.

In MSa, planning persists throughout construction as an interpretative process that progresses along the dimensions from unclear to clearer and from the abstract to more concrete. In that sense, planning does not stop before execution, as in rationalist planning theory, but continues, e.g., as the cognitive activity of craftsmen as part of their work and as new levels of interpretation are realised through object creation or materialisation (e.g., completing a part of a building). The planning process involves 'division of labour in time' and a reversed meeting structure. The crew or craftsmen make a joint work plan for each week (in the meeting of craftsmen), and crew leaders have similar responsibilities for planning activities 2 or 3 weeks before the activities are initiated (in a meeting of crew leaders immediately after the meeting of craftsmen). Next, middle managers assume responsibilities 4–8 weeks before the activities in question are initiated and meet after the crew leaders' meeting. A management team operates in the timeframe 9 weeks before the progressive production front and onwards. In that structure, plans made ahead of time are continually reinterpreted in light of object creation in the physical building process. This organizational structure, in addition to the actual plan development, also provides a basis for an organized, expanded, proactive production control.

The issue of this paper is: what are the underlying causes that inhibit extended use of TTP in construction processes. The empirical research questions are: 1) What are the immediate causes of the failure of TTP/Tack production in these cases? 2) What are the underlying causes of the failure, if any? 3) What guidelines does the analysis introduce for future extended use of TTP in building projects?

THEORY

The traditional theory of project management and planning is based on classical rationalism and ideal rationality (Koskela and Howell, 2002) and the over-confident belief in the possibility of realising maximum rationality. According to Simon (1957), maximum rationality is impossible due to restrictions of human recognition and an inherent element of unpredictability in all processes. Instead of aiming at maximum rationality, one must adapt to a limited ability to predict outcomes and reach for satisfactory solutions in a bounded rationality.

TTP and Tack production (in accordance with the Toyota system) exhibit features of classic rationalism insofar as most of the production system is predefined; the individual subjects, groups, and activities are preconditioned to operate within long, fixed chains of activities forward in time based on tight links between subjects and tasks. However, TTP also has features of modified rationalism through its emphasis on internal production control. In contrast, LPS can be understood to be grounded in modified rationalism as a planning and control system in which one can flexibly make rapid, extensive changes to the plan for single subjects and groups, operations, and the entire production front in light of altered conditions of production and an unpredictable external empirical reality.

By contrast, MSa thematises the outer empirical world influenced by complexity philosophy and the philosophy of objects (Kärrholm, 2014; Andersen, 2018). In a construction processes, and in light of this approach, the empirical outer reality emerges as meaning-based objects in a double sense of the term: first as materiality by virtue of physical building and second as ongoing differentiations and concretions mediated by the human subjects' perceptions of the outer world.

EMPIRICAL DATA AND METHOD

The empirical data of the study is based on case studies: Case 1 is a building connected to a sport hall, and Case 2 a mid-sized hospital. The empirical study of Case 1 took place during 8 months in 2018 (in the construction phase). Craftsmen, crew-leaders, foremen, work-manager and site-manager were interviewed in semi-structured qualitative interviews (10 informants) as part of mid, and endpoints evaluations of the project. The study of Case 2 was carried out in two parts: first, 7 months in 2017 (projecting phase), and then 5 months in 2018 (construction phase). The projecting phase was examined by participatory observations of ICE sessions followed up by interviews of architect, coordinator of technical subjects, projecting manager, work manager, site manager and project manager (6 informants). The last three were also interviewed about the production phase. In both cases, studies of the construction phase involved participatory observations in meetings of crew leaders and managers. The researchers were also engaged in weekly on-site inspections with crew leaders with subsequent debriefing with key informants. The data were validated in initial, mid, and endpoint project workshops on site during the observation period. After the observation period additional workshops were arranged with the craftsmen, and with project managers and regional managers of the contractor, during which the results were discussed and further validated.

The study uses the theory-guided process tracing method (Falleti, 2016). The theory-building process tracing method requires a process outcome for which there is no obvious cause. The researcher starts out from a defined beginning point of the process and then describes a causal stepwise diagram based on the methods/activities that the actors of the process actually have chosen (or events that has happened) and that may have affected the end-result. The researcher then performs a closer analysis of the empirical outcome of the process and traces its causes backwards in the process by help of theory. The structure of the analyses of the causes is first to describe the method used, then to ask why and how it caused the outcome (the problem). The identification of the factual cause of the problem proves to presuppose the identification of the solution as a counterfactual action – that is, what the actors should have done to realize their intentions.

RESULTS

The figure below presents a causal diagram based on steps in the construction process of the two cases. The study is a theory-building process tracing. According to this, the causal diagram moves forward from pre-projecting to the outcome—the building process. The tracing moves backwards from, e.g., an unwished outcome, to prior and underlying causes. Case 1 (building the sports hall) chose to organize the projecting phase the traditional way but used TTP in the construction. Case 2 (hospital) chose lean tools more consistently with ICE in projecting and TTP in construction. Both cases had lean philosophy as a theoretical foundation. The causal diagram of the cases is illustrated below.

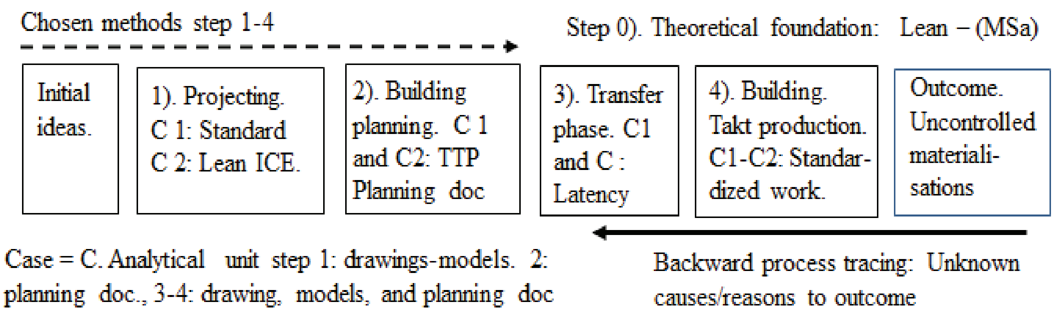


Diagram 1. Causal diagram. Building project. Theory-building process tracing

CASE 1. PROCESS TRACING (BACKWARD)

The construction project (building connected to a sports hall) was based on an ordinary turnkey contract using TTP in the building phase.

Outcome: uncontrolled materializations—immediate causes

Typical signals of problems in Takt production were increased amounts of unfinished tasks in the control areas, an increase in disorder relating to equipment, tools, and materials left behind, and increased traffic of craftsmen between control areas to finish the work. It was especially the carpenters that had problems which caused chain-reactions to the other subjects.

Early in the building process, it was discovered that the Takt schedule was based on relative understaffing of carpenters and that the plans did not sufficiently differentiate between the (non-repetitive) control areas. Use of buffers and corrective measures was not sufficient to relieve the situation. Delayed builder's decisions and changes contributed to unfinished design/engineering and uncertainties regarding the purchase of materials. Due to the resulting lack of production control, the production managers ended up 'firefighting' immediate problems. The production actors interpreted the situation as primarily caused by three external events that garnered attention: one was an unforeseen political process concerning the financing of the building, whereas the other two were ongoing arrangements that took place in the sports hall and the development of outdoor space for the hall; in both, the client was directly involved.

UNDERLYING CAUSES

Step 4. Building. Chosen method: Takt production. According to TTP/Takt production, the work process is defined in detail before execution. In this case, however, the descriptions of the control areas were imprecise, and the plan included too few carpenters. The carpenters attempted to compensate for this by giving priority to tasks with critical dependencies on other subjects, but this led to their own work being not very rational, which escalated the effects of their own understaffing. The project's available buffers and corrective measures were insufficient to maintain the Takt in production.

Material objects consist of structuring materials that give them unity and stability in space and time. The structuring material in buildings comprise, e.g., concrete, wood, and steel for building floors, walls, ceilings, shafts, etc. (the skeleton of the construction). The form of structuring materials creates a foundation for the other individual installations (e.g., light, ventilation) and how they are placed and work together. This gives the structuring subject (e.g., the carpenter) an opportunity to have a practical coordinating role in the construction process and to develop a corresponding coordination competence.

Counterfactuals: In this case, the carpenters' main crew leader had good 'structuring' competence and interacted with the other crew leaders to carry out improvisations to continually develop and implement corrective actions to 'rescue' the Takt production system once the problems arose. This helped expand the life of the Takt system for a certain period of time.

Step 3. Transfer of documents. Chosen method: latency. The transfer phase is the period after the drawings, models, and planning documents are completed and moved through the planning time windows until they are finally used as a basis for the sequential physical building production on site. The operative planning was formally organized according to the principles of MSa (described initially). However, the meetings further ahead on the time axis than the CL-meeting were at a low level of activity. The transfer of drawings, models, and documents instead took the character of passive transport or latency. This occurred at the same time as the three process-exogenous factors (political processes, arrangements in the sports hall, and outdoor space for the hall) contributed to significant disturbances in the Takt production (delayed builder's decisions and changes that resulted in unfinished engineering and uncertainties regarding the purchase of materials). Normally, measures aimed at major changes in project-external production conditions need to be planned and implemented in due time in order not to disturb the production (e.g., active planning development about week three and forward in time before production). If such changes are not recognized early enough, then possibilities for production control are lost. The lack of proactive and well-organized production control appears to be the main reasons for the collapse of the Takt production in this case. **Counterfactuals:** The closer the links are between the activities and the more perfect transitions in the Takt productions system, the more vulnerable the system is to any type of variation that affects the production conditions. The need for increased effective proactive production-control increases when variation in exogenous production conditions increases. When practicing TTP/Takt production, one must simultaneously implement, e.g., MSa (or LPS) so that drawings, models, and planning documents are further developed throughout the transfer process.

Steps 2 and 1. Building planning and projecting. Chosen methods: TTP and traditional projecting. In this project, the projecting and development of TTP followed sequentially. **Counterfactuals:** The integration of TTP and project planning (cf., Frandzen et al., 2014) could have pushed for increased precision and coordination of projection and construction plans. This effect could be enhanced by the use of structured ICE in the design (see counterfactuals step 1, Case 2).

Step 0. Culture. 'Chosen method' (implicit assumption): lean and rationalism.

Data from the case suggest that the project managers were overconfident in their understanding of the TTP/Takt production system as a self-sufficient system for work structuring and flow. Such an 'implicit assumption' explains why these actors may tend to underestimate the need to combine Takt production with proactive production control. **Counterfactuals:** When implicit theoretical assumptions are made explicit, they appear as a choice.

CASE 2. PROCESS TRACING (BACKWARD)

The hospital project was based on a turnkey contract involving interaction between the contractor and the projecting team in the pre-project phase and further in the detailed design phase.

Outcome: uncontrolled materializations, immediate causes

The immediate causes of breakdown in the Takt production system in Case 2 had many of the same features as in Case 1, but the order of cause was different. The informants reported that the problems were related to uncertainty and failure related to the procurement of materials. However, the informants believed that the problems had largely originated in the design: generally, the level of detail was too low. The informants also reported that the flow in the building process was obstructed by walls not being adequately designed, creating immediate problems for the work on piping and drainage and in a chain reaction for other tasks. While the problems with structuring materials were an underlying cause in Case 1, the walls as structuring material were an immediate cause of the problems in Case 2.

UNDERLYING CAUSES

Step 4. Building. Chosen method: Takt production. This case used parts of the recipe for TTP/Takt production as in Case 1. Lack of drawings of walls triggers chain reactions among the structuring subjects with the starting point in the carpenter subject. In this case, however, there was no carpenter crew leader (as in Case 1) entering the multidisciplinary coordinating role between the subjects to create an extra buffer in the Takt production. Instead, the problems with Takt production escalated quickly in this case and led to a quick abandonment of the production method.

Counterfactuals. The alternative is (like in Case 1) to develop a 'structured high involvement production system' (cf., the Toyota system) with continuous development of working standards and with the capability to utilize all available forms of buffers against deviations from expected production conditions. Creative interaction between the craftsmen crews may have mitigated some of the effects stemming from imperfect drawings, models, and planning documents.

Step 3. Transfer of documents. Chosen method: Latency. During the construction process, there were weekly crew leader meetings for all subjects at which the joint production front for the following 1–3 weeks was to be planned. However, those meetings dealt to a limited extent with the second and third week before the production front. The production control further forward in time was also deficient. **Counterfactuals:** The situation is the same as in Case 1. If the MSa had been more consistently practised in the construction phase in Case 2, then obstacles to 'sound' production could have been uncovered earlier and better controlled.

Step 2. Building planning. Chosen method: TTP. TTP was made after and uncoupled from the projecting process. **Counterfactuals:** Integration of projection and development of the building plan will contribute to increased precision in the object definitions used for projecting.

Step 1. Projecting. Chosen method: ICE. The Case used weekly joint ICE meetings with the planning technique 'wallboard and notes', needs-driven special meetings with smaller interdisciplinary teams, self-directed informal processes between the designers, and management of objectives (cf., the engineer-projecting manager of the turnkey contractor).

The ICE meetings had a clear focus on the status of the progress of the projection and on planned actions and deliveries for the subsequent weeks, however, this left a vacuum regarding interdisciplinary processes. The informants (especially architects and design engineers) reported that the lean tools in use did not reveal the 'undergrowth' of interdisciplinary dependencies in the design, and they called for specialized professional competence to comprehend the complexity of the process. Let´s take a closer look at the underlying causes of these experiences.

The overview of immediate causes identified the unfinished design of walls as part of structuring material as a main cause of the failure in production. The analyses (Cases 1 and 2) uncovered how the work of operative building-subjects (e.g., carpenters, carpenters' crew-leader, work manager, etc.) carries in it a special competence for coordinating other subjects. This is grounded in that structuring material also means to structure and give order to the specific material with technological end-effects originating from the other subjects in the building process. When we move the focus back to the design and takes the architect's position and perspective, we look accordingly: in the projecting process, the architect uses his or her own expertise and competence in the modelling of structuring material to coordinate and give meaningful order to the individual user functions ('good light here', 'fresh air', etc.). The individual user functions correspond with individual subjects' deliveries towards the modelling of structuring material. This means that the architect's expertise in coordinating individual user functions also means a special access to competence in order to coordinate other design subjects.

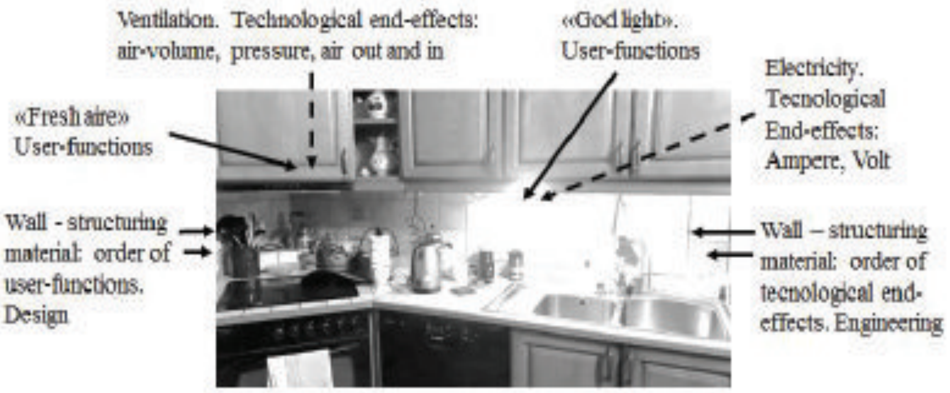


Figure 1. Dimmensions of the building object. Structuring materiel – user functions and end-effects

The practice of ICE highlights the need to develop and integrate the competence and coordination system in projecting with the corresponding system in building execution into one coordination system. The loss of such an integrated coordination system based on structuring material in the projecting phase is, according to our process tracing, a main underlying cause of the failure in the Tact production in the case-project studied.

Counterfactuals. The integrated coordination system is developed through dialogues. The points below outline the actual dialogue and coordination system.

1. The main dialogue and coordination is between the structuring subject axis (architect and operative building subject) and the technical subjects (design engineer and technical engineer subjects) (cf., the main interface of the coordination). See Figure 2.

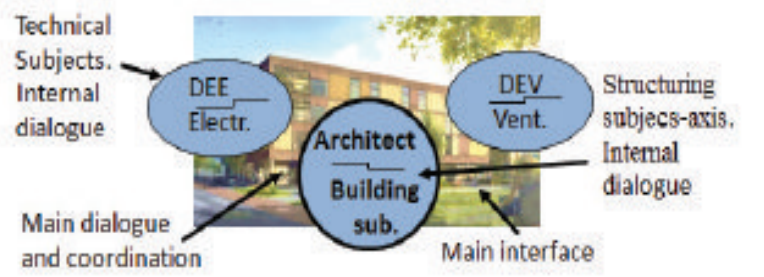


Figure 2. Projecting: dialogue and coordination system. DEE – design engineer electronics and DEV – design engineering ventilation. Electr. and Vent.: electrical and ventilation engineers - execution.

When dialogues and iterations (reciprocal) do not lead to adherence to joint action proposals, the structuring subjects together make decisions – optionally in collaboration with the builder/client.

2. Necessary additional dialogues: a) the structuring subject-axis' internal dialogue (between architect and operative building subject), b) internal technical subjects' dialogues (e.g. between design engineer electronics and electrician engineer subject), c) dialogues design engineering subjects, and d) dialogues between executing subjects.

Related to the case studied, this model of dialogues and coordination will have the

following consequences: The actors in structuring the subject-axis must (e.g., in ICE meetings) go ahead and develop the plan of their own subject as a decision-making premise for other subjects in the common planning process. The structuring subject-axis will have the coordinator role in the fixed-theme groups. In special meetings and informal communications, the structuring subject-axis would also have the role as coordinating actor between the subjects. In all these situations, the structuring axis has decision-making authority in the main interface of the process. The developed counterfactual dialogue and coordination system provides a formalized, self-directed, expert system of communication and decision making. Management by objectives will in this coordination system have a complementary role with responsibility for progress in decision making etc.

Step 0. Culture. 'Chosen method' (implicit assumption): lean - rationalism. As in Case 1, management in Case 2 had high confidence in the TTP/Takt production system as a self-sufficient system. The informants highlighted the tendency of the project to 'fall asleep', that is, subjects conceived the schedules and descriptions to be finished and to be followed slavishly. The same trend has been revealed in other studies (Fyhn and Søraa, 2017). The understanding of the process as static appears to be an underlying cause, an unrecognised assumption and preconception originating from the planning optimism of classic rationalistic thinking and culture.

Counterfactuals. The interpretative and open process thinking of MSa stands out as an alternative theoretical foundation of Takt principles. Diagram 2 below shows the counterfactuals developed for each step analysed in the two cases.

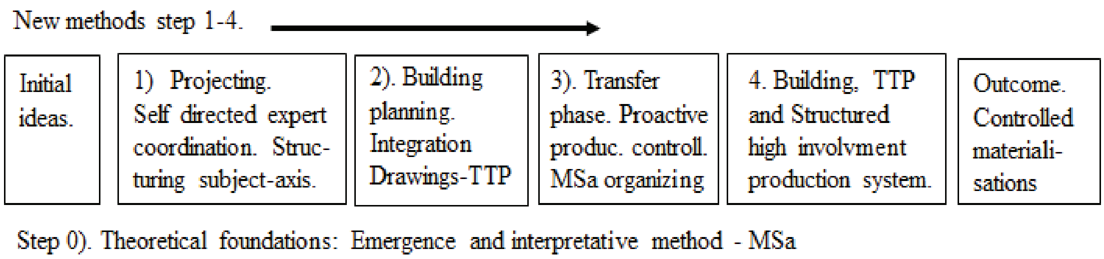


Diagram 2. Building project. Methodes based on counterfactuals

DISCUSSION

When using the theory-building process tracing research method, causes to problems are revealed and counterfactuals developed using theory, which is then tested in the next project. The backward process tracing in this study gave the following results: **Step 1:** The counterfactual ‘expert-driven, self-directed, dialogical coordination system’ presupposes object philosophy and allows one to understand the limitations in ICE caused by unstructured reciprocal social relations between actors. **Step 2:** ‘Radical integration of the making of the building plan with projection (and procurement)’ presupposes self-directed projecting and can uncover the weaknesses in sequenced projection and the making of the building plan. **Step 3:** The counterfactual ‘increased proactive production control’, based on continuous further development of the drawings and plans and on extended organization in the transfer phase, provides a deeper understanding of the problems with latency of the documents in the same phase. **Step 4:** The identification of the solution ‘structured high-involvement production system’ makes it possible to understand how standardized work may contribute to uncontrolled materializations. **Step 0:** The alternative theoretical foundation based on interpretative object-philosophy and open process understanding is used in the causal analyses and to develop individual counterfactuals. The theoretical foundation itself is also further developed through stepwise analysis in the process tracing.

It is known that in LPS, plans and purchasing (and projecting?) must be detailed close to the execution of activities. In contrast, the rationale in TTP assumes detailed plans, predefined activities, and that procurement is decided early in the process. The counterfactuals presented in this paper may contribute to making TTP more resilient. A further possible solution to the paradox of the early detailing of plans and the opposite need for flexibility here and now may be to divide the building projects into many smaller phases and postpone the details (projecting, design of the Takt plan, and procurement) until the individual phase is to be performed.

REFERENCES

Andersen, L. (2018): Complexity and rationality: a material-systemic approach. https://www.emeraldinsight.com/doi/full/10.1108/IJMPB-10-2017-0116

Dlouhy et al. (2018): Mastering complexity in Takt planning and Takt control—using the three-level model to increase efficiency and performance in construction projects. IGLC 2018. Chennai India. 1365–1374.

Falleti, T.G. (2016): Process tracing of extensive and intensive processes. *New Political Economy*. 21:5, 455–462. *Routledge, Taylor and Francis Group.*

Frandson A.G. et al. (2014): Takt-time planning and the Last Planner. Proceedings. IGLC. Oslo, Norway.

Fyhn, H. and Søraa, R.A. (2017): Craftsmanship in the machine: sustainability through new roles in building craft at the technologized building site. *Nordic Journal of Science and Technology Studies* 2017 Vol. 5 (2) s. 71–84.

Kärrholm, M. (2014): Interobjectivity in architectural research and theory: towards a metatheory of materiality and the effects of architecture and everyday life. *The Journal of Architecture.* Taylor & Francis Group. London.

Koskela. L. and Howell, G. (2002): The underlying theory of project management is obsolete. *Project Management Institute.*

Simon, H. A. (1957). *Administrative behaviour.* Fallköping. Gummessons Boktryckeri.

Tommelein, I. (2017): Collaborative Takt Time Planning of non-repetitive work. Proceedings. IGLC. Heraklion, Greece.

STREAM 8: ABOUT TARGET VALUE DELIVERY

Devkar, G., Trivedi, J., and Pandit, D. (2019). "Teaching Target Value Design: Learnings and Challenges." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 479–490. DOI: https://doi.org/10.24928/2019/0244. Available at: <www.iglc.net>.

TEACHING TARGET VALUE DESIGN: A SIMULATION

Ganesh Devkar [1], Jyoti Trivedi [2], and Devanshu Pandit [3]

ABSTRACT

Target Value Design (TVD) is a promising lean tool that drives the design process of a construction project with the sole intent of value maximization for the client within targeted cost. The mainstreaming of this tool in design and construction practice requires not only imparting knowledge about this tool but also providing hand on experience to the budding design and construction management students. The aim of this paper is to describe the development and testing of TVD simulation exercise. The research methodology adopted is a combination of qualitative approach – a case study of simulation exercise, and quantitative approach – questionnaire survey amongst simulation participants. The simulation involves a role play exercise for students to understand the collaboration between designers, owner, and contractor in the design process. Along with these three main stakeholders, the simulation involved BIM modeler for providing rapid cost feedback during the preparation of design alternatives. The simulation was tested on students of the master's programme in Construction Engineering and Management in an Indian university. The research highlights the effectiveness of the simulation in helping students understand the benefits of TVD. Further, the participants of this simulation exercise expressed the value addition of BIM in generating rapid cost feedback during design iterations. Despite the limited scope selected for the simulation and the challenges offered by classroom environments, this simulation improved the practical understanding of IPD and TVD amongst the students.

KEYWORDS

Lean construction, target value design (TVD), collaboration, action learning

INTRODUCTION

There exists various lean tools and techniques for improving the design of construction projects. Target Value Design (TVD) is one of the prominent techniques which not only addresses the procedural dimension, but also the cultural dimension of the design process. TVD envisages active involvement of client and early involvement of the contractor in the

[1] Associate Professor, Faculty of Technology, CEPT University, Ahmedabad - 380009, India, +919099010303, ganesh.devkar@cept.ac.in

[2] Assistant Professor, Faculty of Technology, CEPT University, Ahmedabad - 380009, India, +919925009609, jyoti@cept.ac.in

[3] Professor, Faculty of Technology, CEPT University, Ahmedabad - 380009, India, +919909956661, devanshu@cept.ac.in

design process along with collaboration between client, contractor, and client, which is far different from typical design and construction processes. In general, silo-based design is practiced and the contractor comes on the canvas of construction project only after the award of work (Landgren et al. 2018). The utilization of TVD in the construction industry hinges on imparting hands-on knowledge to the young construction professionals about value addition of this innovative lean tool.

In this context, this paper discusses the development and testing of a TVD simulation exercise at a prominent university in India. This paper comprises five sections; beginning with the introduction described here, the paper processed to provide an overview of TVD and its application in the construction industry in the second section. The third section describes the development of the simulation, followed by its testing in the fourth section. The paper concludes with a post-simulation discussion as the fifth and final section of the paper.

TARGET VALUE DESIGN

The primary driver for the simulation is the hypothesis described by Ballard, G., 2008 stating that facilities better fit for purpose can be provided at less cost through rigorous project definition and through lean design and construction; i.e. through the lean project delivery system. The lean project delivery system involves helping the clients decide what they want, rather than simply developing what they ask.

The expected cost, as defined by Ballard, G., 2008 is the forecast or estimated cost of the project at current best practice. This Expected Cost is referred to as the "Market Cost" in the simulation described in this paper. The Target Cost, referred to as is in the simulation, is what the team commits to deliver, and is typically set below the expected cost in order to spur innovation beyond current best practice. Once a target cost has been established, the project is collaboratively designed to that target cost (Ballard & Rybkowski, 2009).

TVD is an adaption of target costing. Ballard, G., 2009 describes TVD as a management practice that drives design to deliver customer values within project constraints. TVD is driven by an awareness of costs and constructability by harnessing a collaborative approach towards design development. TVD offers designers an opportunity to engage in the design conversation concurrently with those people who will procure services and execute the design (Macomber, Howell, & Barberio, 2008).

From a practical viewpoint of TVD implementation in the industry, researchers have reported that TVD projects have been completed at 15% to 20% below the market price without compromising schedule or quality (Ballard & Rybkowski, 2009). Do et al., 2014 further reinforces these findings through their extensive study of 47 TVD projects, wherein TVD has been noted to be advantageous in controlling the project's budget, by making cost a design constraint from early on. Further, better coordination has been reported by the early involvement of trade partners during the design.

AIA, 2017 describes Integrated Project Delivery (IPD) as a project delivery approach that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. It further states Building Information

Modeling (BIM) as one of the most powerful tools supporting IPD by combining all aspects of a project into one common database for collaboration throughout the project development.

Ballard, G., 2008 describes defining target cost, promoting collaboration and rapid estimating as some of the major steps involved in Design Development in Lean Project Delivery. The simulation highlighted in the paper is based on Target Value Design through Integrated Project Delivery, supported by rapid cost feedback using BIM.

SIMULATION DEVELOPMENT

The demand for construction managers has been increasing continuously because of rapid infrastructure development being experienced in India. As a result, many universities have been offering masters level courses (Master of Technology – M.Tech.) in the domain of Construction Engineering and Management. There has been increasing concern amongst the construction industry fraternity over industry readiness of construction management graduates coming out of these various masters level programmes.

There has been an increasing focus to simulate practical construction site environment in a classroom setting and increased interaction with industry professionals to address these concerns. Along these lines, the authors of this paper who were teaching a studio course named "Construction Project Formulation and Appraisal" as part of the M.Tech Construction Engineering and Management programme at an Indian University developed and tested a simulation of TVD method. The studio course aims to bring real-life problems into the classroom and equips students to solve these problems with the application of theoretical concepts. In reality, it attempts to bridge the gap between theory and practice. The aim of this studio is to equip students with the necessary knowledge and skills for performing appraisal of construction project from the viewpoint of finance, economics, design, and engineering.

There were 24 students taking part in this studio, of which 6 students had a prior educational degree (Bachelor's) in Architecture (known as B. Arch), while the rest had an undergraduate degree in Civil Engineering (known as B.E/B.Tech – Civil). Many of these students had work experience ranging from 2 to 3 years. Of these 24 students, six groups were created and each of these groups had a student with B. Arch qualification and with work experience. The groups were designed to foster cross-learning among students of different educational backgrounds, to hasten the learning trajectories of students without work experience, and to transition students with work experience into the learning mode by raising questions/queries on set practices in the construction industry.

The instructors provided a list of potential projects to be appraised in this studio. This list contained projects from varied sectors like industrial, infrastructure, and real estate. These projects were either in the proposal stage, indicated as in pipeline stages by government departments or private developers, or were at the preliminary stages of construction. The projects were allocated to the groups based on their interests. The groups were expected to perform appraisal of assigned project by collection and analysis of primary as well as secondary data. The primary data was collected from interviews with stakeholders like project proponents, public sector organizations involved in the approval and implementation of the project, industry groups, think tanks and non-governmental organizations. The secondary data was in the form of traffic survey, minutes of meeting, census and demographic parameters, governmental policies, and contracts. The following appraisals were typically carried out by each group: demand and market assessment, technical analysis, legal compliances, project conceptualization and planning, financial analysis, technical analysis, project structuring, and procurement strategy, stakeholder analysis, environmental impact assessment, risk analysis, and project controls. Based on the availability of primary and secondary data, each group performed in-depth analysis or assessment of a few topics, although, the instructors ensured breadth in terms of areas to be typically analysed. Following is the list of projects selected: 1) Garment Factory, Ranoda, 2) ITC Narmada Hotel, 3) Redevelopment of Gandhinagar Railway Station, 4) Vadodara Mumbai Expressway, 5) Surat Metro Rail and 6) Aquatics Gallery, Science City.

To begin with, the student groups investigated the project characteristics covering factors like location, transport connectivity and stakeholders associated with the project. These factors helped in carrying out locational analysis that focused on the advantages and disadvantages associated with the actual project site as well as other potential sites. After completion of this analysis, the studio discussion focused on technical analysis. It comprised the development of design brief, proposed design, and target value design. The students collected information pertaining to bylaws, standards and specifications, site characteristics and guidelines relevant for design development. They also analysed the design features of existing projects having similar scale and area.

The members of each students group were divided into three roles: client, contractor, and designer. Typically, there were 4 students in each student group. The role of designer was assigned to 1 student having bachelor's degree in architecture, while students having work experience and no experience played the roles of the contractor (1 No.s) and client (2 No.s), respectively. The rationale behind the assignment of these roles was to harness the educational background and experience of a student to play the role effectively. The simulation was conducted in two steps; the first step involved emulating silo-based design, wherein the designer, contractor, and client worked independently, within their functional silos. The instructor has used the formats as mentioned in Designing Buildings Wiki (Strategic Brief for construction projects, 2018) for preparation of project brief and design brief. The project brief defines the Client's requirements for the development of the built asset. It is the key document upon which the design will be based. The project brief includes project information, spatial requirements, technical requirements, component requirements, and other issues. Each student group was instructed to select a specific portion of their construction project for the purpose of detailed design. The students were told to design either of the following: structural system, MEP system, and lighting system. Apart from these detailed design features, each group has covered basic design features related to material, layout or space, methods or systems, and specifications. Considering the time available for this simulation and prior skills with the students, it was impractical to perform the detailed design of not only the entire project but also a specific portion of their projects.

DEVELOPMENT OF DESIGN OPTION –D1

Each student was told to select a specific component of their project for the TVD simulation. Firstly, the student playing the role of Client was instructed to develop a project brief for the selected component. The developed project brief was communicated to the designer via email. Since the beginning of this TVD simulation, the students were asked to mark a copy of the email communication to the instructor, with an aim to understand the information flow among the team members. The developed project brief was communicated to the designer. With reference to this project brief, the designer has developed a design brief, following the components described in Designing Buildings Wiki (Project Brief for design and construction, 2019). The student playing the role of Designer has finalised the design brief in consultation with the Client members. Afterward, the designer has developed the Design in 2D format. While developing the Design option – D1, the designer was instructed to note the number of requests for information (RFI) sought, along with the total duration taken to complete the design. After the finalisation of D1, this design was communicated to the contractor team member for estimating the cost of selected project component. This cost was named as market cost (C1).

DEVELOPMENT OF DESIGN OPTION – 2 (D2)

This stage of the design has broken the silos which exist between the Client, Contractor, and Designer, involving collaborative working between these team members. Firstly, the students were exposed to the concept of Target Value Design with the circulation of relevant reading material. It was followed by classroom discussion on challenges associated with silo-based designing and its implications on time and cost performance of projects. Subsequently, the benefits that can be derived from TVD were discussed and debated in the class. In this second round, each group of students was instructed to declare Target Cost for their selected project component. The classroom discussion focused on various ways of designing to Target Cost. It involved case discussion on how material, layout, space, methods, system, and specification can be changed for achieving the Target Cost. The instructors have decided to use the power of Building Information Modeling (BIM) for providing cost feedback during the design process. The benefits of cost feedback in the design process, with the help of BIM, has been discussed by Nguyen et al., 2018. The instructors were inspired by this paper and decided to involve BIM modelers in the preparation of D2. The BIM modeler was a new addition to the existing team, expected to play a passive role in the simulation exercise. This role involved the transformation of design D1 into firstly, BIM models, followed by the development of BIM model with relevant cost. The BIM modeler was present during the process of development of D2 by showing visualisation of design changes suggested by the team and its effect on cost. This iterative process helped in arriving at D2. The attention of students was specifically drawn towards the detailed design for a particular system while preparing D1. Therefore, the students can make detailed changes in the selected design system. Afterward, the groups were instructed to commence the Design Option - D2. The students were instructed to keep the project brief and the design brief, prepared as part of Round – 1, unchanged. It ensured no change in the design goalpost is entertained while preparing D2. The students were expected to work in a collaborative manner for preparation of D2 and were asked to note the time of completion for this design option. The developed design D2 was reviewed and confirmed by the owner. Each group of students was asked to communicate the time taken for the development of D2 and confirmation of D2 with the owner. The team has calculated the cost of D2, which is called the Actual Cost of Design. Finally, the groups were asked to understand the difference between the market cost, target cost and the actual cost for their projects.

SIMULATION TESTING

The simulation was tested for the M. Tech programme students of a prominent university in India. The composition of the student groups is discussed in Simulation Development section. The project components selected by these groups, along with the system for detailed design is shown in Table 21.

Table 21: Project component and detailed design component developed by the groups

S. No.	Project	Project Component	Detail Design Component
1.	Garment Factory, Ranoda	Design Studio	Lighting system and Mechanical ventilation system
2.	ITC Narmada	Hotel Room	Lighting system
3.	Redevelopment of Gandhinagar Railway Station	Meeting Room	Mechanical ventilation system
4.	Vadodara Mumbai Expressway	Toilet Block	Plumbing system
5.	Surat Metro Rail	Ticket Counter	Lighting system
6.	Aquatics Gallery, Science City	Aquarium Tank	Lighting system

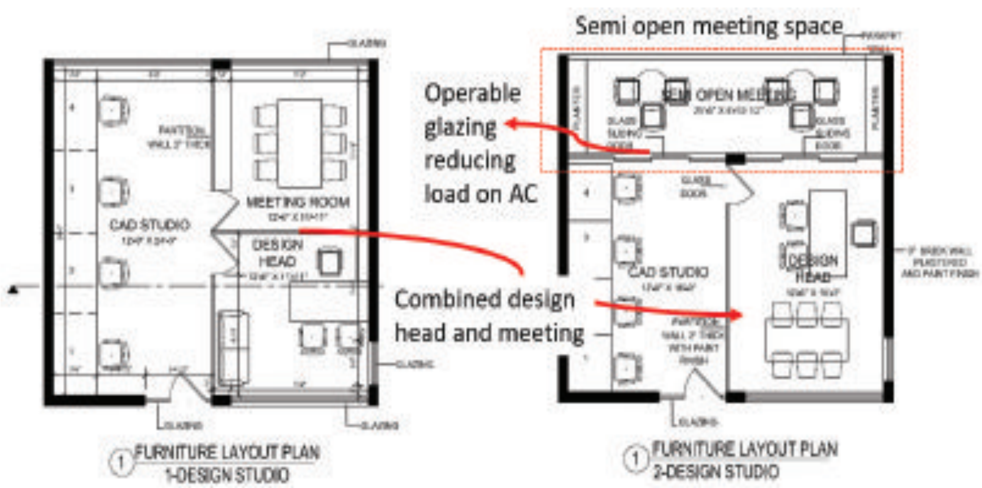


Figure 55: Comparison of Design Options D1 and D2 Garment Factory Project

In Round – 1, the students developed design D1 and arrived at related cost C1. This was followed by Round – 2, involving declaration of Target Cost, and making required changes in the design for arriving at design D2. Table 22 shows the type of changes made by each team, and the associated costs – Market Cost, Target Cost and Actual Cost (Refer Figure 55 and Figure 56).

Table 22: Types of change and the associated costs for the project component

S. No.	Project	Type of Change	Market Cost in USD (C1)	Target Cost in USD	Actual Cost in USD (C2)
1.	Garment Factory, Ranoda	Material Type Layout or space Specifications	16,353.09	13,082.94	13,499.59
2.	ITC Narmada	Material Type Layout or space	75,635.55	64,292.27	60,854.81
3.	Redevelopment of Gandhinagar Railway Station	Material Type Methods or Systems	49,371.29	41,965.59	39,114.97
4.	Vadodara Mumbai Expressway	Material Type Layout or space	11,123.53	10,011.17	9,086.18
5.	Surat Metro Rail	Material Type Layout or space Specifications	5,915.66	5,324.10	5,206.81
6.	Aquatics Gallery, Science City	Material Type Specifications	4,852.63	4,367.52	4,174.47

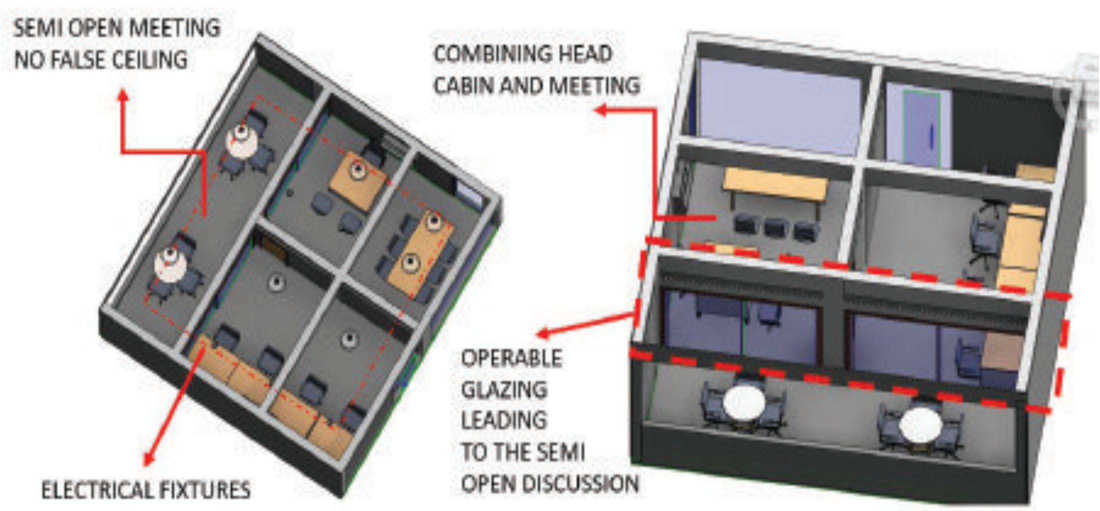


Figure 56: Revit model showing Design Option – D2 for Garment Factory Project

POST SIMULATION DISCUSSION

The instructor decided to understand the effectiveness of this TVD simulation exercise. During the literature review, the authors came across a simulation developed by Rybkowski et al., 2016, called Tower game for TVD. The thesis document (Munankami, 2012) discusses in detail rationale for the development of Tower Game, simulation development and provides an evaluation questionnaire for evaluating the effectiveness of Tower Game. This questionnaire was used for assessing the effectiveness of the TVD simulation undertaken by the authors. The reason being this questionnaire captures the majority of the elements that have been simulated as part of this exercise. Along with these questions, few questions were designed by the authors for understanding the benefits derived from the involvement of the BIM modeler in this exercise. After completion of simulation exercise, a Google Form was created and circulated among the students for inputs. The students were asked to rate various parameters on a 5-point Likert scale; 5 (most effective) to 1 (least effective). The analysis of the responses is as follows.

PARTICIPANT'S RESPONSE TO QUESTIONS ABOUT IPD

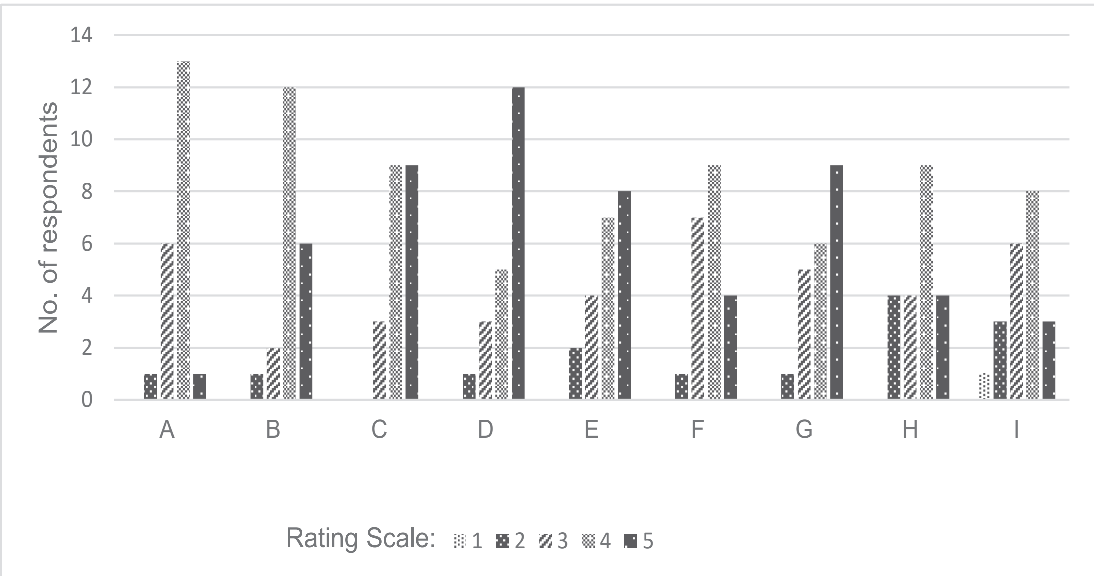


Figure 57: Histogram showing participant's response to questions about IPD

A – Mutual respect and trust, B – Mutual benefit and reward,
C – Collaborative innovation and decision making,
D – Early involvement of key partners, E – Early goal definition
F – Intensified planning, G – Open communication
H – Appropriate technology, I - Organisation and leadership

Based on the analysis of responses shown in Figure 57, it has been observed that majority of participants understood the value brought by the early involvement of key partners in the design process of a project. Further, the participants understood collaborative innovation and decision making and open communication improves the outcome of the design and construction process. Overall, most of the participants agreed that the simulation exercise helped in appreciating softer or cultural aspects of the IPD process, such as mutual respect and trust, mutual benefits and reward. Surprisingly, the appropriate technology was not highlighted as key learning from this TVD simulation.

PARTICIPANT'S RESPONSE TO QUESTIONS ABOUT TVD

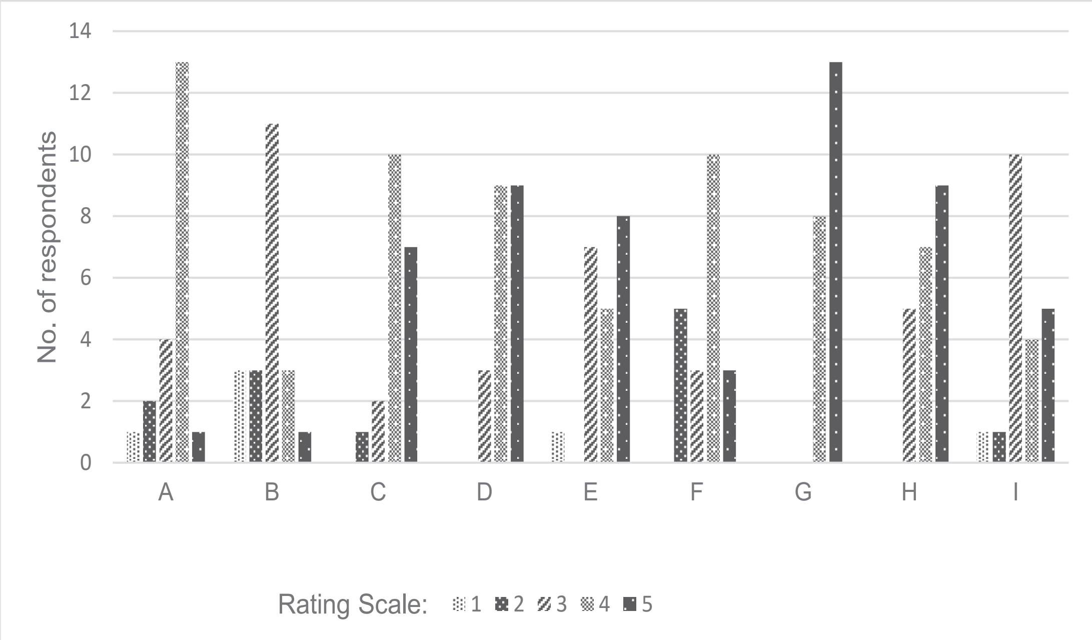


Figure 58: Histogram showing participant's response to questions about TVD

A – Project business care and decisions, B – Feasibility study
C – Client is an active member of the team
D – Understanding the values of customer, E – Relational contract between parties
F – Costs & schedule targets cannot be exceeded and only customer can change scope
G – Continuous estimating & budgeting through collaboration among team members
H – Frequent update of estimates among teams, I – Co-location

Based on the analysis of responses shown in Figure 58, it can be observed that this exercise has immensely helped the participants to understand continuous cost feedback during the estimating and budgeting process, helps in collaboration amongst the team members, and it helps in not only the achievement of target costs, but also satisfying the values of customer. The authors have decided to involve BIM modeler as an intervention to improve the TVD exercise with the premise that continuous cost feedback can hasten the design revisions and achievement of customer values. The findings from the questionnaire corroborate the hypothesis made by the authors prior to the study. Most of the participants agreed that the active involvement of Client plays an important role in the achievement of target cost.

PARTICIPANT'S RESPONSE TO QUESTIONS ABOUT BIM

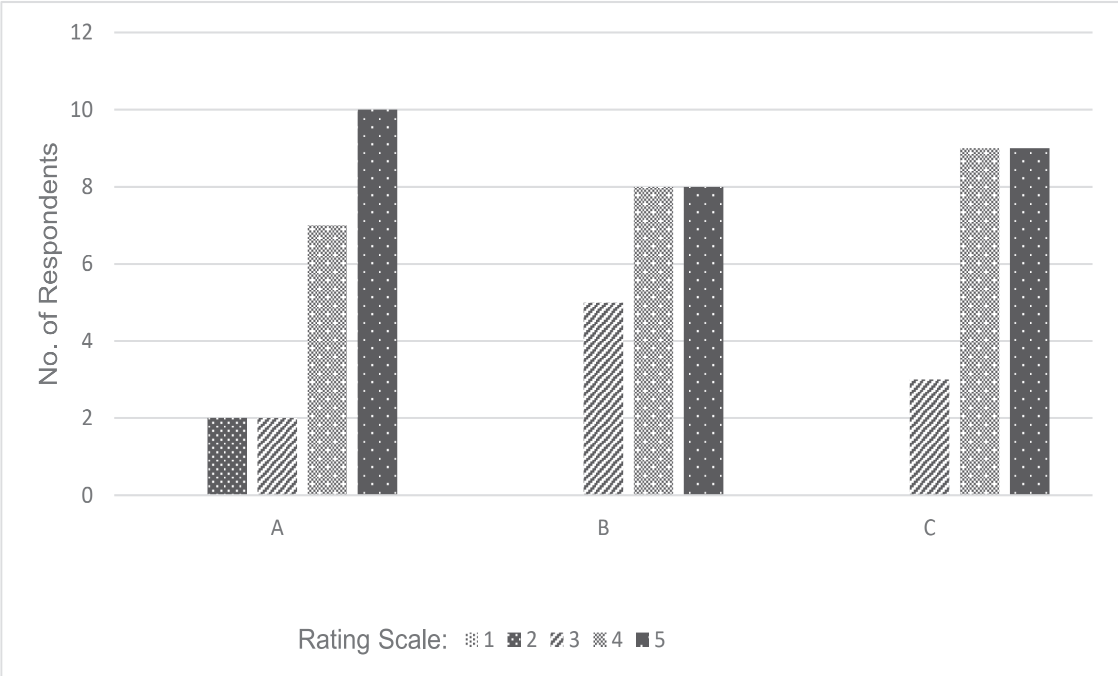


Figure 59: Histogram showing participant's response to questions about BIM

A – BIM in developing D2, B – Role of BIM modeler in the design process
C – BIM in providing rapid cost feedback while developing multiple design alternatives

The analysis of responses, shown in Figure 59, highlights that the involvement of BIM modeler helped in the preparation of alternate designs and provided rapid cost feedback to the team. Therefore, it indicates the value addition of BIM modeler in the design preparation of D2. As indicated by (Nguyen, Tommelein, & Martin, 2018), value addition of BIM in generating rapid cost feedback in the estimating and costing process, the similar scenario has been observed in this TVD simulation.

CONCLUSION

The study has indicated that the simulation exercise developed by the authors was useful to the students in imparting hands-on knowledge on working in the environment envisaged in TVD, as well as benefits by this innovative Lean tool. The contribution of this TVD exercise lies in involving BIM modeler in the design process, which not only tries to depict the revamped cost feedback process, as discussed by (Nguyen et al. 2018) but also simulates TVD experience of the real-life project in the classroom environment. This simulation exercise can be further developed and improved by including more number of construction systems in the detailed design, as well as standardising some of the design components.

REFERENCES

American Institute of Architects, AIA. (2007). *Integrated Project Delivery: A guide.* Washington, DC: AIA.

Ballard, G. (2008). The lean project delivery system: An update. *Lean Construction Journal*, 1-19.

Ballard, G. (2009). *an update on Target Value Design.* St. Louis: Lean Design Forum - Lean Construction Institute & Project Production System Laboratory.

Ballard, G., & Rybkowski, Z. K. (2009). Overcoming the hurdle of first cost: Action research in target costing. *The 2009 Construction Research Congress* (p. 10). Seattle, WA: Construction Institute of ASCE.

Denerolle, S. (2013). *Technical Report: The application of Target Value Design to the design phase of 3 hospital projects.* Berkeley, CA: P2SL:Project Production Systems Laboratory.

Do, D., Chen, C., Ballard, G., & Tommelein, I. D. (2014). Target Value Design as a method for controlling project cost overruns. *IGLC*, (pp. 171-181). Oslo, Norway.

Landgren, M., Jakobsen, S. S., Wohlenberg, B., & Jensen, L. M. (2018). Integrated design processes – a mapping of guidelines with Danish conventional 'silo' design practice as the reference point. *Architectural Engineering and Design Management*.

Macomber, H., Howell, G., & Barberio, J. (2008). Target-Value Design: Nine Foundational and Six Advanced Practices For Delivering Surprising Client Value. *Lean Project Consulting*.

Munankami, M. B. (2012). *Development and testing of simulation (game) to illustrate basic principles of Integrated Project Delivery and Target Value Design: A first run study*. College Station.

Nguyen, H. V., Tommelein, I. D., & Martin, P. (2018). Process-based cost modeling framework and case study. *IGLC*, (pp. 46-57). Chennai.

Project Brief for design and construction. (2019, Jan 03). Retrieved from Designing Buildings Wiki: https://www.designingbuildings.co.uk/wiki/Project_brief_for_design_and_construction

Rybkowski, Z. K., Munankami, M. B., Shepley, M. M., & Fernández-Solis, J. L. (2016). Development and testing of a Lean simulation to illustrate key principles of Target Value Design: A first run study. *IGLC*, (pp. 133-142). Boston.

Strategic Brief for construction projects. (2018, Feb 27). Retrieved from Desining Buildings Wiki:
https://www.designingbuildings.co.uk/wiki/Strategic_brief_for_construction_projects

SUSTAINABLE TRANSIT-ORIENTED DEVELOPMENT: A 'TARGET VALUE' PLANNING & DEVELOPMENT STRATEGY

Christy P. Gomez[1], Rameson N.[2]

ABSTRACT

The positive social, economic and environmental impact of transit-oriented development (TOD) in Malaysia is rather limited. This paper proposes a design and development methodology for achieving sustainable TOD in town and country planning, as part of a wider constructive research on sustainable benefits realization management within TODs.

Content analysis of interview data with key stakeholders of TOD implementation in Malaysia indicates that there are three major constraints in the planning and development phase of town and country planning affecting TOD. They are: lack of multi-model planning approaches, lack of a planning coordination mobilization structure and disjunction regarding ontological categories of 'substance', 'process' and 'value'.

A Benefits Realization Management Set-based Systems (BRM-SBS) planning and development methodology aimed at minimizing the said constraints is proposed. This methodology is centered on having an integrated planning practice that is less hierarchical, that also accommodates diverse planning models. Wherein TOD sustainability benefits are enhanced by using Target Value Design (TVD) and Set-based Design (SBD) approaches based on a transformation, flow, value complementary view of planning and development of TODs. This BRM-SBS methodology is to be validated as part of an extended action research project with the Malaysian National Structure Plan organization.

KEYWORDS

Transit-oriented development (TOD), target value design, set-based design, town and country planning, benefits realization management.

INTRODUCTION

In Malaysia, the National Physical Plan (NPP), the Five-Year Malaysia Plans and other sectoral policies provide the guidelines for development planning in Malaysia. The stated goal of the 2nd Malaysian National Physical Plan (NPP-2) is the establishment of an

[1] Assoc. Professor, Dept. of Construction Management, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Paht, Johor, Malaysia, +60125377247, cpgomez21@gmail.com

[2] Postgraduate Researcher, Department of Real Estate Management, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Paht, Johor, Malaysia, +60125377247, rameson.n@gmail.com

efficient, equitable and sustainable national spatial framework to guide the overall development of the country towards achieving developed and high income nation status by 2020. The NPP-2 is supposed to be aligned to the 17 UNDP Sustainability Development Goals, with local authorities being the final level at which planning conditions are imposed to ensure sustainable development. However, the sustainability initiatives often end up latching on to the 'low hanging fruits', often driven by reductionist policies.

There are a wide variety of issues and challenges related to delivering urban sustainable development. Non-resilient stakeholders tend to end up resorting to weak sustainability practice. This is compounded with the trend of focusing on sustainability outcomes (indicators to assess what is relatively more attainable and amenable to "measurement). It is argued in this paper that this phenomena is very much the result of the traditional transformational view of production (in terms of planning and development) amongst town and country (T&C) planners. Hence, in most instances the rationale of starting on the journey towards higher sustainability performance is often "hijacked"; ending up with mainly tackling "the low hanging fruits" - a form of "greenwash".

Another phenomena regarding sustainability that seems reductionist is the preference by researchers for more readily attainable simplistic sustainability research outcomes that are mainly explanatory, such as identification of "sustainable construction barriers" etc. There is a lack of overarching solution based research. These twin practices amongst majority of industry practitioners and the research community does little to provide for systemic progression to forge strong sustainability practice. It is noted by Du Plessis (2007) that in order to create an enabling environment for sustainable construction, institutions such as the different levels of government, development agencies etc. need to adopt sustainable development and its principles as a seminal aspect of their operations. In addition to creating an enabling environment, it is important that the research community too has to focus more on solution-based research.

This paper is an outcome of the initial phase of a wider research focused on investigating issues related to weak sustainability practice in transit-oriented development (TOD), and also aimed at developing methodologies for embedding better practice. TODs by virtue of being part of integrated transport infrastructure and human habitat development is adjudged to be intrinsically aligned towards sustainability characteristics that needs to be understood in intersubjective terms. The dominant research on T&C planning and development for sustainability is often undertaken based on traditional positivist concepts of value. The term 'sustainable development' is considered to be an "essentially contested concept" (ECC). As noted by Ehrenfeld (2008), basically ECCs cannot be managed in a deterministic and positivist sense. Additionally, value as a construct that is viewed solely as a subjective term can be problematic. However, following Rooke (2010), the notion of value is treated here as being intersubjective or socialised, not exclusively objective or subjective but more like points on a continuum.

It is acknowledged by key respondents from the T&C planning community in Malaysia that TOD is a "new" development trend. The phenomena of resorting to weak sustainability practice in TOD escapes serious scrutiny as it is framed as "new" and requiring an 'experimental" approach. Thus the issue of T&C planning and development of sustainable TOD seems unproblematic. There seems to be a taken for granted view that the implementation of the TOD concept, in itself, is a major societal good; and it is mainly proffered as a solution to reducing private automobile dependency and reducing road traffic. Currently the “buck” seems to stop at walkability, accessibility and affordability - leading to a form of greenwash for sustainable TODs. Hence, there is a strange disconnect between TOD and sustainable construction, wherein sustainable planning and development of TODs is lagging. In order to stress the point, the authors of this paper, would like to invite the research community to liken the current sustainability considerations of Sustainable TOD akin (in an adapted sense) to that of the Green Campus context, calling for a whole-of-TOD approach (see Gomez and Ng 2019).

TOD is rapidly becoming a popular and influential T&C planning concept in Malaysia. Cervero and Sullivan (2011) note that TOD has gained popularity worldwide as a sustainable form of urbanism. However, in Malaysia there seems to be “one-size fits all” approach to implementation of the TOD concept with a singular focus on only developing existing train stations into TODs based on performance of the existing built environment (Kamruzzaman et al. 2014). A number of researchers are increasingly recognizing that TODs can take a variety of forms (Belzer and Autler, 2002; Atkinson-Palombo and Kuby 2011). They emphasize the point that individual TODs can serve different but complementary functions within a system. Following Kamaruzzaman et al. (2014), the view taken here is that the practice of solely developing existing train stations into TODs is not to be recommended, as it does not allow for developing TOD sites based on proper assessment that can lead to achieving wider sustainability outcomes.

The implementation of TOD in Malaysia comes under the purview of a number of authorities; and is caught-up in a multi-directional spiral of loose guidelines, policies and initiatives. This state of affairs is rationalized as being “acceptable” and unproblematic due to TOD being a “new” development trend, and its implementation being in a “state of transition”. In a top-down “over the wall” hierarchical planning process, the implementation of TOD finally ends up under the remit of the local authority that often takes it on as an ‘experimental’ challenge. In essence, TOD planning and development in Malaysia ultimately comes under the purview of the Town and Country Planning Department of the local authority, and the sustainability aspect is encapsulated within multi-disciplinary fields of responsibility (e.g. sustainable township, low carbon city framework etc., lacking coordination at inter and intra levels). In a nutshell, there seems to be a tendency to focus on ‘substance’, lacking a process and value perspective; affecting the opportunities for more adaptive and integrated planning and development.

It is argued here that TOD must deal not only with the tension between node and place, but address development in the context of being constitutive of larger adaptive organic systems that can contribute significantly to sustainable development. The authors of this paper are convinced that there is a need to open up control-oriented planning practices to more adaptive approaches to planning. Rauws and De Roo (2016), they explore how Organic Development Strategies (ODS) can be more responsive in tackling the wide variety of uncertainties which challenge spatial planners and decision makers. The current approach in Malaysia of using assessment tools and scoring methods to enable local and state governments to optimise land use and transport integration, as well as approve TOD applications for development is questionable. One such tool is the Land Use & Public

Transport Accessibility Index (LUPTAI) decision making tool that measures accessibility performance as a product of land use and public transport. Zainuddin (2013) cautions that regardless of the established benefits and potential of TODs, it is crucial to be realistic in analyzing the actual outcome of TOD initiatives. He reiterates that several cases of implementation of the transit community concept have not achieved the primary planning target in providing sufficient community benefit to the local people.

The theoretical basis of this paper is founded on design science (constructive research), T&C planning theory and lean construction theory. The many definitions of design science informs that design science is about producing knowledge through the creation and implementation of a solution aimed at altering a specific phenomenon to a preferred one (see Vaishnavi and Kuechler 2007; Simon 1996). Amongst the key practice principles of design science is the creation of an artefact (a method, in this case) to address the research problem (see Havner et al. 2004). Although design science research (DSR) is recognized as an important and legitimate Information Systems (IS) research paradigm (Gregor and Havner 2013), it is only of recent that DSR started to gain ground within construction management research. However not to the extent proposed by Koskela (2008).

CONTEXTUALIZATION OF RESEARCH

The Malaysian government introduced the Town and Country Planning Act 1976 (Act 172), which was enacted pursuant to Article 76 (4) of the Federal Constitution, for the purpose of ensuring uniformity of law and policy to make a law for the proper control and regulation of T&C planning in Peninsular Malaysia. T&C planning takes place in Malaysia as a top-down hierarchical approach; federal to state to local authority, culminating in Special Area Plans. TODs are incorporated within the local authorities Special Area Plan, and currently left to the purview of the local authorities based on a very broad national policy. The Malaysian National Physical Plan (Policy NPP27 in 2005, and Policy NPP32 in 2010) clearly states that "Transit Oriented Development shall be promoted as the basis for urban land use planning to ensure viability of public transport". It is evident that the state structure plans and local plans, for example the Selangor Structure Plan 2020, and KL City Plan 2020, as well as in regional plans, for example Iskandar Region's (a local authority) Comprehensive Development Plan (CDP) promotes the TOD concept mainly as a contributor to an effective and viable mode of public transport. What about sustainable development?

Currently the progression towards more adaptive and integrated town and country (T&C) planning methodologies that are more aligned towards ecologically sustainable planning and development is lacking. There are attempts at incorporating theoretical planning perspectives of collaborative, new urbanism and just society alongside the dominant rational planning model. However this is done in instances, and as alternatives, rather than complementary. Similarly there is a tendency to understand planning and development as either a transformation, flow or value (using disjunctive ontological descriptions within the planning and development environment); and not as transformation, flow and value. Thus limiting the potential for achieving better planning and development. This paper reports on the initial phases of a constructive research endeavour to advance current planning of TODs with respect to prioritisation of considerations for sustainable development. Not much previous research has significantly addressed the constraints identified in this paper and also there is lack of 'constructive' content within much of the research. Literature review on T&C planning and findings from 1st round of interviews with key stakeholders of T&C planning in Malaysia was instrumental in identifying the constraints limiting the ability to attain stronger sustainability outcomes for TODs.

In this paper, the T&C planning and development practice is considered as being a form of production that is understood based on Koskela's (2000) integrated transformation, flow, value (TFV), allowing for the incorporation of complementary planning theories. The more thorough complementary TFV perspective towards T&C planning and development allows planners to work with the four T&C theoretical planning models as described by Fainstein (2000). The four planning theories or models are: the traditional-rational, collaborative, just society and new urbanism models. In order to optimize the sustainability benefits that can be accrued in TODs, a systemic 'planning and development production space' of engagement for delivering optimized benefits (framed here as an integrated benefits maximization framework, is formulated). This is viewed as an intervention mobilization structure that is constitutive of a method.

PLANNING THEORY AND TOD

The research problem of 'planning, design and development of TODs with respect to sustainability characteristics is investigated here at the planning stage - as the first phase of a three phased research programme. Here, relevant urban planning theoretical modelling typologies provide the analytical frame of reference that forms the basis in formulating a benefits maximization methodology for value delivery that is able to deal with attainment of intersubjective value-based targets - as is with the complex concept of sustainability. This paper draws on the work of Zuziak (2015), to address the contrasting characteristics of urban planning practice. According to Zuziak (2015) sustainable development, public good and social justice feature as three doctrinal foundations of contemporary urban planning theories. Additionally, following Fainstein (2000), the approaches to planning can be typified and identified in a broad sense to consist of four models, namely: the traditional rational model, the communicative model, the new urbanism and the just city model. The communicative model in planning draws on two philosophical approaches, that of American pragmatism and the theory of communicative rationality. This is exemplified in the democratic process involved, searching for instances of 'best practice' and arriving at a 'consensus' towards a final plan. Wherein the planner takes on a mediating role amongst the various stakeholders within the planning domain. "The new urbanism" refers to a design-oriented approach to planned urban development. Great emphasis is placed on public space, as well as emphasis is placed on the relationship between work and living and takes a strong stance toward environmental quality. The new urbanism stresses the substance of plans rather than the method of achieving them. Whilst the theory of the just city values both participation in decision making by relatively powerless groups and equity of outcomes (Sandercock 1998).

In reviewing extant literature on T&C planning in Malaysia, it is evident that the continued reliance the dominant rational planning approach is not seen as being problematic by researchers and practitioners, not even in the lack of considerations for sustainable development. There seems to be an unquestionable acceptance, and even attempts to "improve" on the existing rational planning approach, relegating importance of all the other planning approaches. For instance, Ahmad et al. (2013) subscribe to the view that building the competency level of T&C planners can contribute to better T&C planning in Malaysia based on rational planning theory. Analysis of interview data with key TOD stakeholders, indicates that current planning for TODs is being undertaken in silos and in a piece-meal manner. The hierarchical layers of national, regional/state, and finally local and special area planning is undertaken within a non-integrative structure. The proposed sustainable TOD maximization framework is structured as a planning space with a membership drawn from all three levels, forming a TOD town planning and development (P&D) matrix organization, referred to here as a TOD MATRIX P&D SPACE.

METHODOLOGY

The epistemological basis of this paper is based on constructivist understanding of knowledge as being socially constructed. The planning process is viewed as being a social phenomenon undertaken through the process of active social engagement. The interpretive understanding of the data communicated, both primary and secondary (as provided by the respondents), is undertaken by the authors who are involved with the respondents based on a commitment to communicative understanding. Whilst, the additional secondary data made freely available by the respective public authority agencies as hardcopy documents as well as softcopies on their websites are viewed in the same light.

It is observed that besides the general state-of-transition of sustainability practice, there is a current state-of-tension with regards to T&C planning practice in Peninsular Malaysia. This state of tension, arising out of prevalent constraints is identified through desk study and 2nd party practice insights on the implementation of sustainable TOD. The three prevalent constraints are: over-reliance on the rational planning model, lack of an intervening mobilization structure for ensuring emphasis on optimized delivery of sustainable benefits; and there being a disjunction between ontological categories of 'substance', 'process' and 'value' affecting the understanding of planning and development as an integrated TFV phenomena.

Based on a constructive research methodology, it is proposed that the above constraints can be overcome as follows:

Through the practice of planning to be undertaken as a design science initiative, allowing for the presence of a 'flexible and adaptive planning and development space for knowledge construction and sharing' at all levels, and between levels of T&C planning in Malaysia (see Figure 1). This being the context for a dynamic inter and intra level iterative planning practice that can accommodate multi-model planning practice, such as New Urbanism Model and the Collaborative Model.

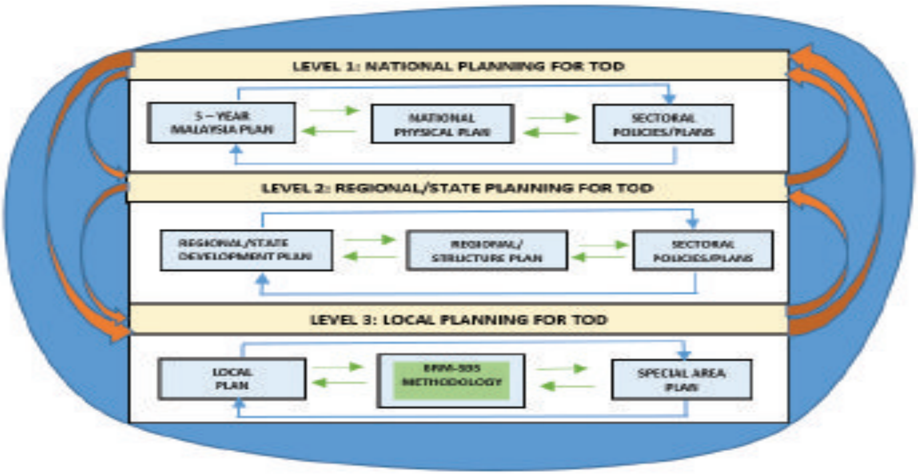


Figure 1: The Bottom-up Integrated BRM-SBS Planning & Development Model

Within this proposed space, TOD planning is to be optimized based on utilizing the principle of Target Value Design (TVD) and Set-based Design (SBD), mobilized through a Benefits Realization Management (BRM) structuration programme that supports sustainability system design that can maximize benefits for better delivery of TODs. Although this paper focuses on T&C planning with respect to TODs, this constructive design science approach can be implemented as a BRM Set-based Systems (BRM-SBS) planning methodology for T&C planning, in general (see Figure 2).

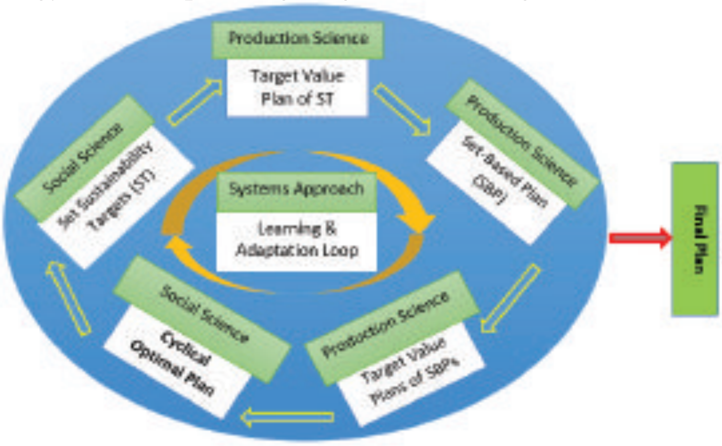


Figure 2: The BRM-SBS Methodology

A Design Science Methodology

The work of Tillmann et al. (2010) forms the basis of the mobilization frame with respect of planning to be undertaken within a Benefits Realization Management Programme that is based on the fundamental Plan-Do-Check-Act cycle. However, here the emphasis is on Benefits Maximization. Following Tillmann et al. (2010), the three theoretical perspectives offered under a design science approach to BRM for construction projects is proffered as a mobilisation frame. The three perspectives of social science, production science and systems thinking form the action frame underpinned by the concept of setting targets based on Target Value Planning and Development (TVPD) approach (see Figure 2). The concept of TVPD that is applied here is similar to that of Target Value Design (TVD). For planning of TODs, infrastructure is the critical component and the focus is on land transport; primarily that of rail transport. This planning model for value delivery is based on a bottom-up approach that is to be undertaken by the local authority, wherein cost targets (one of the main barriers to sustainable planning, design and construction) are planned for. Following Macomber et al. (2012), in their reference to TVD, the aim here is similarly to have TVPD that transforms the current planning and development practice of TOD upside down, wherein the costs determine the plan and development instead of vice versa.

According to Miron et al. (2015) the TVD approach enables a project environment with favourable characteristics to generate value. Following Tillman et al. (2010), the proposal here is to take a similar TVPD approach, making the key stakeholders as important participants of the process, and enhance the stakeholder-planner/developer relationship through a structured Benefits Realization Management Process (BRMP). BRMP will enable the attainment of value maximization from planning through to development. This planning and development space is to be realized as a matrix organization, conceptualised in Figure 2 within the BRM-SBS methodology. For this to happen, the process of planning and development needs to be undertaken based on applying complementary planning theories rather than relying on the dominant rational planning model. Thus for optimal value delivery, the planning and development of TODs has to be complemented with a collaborative, new urbanism and just society theoretical grounding. Ideally, this should be undertaken at a regional level, as TOD within just a 4 mile radius does not allow for continuity. Currently, the focus of the local authorities in Malaysia is just a 1km radius. It is proposed here that the BRM-SBS planning model, needs to be introduced and practised at the lowest special area detail planning level before being undertaken at a regional level, as a bottom-up approach, based on wider metropolitan areas.

The rationale of resorting to the Set-based Systems approach is based on the current failings of having a singular TOD plan that limits the opportunity to leverage on best value alternatives. The SBS approach follows the principle of Set-based design (SBD). SBD is a lean design management strategy to promote delaying design (and development) decisions until necessary (in this case for TODs) in order to allow time for a team to explore and evaluate as many feasible design solutions as possible (Lee et al. 2010).

DATA INTERPRETATION AND DISCUSSION ON PLANNING OF SUSTAINABLE TODS

The primary data to construct solution-based knowledge on planning and development practice with regards to TOD is based on content analysis of transcribed interview data from four respondents. R1: deputy director in the department of town and country planning; R2: planning officer of a major transit agency; R3: the R&D officer at the National Structure Plan organization and R4: the senior staff of Stakeholder Management & Communication Iskandar Malaysia Bus Rapid Transit. Whilst verification of TOD sustainability benefits was undertaken based on analysis of questionnaire survey data obtained from the transit community. Based on analysis of the data on agreement as to the sustainability benefits to the transit community at KL Sentral TOD (from a personal and general perspective), there was agreement to over 90% of the listed benefits collated from extant literature. This indicates that TODs are intrinsically aligned to sustainability. However, it is clear that TOD planning is rather a “new” development strategy that is being explored by T&C planners and urban designers, rather cautiously undertaken in a rather ‘experimental’ manner. There are no clear targets, such as strong sustainability targets, except a checklist to demonstrate sufficient compliance to the 9 principles of TOD. Hence, TOD planning is often subsumed under the wider, mainstream T&C planning practice, that is driven by the dominant rational planning model.

Based on analysis of data provided by R1 (additionally, scrutinized based on printed reports), it is evident that TOD is a “new” feature of development planning in Peninsular Malaysia. The description of T&C planning by the research respondents R1 and R2 fit with that of a rational planning approach, which is perceived as being the dominant practice by the public authorities in Malaysia. R1 and R2 agree that predominantly, the approach to planning in Malaysia has been to integrate land use mainly with road networks. This traditional form of transport planning and land use practice has mainly contributed to urban sprawl. Historically, road transport planning seems to have had a prime influence in terms of plot density ratios, contributing to urban sprawl with lower population density. Currently, in Malaysia, road transport planning and development plans as well are very much focused on the hierarchical approach of masterplan, regional, then district and eventually area planning based on the rational planning model.

This form of public authority-oriented urban planning, which is predominantly a top-down rational planning approach, was initiated in the 1950s and is considered as one of the major traditions in Planning Theory (Fainstein 2000). The rational model approach features strongly in the development of the Malaysian national physical masterplan, although some elements of the collaborative model, in terms of a less inclusive stakeholder participation is favoured on a discrete and not so continuous basis. This model does allow for the possibility of having a more integrated planning approach. Elements of the collaborative model are progressively being subscribed to alongside the rational model as evidenced in tackling the much more complex planning scenarios and those that involve ‘novel’ development concepts. An example of such a development is that of the Iskandar Regional Development (IRD) in the South of Johor state in Malaysia; which is relatively complex development and hinges on a more integrated land transport and development planning strategy (as described by R4) within a larger metropolitan area.

The main considerations for proposing and planning for TODs is the population density within the catchment area. The area can have a maximum plot ratio of 8:1 (revised from 4:1) and the land area for the transit station identified as TOD potential to be more than 2 acres. The prime attraction for involvement in TOD development from a private sector perspective is currently that of profit maximization, as it allows for higher population density development. The private developer’s application for approval of proposals within TOD designated transit-station area for development is currently based on a rating mechanism, that prioritizes reduced parking provision, green buildings and requirement of 60% open area. The state of Selangor in Malaysia has prepared a report that identifies potential TODs. Based on the report, 88 areas with existing rail and bus transit nodes have been identified as having potential to be developed as TODs based on the Land Use &

Public Transport Accessibility Index (LUPTAI) technique. This approach tends to lead to a singular TOD plan, arising mainly out of a rational theoretical modelling technique that is focused on standard benchmarks, lacking a customized systems-based adaptive plan that can realize potential for optimizing sustainability benefits.

It is noted by Ahmad et al. (2013) that town planners in Malaysia need to have stronger collaborations with players that can contribute to sustainable development. It is clear from content analysis of primary interview data and secondary data sourced from national, regional structure plans, state and local authority plans that Malaysian T&C planning practice is based on a very specific hierarchical rational or logical theoretical planning perspective that is constrained by classical economics principles of exacting wholly outcome-based measurables that are short-term. This approach intrinsically does not allow for incorporating considerations on integrative and adaptive planning that needs to be considered under the banner of tackling complex and dynamic development systems and complex sustainability concepts, as is observed in the case of TOD implementation. Although the TOD concept is essentially founded on key sustainable development principles, currently the approach to TOD in Malaysia, at its best, is more aligned to weak sustainability practice. The fundamental problem of using a "one size fits all" approach to planning and development of TODs (both in terms of the theoretical planning model and also type of TOD) in Malaysia has put a strangle-hold on sustainable TOD planning and development, resulting in a black box planning environment.

The conceptualization of a solution to overcome the above mentioned problem is based on a constructive research design methodology, focused on overcoming the three major constraints in current T&C planning and development practice affecting TOD. It is thus proposed that value delivery and attainment of the wider sustainability benefits in the planning and design/development of TODs can be secured by applying the principle of Target Value Planning and Design/Development (TVPD) approach within a Set-based Systems (SBS) planning strategy, mobilized through a benefits realization management model, termed here as the BRM-SBS methodology.

CONCLUSION

The current approach to town and country planning is seen as an overly-institutionalized endeavour that more readily caters for satisfying weak sustainability targets. The proposed Benefits Realization Management Set-based Systems (BRM-SBS) planning and development methodology can pave the way for, not only maximizing TOD sustainability benefits, but to also unlock the potential for addressing other systemic inefficiencies within T&C planning and development space.

This conceptual BRM-SBS methodology that is centred on a TFV target value design and development strategy is the research outcome of the initial phase of a wider constructive research to be undertaken with the R&D section of the National Structure Plan. The extended action research project will be piloted with a particular local authority in Malaysia as a bottom-up approach. The final phase of the constructive research process aims to test the BRM-SBS methodology and assess the results of the implementation.

REFERENCES

Ahmad, F., Maidin, S.L., Zainol R., and Norzailawati, M.N. (2013). "Malaysian Development Plan System: Issues and Problems." *PLANNING MALAYSIA: Journal of the Malaysian Institute of Planners* VolXI, 1 - 20

Cervero, R., and Sullivan, C. (2011). "Green TODs: Marrying Transit-oriented Development and Green Urbanism." *International Journal of Sustainable Development and World Ecology*, 18(3), 210-218.

Du Plessis, C. (2007). A strategic framework for sustainable construction in developing countries. *Construction Management and Economics*, Vol. 25, 67-76.

Ehrenfeld, J. R. (2008). "Sustainability Needs to be Attained not Managed." *Sustainability: Science, Practice, & Policy* Vol. 4(2), 1-3.

Fainstein, S.S. (2000). "New Directions in Planning Theory." *Urban Affairs Review,* 35 (4) 451-478.

Gomez, C.P., and Ng, Y.Y. (2019). "*Development of a progressive green university campus maturity assessment tool and framework for Malaysian universities*." https://www.matec-conferences.org/> (March 15 2019).

Gregor, S., and Havner, A.R. (2013). "Positioning and Presenting Design Science Research for Maximum Impact." *MIS Quarterly*, Vol. 37(2), 337-355.

Hevner, A.R., March, S.T., and Park, J. (2004). "Design Research in Information Systems Research." *MIS Quarterly*, 28(1), 75-105.

Horcea-Milcu, A.I., Abson, D.J., Apetrei, C.I., Duse, I.A., Freeth, R., Riechrs, M., Lam, D.P.M., Dorninger, C., and Lang, D.J. (2019). "Values in Transformational Sustainability Science: Four Perspectives for Change." *Sustainability Science*, Jan 2019, 1–13.

Kibert, C.J. (2009). "Resource Conscious Building Design Methods." In *Sustainable Built Environment Vol 1*. (eds.) Haghighat, F. and Kim Jong-Jin. EOLLS: UK.

Koskela, L. (2000). "*An exploration towards a production theory and its application to construction*." VVT Technical Research Centre of Finland.

Koskela, L. (2008). "Which Kind of Science is Construction Management?" *Proc. 16th Ann. Conf. of the Int'l Group for Lean Construction*, Manchester, UK, July 16-18.

Lee, H.W., Tommelein, I.D. & Ballard, G. (2010). "Lean Design Management in an Infrastructure Design-Build Project: A Case Study." *Proceedings of 18th Annual Conference of the International Group for Lean Construction*, Haifa, Israel. 113-122.

Macomber, H., Howell, G. and Barberio, J. (2012). "*Target Value Design: Nine Foundational Practices for Delivering Surprising Client Value. [White paper]*" http://www.leanproject.com/access-whitepapers/> (Dec 12, 2018)

Miron, L.I.G., Kaushik, A., and Koskela, L., (2015). "Target Value Design: The Challenge of Value Generation." *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction.* Perth, Australia, July 29-31, 815-825.

Rauws, W. S., and De Roo, G. (2016). "Adaptive Planning: Generating Conditions for Urban Adaptability. Lessons from Dutch Organic Development Strategies." *Environment and Planning B*, 43, pp. 1052–1074.

Rooke, J. A, Sapountzis, S., Koskela, L., Codinhoto, R., and Kagioglou, M. (2010). "Lean Knowledge Management: the Problem of Value." *Proceedings of 18th Annual conference of International Group of Lean Construction*, Haifa, Israel, 12-21.

Sandercock, L. (1998). "Towards Cosmopolis: Planning for Multicultural Cities." Chichester: Wiley.

Simon H.A. (1996). "The Sciences of the Artificial." 3rd ed. Cambridge, MA: MIT Press; 1996.

Tillmann, P. A, Tzortzopoulos, P., and Formoso, C. T. (2010). "Analysing Benefits Realisation From a Theoretical Perspective and Its Contribution To Value Generation." *Proceedings of 18th Annual Conference of the International Group for Lean Construction*, Haifa, Israel. 73-82.

Vaishnavi, V.K., and Kuechler, W.Jr. (2007). "Design Science Research Methods and Patterns Innovating Information and Communication Technology." Taylor & Francis Group.

Wetherill, M., Rezgui, Y., Boddy, S., and Cooper, G.S. (2007). "Intra- and Interorganizational Knowledge Services to Promote Informed Sustinability Practices." *Journal of Computing in Civil Engineering*, Vol. 21 (2), 78-89.

Zuziak, Z.K. (2015). "The Idea of the Cities and Planning Theories." *Czasopismo Techniczne, Architektura Zeszyt* 12-A (27), 3-27

.

Musa, M., Pasquire, C., and Hurst, A. (2019). "Using TVD Simulation to Improve Collaboration." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 503–.514 DOI: https://doi.org/10.24928/2019/0268 Available at: <www.iglc.net>.

USING TVD SIMULATION TO IMPROVE COLLABORATION

Muktari Musa [1], Christine Pasquire[2], and Alan Hurst[3]

ABSTRACT

Target Value Design (TVD), a lean approach, has been implemented successfully in the past decade in various countries and its process mandates the collaboration of project participants. However, issues of adapting collaborative practices and the time it takes first-time users to understand TVD practices have been a challenge in TVD projects. Recently, there has been an increase in the creation, reinvention and use of simulations and serious games to teach TVD and other lean principles to project stakeholders encountering them for the first time.

The 50 minute version of the simulation game developed in Texas A & M University was used to illustrate TVD practice and collaboration in this study. The study used 24 industry stakeholders from a reputable real estate developer during the implementation of TVD on a live project in Nigeria.

The results reported that the simulation is effective in illustrating the practices of TVD including collaboration and designing to set targets. Finally, this study recommends the inclusion of the TVD simulation game in training and workshops for project team before the commencement of construction projects because it demonstrated to be a simple and practical method of understanding collaboration and TVD practices.

KEYWORDS

Lean construction, simulation game, collaboration, target costing, target value delivery.

INTRODUCTION

Target Value Design (TVD) emerged from lean construction and serves as a strategic pathway for achieving more collaboration by adopting value perceived by the client (specific design criteria, cost, schedule) as a driver of design (Oliva et al., 2016; Kim and Lee 2010). Essential to TVD is the practice of designing to targets rather than designing, then preparing budgets, schedules, etc. which leads to rework, change-orders, and re-pricing, thus making it unaffordable and off-target for stakeholders. Collaboration is one of the foundational principles of TVD; face-to-face and virtual collaboration are not

[1] PhD Research Student, School of Architecture, Design and Built Environment, Nottingham Trent University, United Kingdom. +447436554017 muktari.musa@my.ntu.ac.uk

[2] Professor, School of Architecture, Design and Built Environment and Director Centre for lean Projects, Nottingham Trent University, UK. +44(0) 115 848 2095 christine.pasquire@ntu.ac.uk

[3] Senior Lecturer, School of Architecture, Design and Built Environment, Nottingham Trent University, United Kingdom. +44(0) 115 848 2878 alan.hurst@ntu.ac.uk

options in the TVD process, they are necessities. Hyun (2012) stated that TVD process mandates the collaboration of project participants. However, issues of adopting collaborative practices have been observed to be a prominent challenge in TVD projects, this may be predominantly due to difficulty in developing trust within the project environment, lack of early involvement of subcontractor and suppliers, and lack of interaction among estimation and design teams (Do et al., 2015b; Oliva et al., 2016). Additionally, successful implementation of TVD by organisations and team members has been hindered due to lack of awareness, the time it takes first time users to understand its principles, the mind shift needed and the cultural and organizational change (Olivia et al., 2016; Do et al., 2015).

Recently, there has been an increase in the creation, reinvention and use of simulations and serious games to teach TVD and other lean principles to project team stakeholders encountering them for the first time. This can enhance learning in an applied setting (Rybkowski, 2017; Pollesch et al., 2017). Munankami (2012) developed a TVD simulation game to illustrate TVD principles. TVD simulation and games help to create awareness and build teamwork and trust required for collaboration. Available studies on the simulation game have neither shown the iterative process in TVD nor reported the impact of the simulation game on a live project. They also have not emphasised the need for collaboration by discussing the interrelationship between the levels of collaboration. cooperation, coordination coalition and networking. This paper seeks to:

- Adopt the simulation game on a case study project with the hope of mitigating the aforementioned challenges and report the findings while identifying the differences between environments with and without collaboration
- Emphasise the need for collaboration by discussing the interrelationship between collaboration, cooperation, coordination coalition and networking.
- Report the iterative aspect of redesigning to set targets encountered during the simulation where two teams exceeded the target leading to a second attempt; as well as participants interviewed after the live implementation of TVD.

LITERATURE REVIEW

TVD SIMULATION GAME

A TVD simulation game was developed by Munankami (2012) in Texas A & M University to illustrated TVD principles. The game uses the same concepts of Peter Skillman and Tom Wujec's "Marshmallow Challenge" but applies TVD processes (Ebbs 2015). Since its development, the simulation has been tested at the Department of Construction Sciences of Texas A & M University. Rybkowski et al., (2016) who tested it on students and professionals, stated that most people that have tested and played it reported that it effectively illustrates and teaches TVD. They also advocated for additional testing of the simulation in projects.

Other researchers that have used the game include; Carolina Asensio Oliva in 2014; the Associated Schools of Construction Conferences, College Station, TX in 2015; Tobias Guller in Germany (lean consultant) who translated it into German; and Centre for Lean

Projects 4th Annual Research Showcase, Nottingham Trent University in 2019 where the moods of the participants were reported after both rounds.

A review of the literature on testing and application of the simulation reveals that the simulation places emphasis on collaboration and cooperation. For example, Munankami (2012) noted that the game was effective when tested, however, he suggested that owners, designers, and contractors should be separated in the first round to help participants think about the value of cooperation during the discussion and some terms should be explained properly. De Melo (2015) also tested the simulation on an exploratory case study to understand the mindset of construction-minded individuals who are willing to apply target costing in Brazil. Ebbs (2015) tested the simulation at the Boise State University workshop to prepare 30 practising professionals for the application of TVD on an actual project. He noted the game illustrates cooperation, competition, team building, collaboration, creativity, innovation, and design within budget constraints.

The literature reviewed further shows that the various studies available have not highlighted the concepts of cooperation, collaboration, coordination, coalition, and networking after round one of the simulation as collaboration is discussed in only after round two. They also do not report findings of the iterative aspect of redesigning to targets in round two. None of the several researchers that have conducted the simulation reported their findings after implementation of TVD on a project by participants of the simulation game.

THE LEVELS AND INTERRELATIONSHIP OF COLLABORATION

One of the most important discussions in the construction industry and research is the shift towards new collaborative project delivery systems (Hamid and Pardis 2014). Schrage (1990) defines collaboration as "the process of shared creation between two or more individuals with complementary skills interacting to create a shared understanding that none had previously shared or could have come to on their own". This implies that the underlying principle of collaboration is that there must be an interaction between the parties that will culminate in the creation of value to both parties. Attaran and Attaran (2007) maintained that collaboration does not only include the joint working of two or more organisations but three core criteria must be satisfied. These are: (1) having shared common information; (2) ensuring plans are made based on the shared information; and (3) executing the planned task collectively rather than individually.

The term cooperation has been used unknowingly to mean collaboration, which has led to the non-achievement of some so-called collaborative efforts. The Oxford Advanced Dictionary defines cooperation as the "process or the action of working together to the same end". This definition does not show the three core elements of collaboration as identified by Attaran and Attaran (2007). Cooperation could allow information to be shared between organisations, yet each organisation could still be acting independently, without regard for the other.

Coordination is the act of managing and unifying different activities on a project with multiple tasks, participants or organisations (O'Brien et al., 1995). The focus of coordination is to define a formal approach to organising how operations and activities should be conducted, which suggests that coordination is still based on the command and control philosophy. This implies that the mutuality element of collaboration is absent, even though the approach is formal.

Networking is a process that nurtures the exchange of information and ideas among individuals or groups that share a common interest (Investopedia 2017). Page (2018) opined that networking strengthens business connections, ensures fresh ideas, supports the gaining of different perspectives, and develops long-lasting relationships. On the other hand, Gaida and Koliba (2007) argue that networking is the weakest operational form of relational collaboration.

Coalition is defined by Lerbinger (2005) as the interrelating group of organisational actors, who: agree to pursue a common goal; manage their resources in a bid to accomplish this common goal and adopt a mutual strategy in chasing this goal. Foster-Fishman et al., (2001) are of the opinion that one of the important purposes of a coalition is to produce a collaborative capacity among coalition members through the organisational structure and programs of the coalition.

Table 1 shows the relationship between the levels of collaboration. From Table 1 and the prior discussion, it can be concluded that an organisation could practice cooperation and coordination without collaborating. Additionally, cooperation and coordination are processes that will naturally occur in the collaboration process.

Table 1: Relationship between networking, cooperation, coordination, coalition and collaboration

	Networking	**Cooperation**	**Coordination**	**Coalition**	**Collaboration**
Relationship characteristics	-Aware of Organisation	- Provide information to each other	-Share information and resources	-Shared ideas -Shared resources	-Members belong to one system
	-Loosely defined roles	-Somewhat defined roles	-Defined Roles		
	-Little communication	-Formal communication	-Frequent communication	-Frequent and prioritised communication	-Frequent communication characterized by mutual trust
	- All decisions are made independently	-All decisions are made independently	-Some shared decision making	-All members have a vote in decision-making	-A consensus is reached on all decisions

(Source: Frey et al., 2006)

It has been observed that interaction naturally occurs between construction project stakeholders before the delivery of the construction product, however, such interaction based on the old sequential model of project delivery cannot be viewed as collaboration since each team works independently of each other (Shelbourne et al., 2012).

METHODOLOGY

The materials, methods, and instructions for the 50 minutes version of the game developed by Munankami (2012) were adopted for this paper with few modifications. The study used 24 industry stakeholders from a reputable real estate developer in Nigeria, it was conducted during the workshop and training exercise at the initiation phase of a live project. The simulation concluded with interviews and survey of the participants.

After the simulation game, TVD was applied to a live project. The implementation of TVD was carried out on a project in Abuja, federal capital territory (FCT) of Nigeria. The project is the development of a self-sufficient and affordable city on 72 hectares, composed of 3,500 units of various house types. It also includes infrastructure covering a 7 km dual carriage road to connect with the existing road network, 10 km internal roads; sewer and stormwater drainages. The detail description of the TVD implementation process is beyond the scope of this paper. At the end of the TVD implementation on the live project, 14 of the 24 simulation game participants were interviewed.

Simulation Rounds: Two rounds of the simulation were done. Round one simulated traditional design-bid-build (DBB) processes while Round two simulated TVD processes. The simulation required four teams, each comprising three groups: owners, designers, and constructors. They were required to use only supplied materials to build a free-standing table-top tower that is two feet tall, no more than two inches out of plumb and capable of holding a marshmallow at the top. Each round was expected to last about 15-20 minutes.

Round one: The team groups worked in separate rooms to design, the owner approves, and the towers were constructed without regard for cost during the design process.

Costing: Costs were calculated only after the towers were completed, and teams were given a costing sheet as seen in Table 2. The following were calculated: market cost (122.38); allowable cost (97.90); target cost (86.75).

After round one, the facilitator asked the teams if they had collaborated and how they did. They answered in the affirmative, stating that they collaborated by providing information to team members and making decisions within individual groups.

Table 2: Round one; Establishing Target Cost

		Team Abuja		**Team Lagos**		**Team Port Harcourt**		**Team Ibadan**	
Materials	Unit cost	Units	Subtotal	Units	Subtotal	Units	Subtotal	Units	Subtotal
Spaghetti sticks	₦ 1.00	13	₦ 13.00	0	₦ -	0	₦ -	0	₦ -
Coffee stirrers	₦ 5.00	4	₦ 20.00	0	₦ -	3	₦ 15.00	4	₦ 20.00
Drinking straws	₦ 2.00	12	₦ 24.00	0	₦ 16.00	12	₦ 24.00	12	₦ 24.00

Bamboo skewers	₦ 3.00	12	₦ 36.00	8	₦132.00	15	₦ 45.00	12	₦ 36.00
Masking Tape	₦ 0.50	22	₦ 11.00	44	₦ 9.00	18	₦ 9.00	22	₦ 11.00
Subtotal			₦104.00		₦157.00		₦ 93.00		₦ 91.00
Profit (10%)			₦ 10.40		₦ 15.70		₦ 9.30		₦ 9.10
TOTAL			₦114.40		₦ 72.70		₦102.30		₦100.10
Market cost (= ave. of all towers)			₦122.38						
Allowable cost (= 20% < Market cost)			₦ 97.90						
Teams declared target cost (< allowable)			₦ 90.00		₦ 89.00		₦ 85.00		₦ 83.00
Target Cost (= ave. of all declared TCs)			₦ 86.75						

The researcher then informed the teams that they were cooperating not collaborating. He noted that 'cooperation' has been wrongly used to mean 'collaboration' which has led to non-achievement of some so-called collaborative efforts. He noted that team members should work collaboratively and consensus be reached in all decisions by all stakeholders. He then went further to give the participants talk on cooperation, coordination, networking, coalition and collaboration. In preparation for the second round, the talk highlighted the differences between cooperation, coordinating, coalition, networking and collaboration to the teams.

Round two: In the second round, designs, approval, and construction were done collaboratively with all team members, with the aim of designing to target cost. Two teams (Abuja and Lagos) exceeded the cost target of ₦ 86.75 (see table 3).

Table 3: Round two calculated design cost for all teams

		Team Abuja		**Team Lagos**		**Team Port Harcourt**		**Team Ibadan**	
Materials	Unit cost	Units	Subtotal	Units	Subtotal	Units	Subtotal	Units	Subtotal
Spaghetti sticks	₦ 1.00	0	₦ -	0	₦ -	0	₦ -	0	₦ -
Coffee stirrers	₦ 5.00	0	₦ -	0	₦ -	0	₦ -	0	₦ -
Drinking straws	₦ 2.00	19	₦ 38.00	6	₦ 12.00	0	₦ -	3	₦ 6.00

Bamboo skewers	₦ 3.00	13	₦ 39.00	21	₦ 63.00	15	₦ 45.00	12	₦ 36.00
Masking Tape	₦ 0.50	6	₦ 3.00	10	₦ 5.00	10	₦ 5.00	3	₦ 1.50
Subtotal			**₦ 80.00**		**₦ 80.00**		**₦ 50.00**		**₦ 43.50**
Profit (10%)			₦ 8.00		₦ 8.00		₦ 5.00		₦ 4.35
TOTAL			₦ 88.00		₦ 88.00		₦ 55.00		₦ 47.85

A second attempt was carried out to redesign to cost by the teams that exceeded the target cost. Cost less than the target cost was achieved at the second attempt after value engineering and brainstorming sessions were used to iteratively redesign to target cost without affecting function and quality (see table 4)

Table 4: Costing redone after the iterative redesign to target cost

		Team Abuja		**Team Lagos**	
Materials	Unit cost	Units	Subtotal	Units	Subtotal
Spaghetti sticks	₦ 1.00	0	₦ -	0	₦ -
Coffee stirrers	₦ 5.00	0	₦ -	0	₦ -
Drinking straws	₦ 2.00	15	₦ 30.00	6	₦ 12.00
Bamboo skewers	₦ 3.00	12	₦ 36.00	16	₦ 48.00
Masking Tape	₦ 0.50	8	₦ 4.00	8	₦ 4.00
Subtotal			₦ 70.00		₦ 64.00
Profit (10%)			₦ 7.00		₦ 6.40
TOTAL			₦ 77.00		₦ 70.40

RESULTS AND DISCUSSION

The facilitator conducted interviews and surveys for the participants of the game to assess their experiences playing the simulation and its effectiveness in teaching TVD principles.

FINDINGS FROM THE POST-SIMULATION INTERVIEW

The participants were asked the following questions after the game:

What were some basic differences between the two rounds? How did the decision-making processes differ between the two rounds? Which round was more stressful for you? Which round offered better cooperation? In which real-life circumstances might round one be more appropriate? How about round two?

The respondents' collective answers reveal that less time was spent in the second round compared to the first because of the collaborative working of the team. While the teams' average completion time for round one was 23 minutes, it was 16 minutes for round two. The teams understood the scope of work in round two compared to round one.

The participants noted that all decisions were made independently during round one but in round two, a consensus was reached on all decisions; this shows that in round one, the teams were just cooperating while in round two, ideas were put together collaboratively. Participants considered round one more stressful. They also noted that there was more frequent communication characterised by mutual trust in round two compared to round one.

The participants noted that the round one would be suitable for projects where collaborative practices cannot be adopted and where designs are completed before costing is done. While round two would be suitable for projects with predetermined and benchmarked budget that must be design to and not exceeded. Round two can also be suitable for projects where cost drives the design; where collaborative designing to targets is a requirement. All the respondents agreed the simulation game was very effective in teaching and understanding the principles and practices of TVD. Figure 1 shows the round two towers constructed to target cost

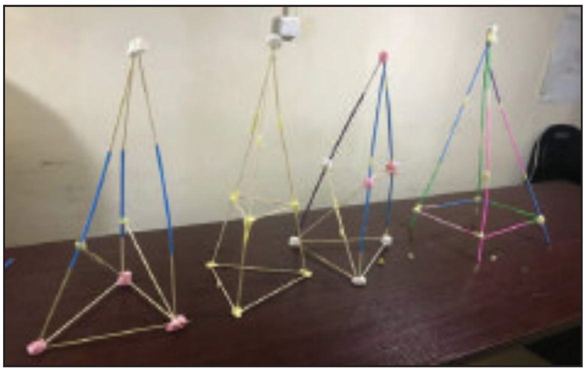


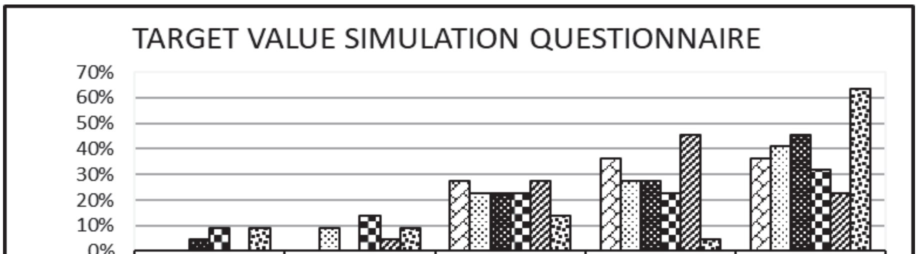
Figure 1: showing the Round two towers constructed to target cost

FINDINGS FROM THE POST-SIMULATION QUESTIONNAIRE SURVEY

At the end of both rounds, a 5-point Likert scale questionnaire ranging from "not effective" to "extremely effective" was administered to 22 out of 24 participants (92%). The questions focus on the effectiveness of the simulation in explaining: Q(a) mutual respect and trust;

Q(b) mutual benefit and reward; Q(c) Collaborative innovation and decision-making; Q(d) early involvement of key partners; Q(e) early goal definition, Q(f) open communication. Results from questionnaire responses are shown in Figure 2.

The analysis of the questionnaire indicated that majority of the respondents reported that the game was very effective in illustrating the following: Q(a) mutual respect and trust (100%); Q(b) mutual benefit and reward (91%); Q(c) Collaborative innovation and decision-making (95%); Q(d) early involvement of key partners (87%); Q(e) early goal definition (95%); Q(f) open communication (82%).



	Not Effective	Somewhat effective	Effective	Very Effective	Extremely effective
Q(a)	0%	0%	27%	36%	36%
Q(b)	0%	9%	23%	27%	41%
Q(c)	5%	0%	23%	27%	45%
Q(d)	9%	14%	23%	23%	32%
Q(e)	0%	5%	27%	45%	23%
Q(f)	9%	9%	14%	5%	64%

Figure 2 Graph of response from 22 respondents

FINDINGS FROM A POST- TVD IMPLEMENTATION INTERVIEW

Subsequent to the TVD implementation on the live project, 14 of the 24 simulation game participants were interviewed; representing 58% of the participants which is a good representation of the total participants of the simulation. Analysis of the interviews indicated all the interviewed participants agree the simulation was explanatory and enabled them to implement TVD successfully. They also reported that the simulation will serve as a support and success factor for the implementation of TVD on any project. The simulation has proven to be a simpler and more practical method of understanding collaboration and TVD practices than formal training and workshops.

It was observed that during the TVD implementation on the live project, team members that participated in the simulation game were assigned to be team heads during cluster formations because they had a better understanding of TVD and performed better than those that did not.

CONCLUSION

This paper presented a report of the TVD Marshmallow Simulation Game conducted to illustrate the basics of TVD. It further points out the significance of collaborative working through early involvement of key stakeholders. The simulation shows how stakeholders can work collaboratively to bring about innovative design alternatives, steer cost below the target, agree on a realistic schedule, the best quality standards and ensure customer satisfaction. Work environments characterised by collaboration is more enjoyable to work in and work takes little time when compared to the environment without collaboration. The study also illustrated the iterative redesigning to a set target in a scenario when initial targets have been exceeded.

The TVD simulation game has demonstrated to be effective in teaching the principles and practices of TVD to first time users; it is also very effective in illustrating mutual respect and trust, collaborative innovation and decision-making. The traditional design-bid-Build contracts are suitable for projects where collaborative practices cannot be adopted and when costing is done after designs have been completed, while the TVD approach is suitable for projects with a predetermined and benchmarked budget that must be designed to and not exceeded.

There is a need to conduct discussions on the different levels of collaboration preferably before the commencement of the second round; this is to enable participants to have a better understanding of the various concepts and how to apply them on projects. Also, before the commencement of the game, the specification of the tower to be constructed like the quality, height, and width should be properly stated, otherwise participants may reduce the scope to reduce the cost especially in round two.

Finally, this study recommends the inclusion of the TVD Simulation Game in training and workshops for project team before the commencement of construction projects since it has demonstrated to be a more simple and practical method of understanding collaboration and TVD practices.

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to Zofia Rybkowski and the entire Texas A&M University for supplying the instructions and spreadsheet used in the game. I also wish to appreciate the Centre for Lean Projects, Nottingham Trent University.

REFERENCES

Attaran, M. & Attaran, S. (2007). Collaborative supply chain management: the most promising practice for building efficient and sustainable supply chains. *Business Process Management Journal,* 13(3), 390-404.

De Melo R. S. S. (2015). Guidelines for target costing introduction in the real estate products development process. *Doctorate thesis presented to the School of Civil Engineering, Architecture and Urban Design, University of Campinas, to obtain the Ph. D. degree in Civil Engineering, in the area of Architecture and Construction.*

Do, D., Ballard, G. and Tommelein, I. D. (2015). An Analysis of Potential Misalignment of Commercial Incentives in Integrated Project Delivery and Target Value Design. In: *Proc. 23rd Annual. IGLC Conference Perth, Australia*, July 29-31, pp. 277-286, available at www.iglc.net.

Do, D., Ballard G., and Tillmann P. (2005b). Part 1 of 5: The Application of TVD in the Design and Construction of the UHS Temecula Valley Hospital. Technical Report Project Production Systems Laboratory University of California, Berkeley

Ebbs. (2015). Target Value Design and the Marshmallow Team Building Game.

Foster-Fishman, P. G., Berkowitz, S. L., Lounsbury, D. W., Jacobson, S. and Allen, N. A. (2001). Building Collaborative Capacity in Community Coalitions: A Review and Integrative Framework. American Journal of Community Psychology, Vol. 29, No. 2.

Frey, B, et al. (2006) Measuring Collaboration Among Grant Partners. *American Journal of Evaluation* 27(3), 383-392.

Gajda, R. and Koliba, C. (2007). Evaluating the Imperative of Intra-Organizational Collaboration, A School Improvement Perspective. American Journal of Evaluation, Vol. 28 No. 1, 26-44 DOI: 10.1177/1098214006296198.

Hyun, W. L. (2012). Application of Target Value Design to Energy Efficiency Investments. University of California, Berkeley.

Hamid A. and Pardis, P. (2014). Developing a Framework of Metrics to Assess Collaboration in Integrated Project Delivery. *50th ASC Annual International Conference Proceedings.* 1-8.

Investopedia. (2017). Networking. Dotdash publishing family.

Iyer, K. C., and Jha, K. N. (2005). Factors affecting cost performance: evidence from Indian construction projects. *Int. Journal of Project Management,* 23, 283-295

Kim, Y. and Lee, H.W. (2010). Analyzing User Costs in a Hospital: Methodological Implication of Space Syntax to Support Whole-life Target Value Design. *Lean Construction Journal*, 11, pp.55-63.

Kochhar, S. (2013). A Conceptual Model for Measuring Coalition Building Effectiveness. A research paper submitted to Institute for Public Relations as part of the Ketchum Excellence in Public Relations Research Award.

Lerbinger, O. (2005). Corporate Public Affairs: Interacting with Interest Groups, Media, and Government (Routledge Communication Series). Routledge.

Munankami, M. B. (2012). "Development and testing of a simulation (game) to illustrated basic principles of Integrated Project Delivery and Target Value Design: A First Run Study," Graduate Thesis, Texas A&M University, College Station, TX.

O'Brien, W., Fischer, M.A. & Jucker, J.V. (1995). 'An Economic View of Project Coordination', Construction Management and Economics, 13:393-400.

Oliva, C.A., Granja, A.D., Ballard, G., Melo, R.S.S. (2016). "Assessing Suitability of Target Value Design Adoption for Real Estate Developers in Brazil." In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.4 pp. 93–102. Available at: <www.iglc.net>.

Oxford English Dictionary. (2018). Rigour. Oxford University Press.

Page, M. (2018). Top 11 benefits of networking. Michael Page International. Australia.

Pollesch, P., Rovinsky, A., Alvarado III, R., and Alves, T.C.L. (2017). "House of Cards – a Simulation of Lean Construction Principles" In: LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction

(IGLC), Walsh, K., Sacks, R., Brilakis, I. (eds.), Heraklion, Greece, pp. 373–380. DOI: https://doi.org/10.24928/2017/0212

Rybkowski, Z. K., Munankami, M., Shepley, M. M., and Fernández-Solis, J. L. (2016). "Development and testing of a lean simulation to illustrate key principles of Target Value Design: A first run study." In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.4 pp. 133–142. Available at: <www.iglc.net>.

Rybkowski, Z. K. (2017). Serious Games and Simulations: Transforming Culture to enhance building project delivery. National Institute of Building sciences conference and Expo; Preparing the High-performance workforce.

Schrage, M. (1990). Shared Minds: The New Technologies of Collaboration, New York: Random House.

Shelbourne, M, Sheriff, A., Bouchlagham, D., El-Hamalawa and Yeomans, S. (2012). Collaboration Key concepts. In Bouchlaghem, Collaborative working in construction. London; Spon Press

Solhjou Khah, F., Rybkowski, Z, Pentecost, A. R, Smith, J. P., and Muir, R. (2019). "Development and Testing of an Innovative Architectural Programming Simulation as a Precursor to Target Value Design" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.)*, Dublin, Ireland, pp. 515–526. DOI: https://doi.org/10.24928/2019/0221. Available at: <www.iglc.net>.

DEVELOPMENT AND TESTING OF AN INNOVATIVE ARCHITECTURAL PROGRAMMING SIMULATION AS A PRECURSOR TO TARGET VALUE DESIGN

Fatemeh Solhjou Khah[1], Zofia K. Rybkowski[2], A. Ray Pentecost[3], James P. Smith[4], and Robert Muir[5]

ABSTRACT

More than half of international construction projects are underperforming. Poorly defined scope of work has been ranked as the one of the highest reasons for poor performance over which owners and construction stakeholders have control. An owner's requirements and expectations are specified during the programming phase of a project and these define a design's scope of work. One focus of Target Value Design (TVD) is making owner's value a primary driver of design by improving project definition during programming—thus optimizing the design phase. While the number of published research articles praising TVD has been increasing, there is a dearth of information regarding the application of architectural programming (AP) to Target Value Design exercises, which engage stakeholders in a design decision making process called Choosing by Advantages (CBA). CBA first requires identification of attributes that are of value to an owner. The purpose of this research was to explore the importance of architectural programming in helping to identify key attributes of value to an owner, and to report on a lean game designed and preliminarily validated by the authors to investigate the accuracy and perception of attribute identification through AP as represented by the game.

KEYWORDS

Target value design, value, design science, architectural programming, serious games and simulations

[1]Graduate Student, Department of Construction Science, Texas A&M University, College Station, TX,77843 USA, +1 979-900-0654, ellie.solhjoukhah@gmail.com

[2]Associate Professor, Department of Construction Science, Texas A&M University, College Station, TX,77843, +1 979-845-4354, zrybkowski@tamu.edu (corresponding author)

[3]Professor of Practice, Department of Architecture, Texas A&M University, College Station, TX, 77843, +1 979-845-7009, rpentecost@tamu.edu

[4]Assistant Professor, College of Engineering, Brigham Young University, Provo, UT 84602-8200, +1 801-422-2023, james_smith@byu.edu

[5]Principal Faculty, Myers-Lawson School of Construction, Virginia Tech University, Blacksburg, VA, 24061, +1 540-231-9959, rmuirjr@vt.edu

INTRODUCTION

Many reasons have been attributed to construction project cost overruns worldwide (**Figure 1**). The pre-eminent reason known as “material price escalation” refers to insecurity of an economy and inflation over which construction stakeholders have no control. However, poorly defined scope has been identified to be the second most influential reason for cost overruns in the construction industry, but the first over which the Owner, Architect, Engineer, and Contractor (OAEC) stakeholder team has control.

Architectural Programming (AP) is defined as the research and decision-making process that identifies the scope of work to be designed (WDBG 2016). It has been cited as a poorly implemented phase in the construction industry (Morêda Neto et al. 2016).

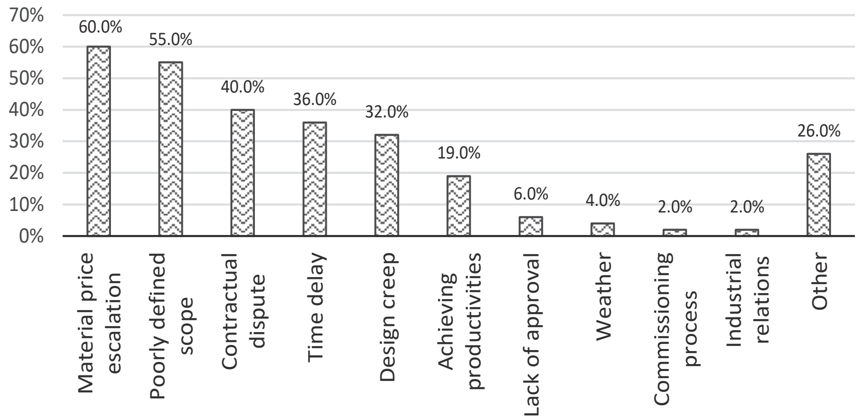


Figure 60. Reasons for cost overrun in construction projects worldwide, as of 2008. Adapted from PMI

LITERATURE REVIEW

“Target Value Design (TVD) is a management strategy and known as a complex system, with stages including: Project definition (A), Design (B), and Construction (C) (**Figure 2**). It correlates closely with Lean thinking in design and construction” (p. 2, Zimina et al. 2012). TVD tools help stakeholders meet an allowable cost, while enhancing value, for a project owner, often saving a project as much as 15-20% on first cost (Ballard and Rybkowski 2009; Denerolle, S. 2013, Rybkowski et al. 2016).

To help educate participants about TVD, Rybkowski et al. (2016) developed a two-phase estimating simulation to illustrate to participants the “Design/Develop Design/Detail Design” process (**Figure 2**, phase B) of TVD. However, “Project Definition/Business Planning/Plan Validation” (**Figure 2**, phase A) must precede the design process as it informs designers of what an owner values. A simulation to introduce participants to stage A was needed and

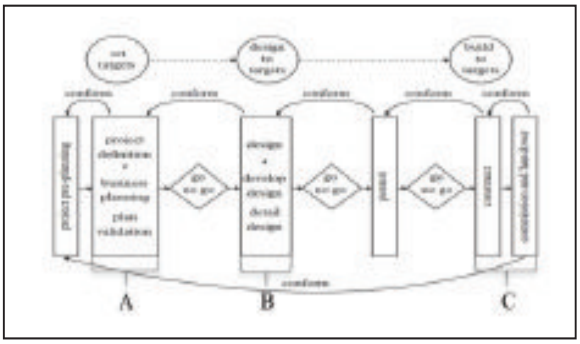


Figure 61. Target Value Design process scheme (Figure 4 in

did not yet exist. Filling this gap was the basis for this paper.

For this study, seven architectural programming methods were identified including: Davis's Programming, Farbestian's Programming, McLaughlin's Programming, Kurtz's Programming, Moleski's Programming, White's Programming, and Peña's Programming (Sanoff 1992). For example, Peña's programming method addresses four primary elements including Function, Form, Economy, and Time. Peña's programming requires work sessions that gather all stakeholders involved in the project to explore 132 considerations covering many aspects of a project (Peña and Parshall 2001, Sanoff 2016).

In the construction industry, training and its advantages are underestimated, which leads to inadequate formal training activities (Kuykendall 2007). In a study conducted by Cox et al. (1998), it was found that companies, which invested in training practices, increased their productivity by 42%. As with other skills, lean training is vital in establishing an advanced mindset and culture, which is critical to successful lean implementation (McGraw-Hill 2012). This training leads to the foundation for successful changes in an organization (Wan et al. 2008). Lean training is applicable in many forms, including lectures, presentations, hands-on games and activities, videos, and case studies. These approaches are effective when used separately, but they can also be adopted together for better overall performance. Serious games and simulations are some of the most efficient methods to demonstrate the advantages of lean tools and concepts (Kuriger et al. 2010). They differ from simple "gaming" in that the primary aim is educational—i.e. to learn through entertainment (Wouters et al 2007).

PROBLEM STATEMENT

This study seeks to address the need for construction stakeholders to develop an appreciation for systematic architectural programming at the start of a construction project during the early stages of TVD. The amount of information regarding the application of architectural programming to TVD is insufficient. In TVD, project definition is included as a separate upfront design step that should involve architectural programming. Therefore, the focus of this study is to design and test via proof of concept an innovative and functional Lean simulation in order to communicate the importance of architectural programming on value creation for the owner.

RESEARCH OBJECTIVES

The overall goal of this study is to develop and test a new lean simulation that introduces systematic architectural programming as a way to determine value for a building owner at the start of TVD. The objective of this specific research is to collect feedback after testing the simulation, and to use that feedback as a guide to improve future versions of the simulation. The ultimate aim is to help increase value of the built environment.

PROPOSED METHODOLOGY

This paper documents the exploratory, quantitative and qualitative development and testing of a lean architectural programming simulation at Texas A&M University, Virginia Tech University, and Brigham Young University. In addition, a questionnaire was distributed to participants to evaluate the simulation's effectiveness. To the best of the authors' knowledge, there is no previous lean simulation which explores the impact of architectural programming. In this research, the authors developed a simulation to evaluate the importance of architectural programming (AP) by using an algorithmic manipulation of three floor plans to yield a compilation of 144 possibilities. By conducting a subsequent evaluation, research tested how systematic architectural programming (AP) might benefit the participants, who are about to embark on TVD exercises.

The Architectural Programming lean simulation was designed to investigate perceptions about the importance of AP. It was originally designed and tested at the College of Architecture at Texas A&M University. It was pilot tested on graduate and undergraduate students, who were being prepared to enter construction related industries within the next one to five years. Students were affiliated with the departments of Construction Science, Architecture, and Civil Engineering. The Institution Review Board permitted testing to be performed in classrooms by the facilitators in the aforementioned departments at Texas A&M University, and exact dates and times were set to conduct the simulation in classes. To administer the simulation, the facilitator read aloud instructions. At various points the facilitator clarified aspects of the game as needed, based on verbal questions from the participants, and provided written questionnaires to secure feedback from the students following play.

Simulation Process:

Before starting the game, instructions were delivered orally by the facilitator. Participants were divided into pairs of two members: one as an owner, and the other as an architect. Required material for this simulation included: Template for Scenarios (**Figure 5**), six Architectural Programming Scenarios which portrayed scenarios to define owner's expectations and requirements (**Figure 6**), Two 11" X 17" landscape format photocopies with 144 apartment layouts were provided for each pair with five variables including: Number of bedrooms, Ability/Disability, Solar Orientation, Open vs. Closed Kitchen, and Quality of Finishes (**Figure 8**). Each plan was given an identifier and three assigned potential quality of finishes (Low, Medium, High). The purpose of this lean game is for architect players to understand the difference of impact between *not* listening and listening carefully to an owner's needs before recommending to the owner appropriate diagrammatic apartment plan layouts with associated quality of finishes. The lean simulation was administrated in two rounds.

Round I:

Selected plan identifiers with associated quality of finishes were written on slips of paper and shuffled in a bowl for owners to draw (**Figure 4**). Owners memorized the drawn plan identifier with quality of finishes, and the architect was instructed to guess the plan identifier with quality of finishes. Architects were allowed to ask two yes or no questions pertinent to the given criteria on the blank "Template for Scenarios" in four minutes and owners were permitted respond to their questions based on the given information in the related Scenarios. At the end of the first round the architects were asked to guess what they believed was the owner's desired plan identifier and its quality of finishes. The facilitator then asked each architect to announce his or her guess. The results of the guess were collected onto a table drawn onto the room's white board.

Round II:

In the second round, owners read their scenarios slowly to their architects. Architects were not allowed to ask any questions. But they were permitted to ask their owners to read their scenario again. Within six minutes, the architect players guessed the plan number and its quality of finishes. Participants' guesses were again recorded by the facilitator on the whiteboard table. The results for the two stages were compared. At the end of the game, Peña's Programming table was projected onto a screen in order to demonstrate how the lessons of the game can be applied to actual projects. In addition, a questionnaire was distributed to participants to collect feedback regarding their perceptions of the game (**Figure 7**).

This simulation is an effort to help the participants understand the importance of systematic architectural programming in meeting owner's requirements and expectations—i.e. what an owner deems to be of a greatest value. Moreover, the simulation indicates adverse effects of lack of communication between owners and architectural programmers on the outcomes of construction projects. An example of data collected on a whiteboard by the facilitator is shown (**Table 1**). All white board tables were photographed. These data, along with data from questionnaires completed by participants and all players were cumulatively inputted into excel and evaluated.

	Team #									
RND I	1		2		3		4		5	
Guessed DWG # and Quality of Finishes	E1-2 Low		D4-2 Medium		A4-2 High		D2-1 Medium		B4-1 Medium	
	Y	N	Y	N	Y	N	Y	N	Y	N
RND II										
Guessed DWG # and Quality of Finishes	A2-2 Medium		D4-2 Medium		B3-2 Low		C4-1 Low		D4-1 Medium	
	Y	N	Y	N	Y	N	Y	N	Y	N

Table 23. Example of "Guess Table" drawn by facilitator on whiteboard

RESEARCH LIMITATIONS

While the outcome from these initial tests were promising, it must be acknowledged that the sample size was relatively small (N=136, combining results from three universities); thus, the conclusions might not convincingly reflect the attributes of players from practice or industry. Also, the simulation does not take into consideration cultural differences among participants.

RESULTS AND DATA ANALYSIS

Results from the Architectural Programming (AP) Lean experiment from three universities (Texas A&M, Virginia Tech, and Brigham Young; **Table 2**) indicate there was a marked decrease in the percentage of incorrect guesses from Round 1 (95.38%) and Round 2 (21.5%)—a decrease of 77.5%. In other words, owner's requirements and expectations were not met during the first round but were largely met during the second round.

Table 24. Summarized pilot test results for AP lean simulation from three universities

Round I	Percent of Correct Guesses	Percent of Incorrect Guesses
TAMU	4.54%	95.65%
VTech	12.50%	87.50%
BYU	2.94%	97.06%
Round I Total	**4.62%**	**95.38%**
Round II	**Percent of Correct Guesses**	**Percent of Incorrect Guesses**
TAMU	78.26%	21.74%
VTech	37.50%	62.50%*
BYU	88.23%	11.77%
Round II Total	**78.50%**	**21.50%**

* Deviation in game implementation during Round II may be responsible for this number.

Various purposes for the AP lean simulation experiment were identified by participants. As **Figure 3** shows, approximately 55% of players believed that "Communication" is the primary purpose of the simulation. Players perceived this simulation to be a useful tool to indicate the importance of communication and identifying owner's expectations, which ultimately outlines the importance of utilizing a comprehensive AP tool in the construction industry. Other evaluations were conducted to assess difficulty and levels of enjoyment while playing the Architectural Programming lean simulation. Approximately 77% of players believed that this simulation was "moderately easy" or "easy to understand", and 61% of players agreed that this simulation was "very fun" or "extremely fun to play." These scores outline the

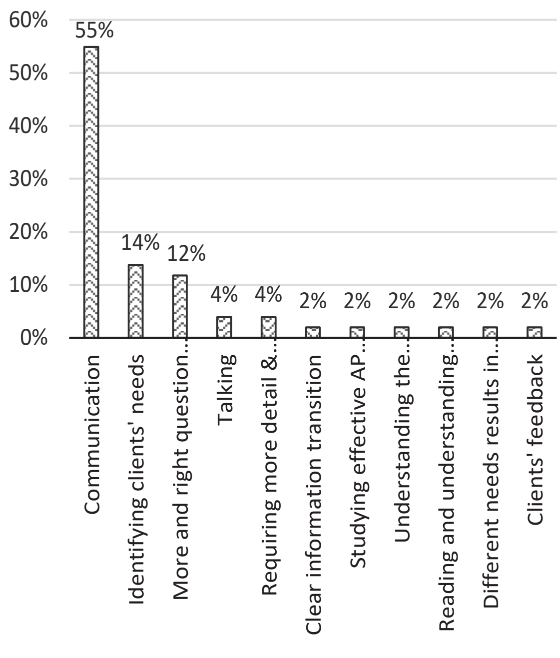


Figure 3. Results from questionnaire following play by

convenience of this innovative lean simulation with respect to being played at organizations for the purpose of teaching the importance of AP in construction and other related fields. Participants' demographic data indicates that 86% of participants were male players, and 14% of them were female players. Approximately 87.5% of the players were undergraduate students, and 12.5% were graduate students. Players' academic majors were classified based on the degree they planned to earn within five years: 77.2% of participants were studying construction science, 10.3% architecture, 3.7% business, 2.2% civil engineering, 3.7% facilities management, 2.2% technology and engineering studies, and 0.7% product design. Typical feedback on how the AP lean simulation can be improved included: this simulation is a good game, provide more clear instruction, make it more challenging, provide more time, and permit more questions and guesses during Round I[137]. Outcomes of the AP lean simulation suggest that there was substantial alignment between an owner's expressed needs and an architect's design after the AP method was implemented e.g. 3 correct guesses in Round I vs. 51 correct guesses in Round II.

DISCUSSION

Although an in-depth discussion of Choosing by Advantages exercises (CBA; Suhr 1999) is beyond the scope of this paper, it is important to clarify that this simulation simply helps identify basic attributes that are critical to an owner. Target Value Design typically engages participants in CBA, which encourages stakeholders to brainstorm and then subject to criterion analysis multiple alternatives embodying these attributes (Arroyo et al. 2013; Schöttle et al. 2007). In other words, while there are many ways to design a two-bedroom home, the designer needs to first recognize an owner wants a two-bedroom home, for example. Architectural programming helps identify critical attributes of value to an owner.

The AP lean simulation was developed as an attempt to communicate to OAEC (Owner, Architecture, Engineering, and Construction) stakeholders the importance of reliable architectural programming methods (AP) on OAEC projects. Preliminary feedback from simulation participants indicates that this simulation can be applied to real-world scenarios. While studies have been conducted on TVD in the fields of Lean Construction and Architectural Programming individually, there are few publications that address both simultaneously. The aim of this research is to integrate lean strategies and AP components to fill this gap. Indeed, these methods can both coexist and complement one other.

CONCLUSION

Project success has been defined by two key factors including managing costs to achieve efficiencies, and creating and enhancing value (Venkataraman and Pinto 2011). Lean Construction strategies can be applied in order to create and improve values in construction projects. However, 53% of construction projects are underperforming overall (KPMG 2015). Poorly defined scope of work by OAEC stakeholders has been identified as the most

[137] The authors believe this feedback may reflect a misunderstanding of some participants of the purpose of the simulation.

frequent reason for project cost overruns. By improving the architectural programming stage of a project, stakeholders can improve scope of work related to owners, meet their expectations and requirements, and ultimately, increase the probability of project success. This paper suggests exploring ways to integrate lean strategies with architectural programming methods to fill a gap that synergistically addresses the needs of owners, architects, engineers, and contractors when embarking on TVD. The intent of this research was to develop and test an innovative simulation to effectively highlight the value of architectural programming and its associated long-term benefits, thus helping to reduce cost overruns and increase project success among OAEC stakeholders. After playing the Architectural Programming simulation, participants indicated they understood the importance of architectural programming in the construction industry. Student participants in this study represented potential stakeholders in the construction industry, and it would be worthwhile for a future longitudinal research project to explore whether their understanding endures or is transformed as the student participants pursue careers following graduation.

Cut Here

C4-1 (Low)	E3-1(High)
D4-2 (Medium)	B3-2 (Low)
D3-1 (Medium)	A2-2 (Medium)

Figure 4 (above). Slips of paper
(To be drawn by owners out of the bowl).

Figure 5 (right). Template for Scenarios
(To be given to architects only).

Template for scenarios

	Variables	RND I (Pick 2 Variables to ask)	RND II
1	# of bedrooms		
2	Ability / Disability		
3	Solar Orientation		
4	Open vs. closed kitchen		
5	Cost of Finishes		

E3-1 (High)

1	My wife and I have a 17-year old teenage daughter and a 9-year old son. The children need to have their own bedrooms.
2	Everyone is healthy and my wife and I are very active.
3	We live in a part of New Zealand (i.e. southern hemisphere) which is so cold it has penguins. Give us sun in our bedrooms and living room please!
4	I am the cook in the family and like peace and quiet when I cook after work. The kids like watching TV in the living room which can be noisy, so I want some barrier between us.
5	I am a data scientist and make good money so cost is not a constraint.

B3-2 (Low)

1	My husband and I are retired and 65 and 60 years old, respectively.
2	We are currently in good health but want a place to live well into our 70s or even 80s, assuming we live that long.
3	We live in Arizona which is really hot. So we don't want to have direct sunlight in our bedroom at midday when we take naps. We also don't want sunlight in the afternoon in our bedroom.
4	We have young grandchildren and will be taking care of them during the day while their parents are at work. We want to be able to supervise them while they play in the living room, even while we cook.
5	We are living off of social security so need a modestly-priced home.

A2-2 (Medium)

1	I am a night security guard in New York City and prefer to live alone.
2	I lift weights when I can and am in tip-top shape.
3	Since I work at night and sleep during the day I don't want light coming into my bedroom.
4	I have a great film collection, and want to be able to see my plasma screen in the living room while I am cooking.
5	I am solidly middle-class. I'm not rich but I'm not poor either.

12. What were the best parts of the game? Please be specific.

An Innovative Architectural Programming Simulation

To help us assess the effectiveness of the simulation, we appreciate your help completing the following information:

1. What is your gender? --------------------
2. Circle your role in AP simulation (Architect/Owner)
3. Circle your classification (Undergrad/ Grad/ Neither)
4. What is/was your undergraduate major (if applicable)? --------------------
5. What is/was your graduate major (if applicable)? --------------------
6. What is your job title? --------------------
7. How many years do you have industry experience? --------------------
8. What do you think was the purpose of this simulation?
9. Do you think the instructions were easy to understand? Please answer on a scale of 1 to 6.

Hard to understand	1	2	3	4	5	6	Easy to understand

10. Do you think the game was fun to play? Please answer on a scale of 1 to 6.

Not at all fun to play	1	2	3	4	5	6	Extremely fun to play

11. How do you think this simulation is applicable to an actual project?

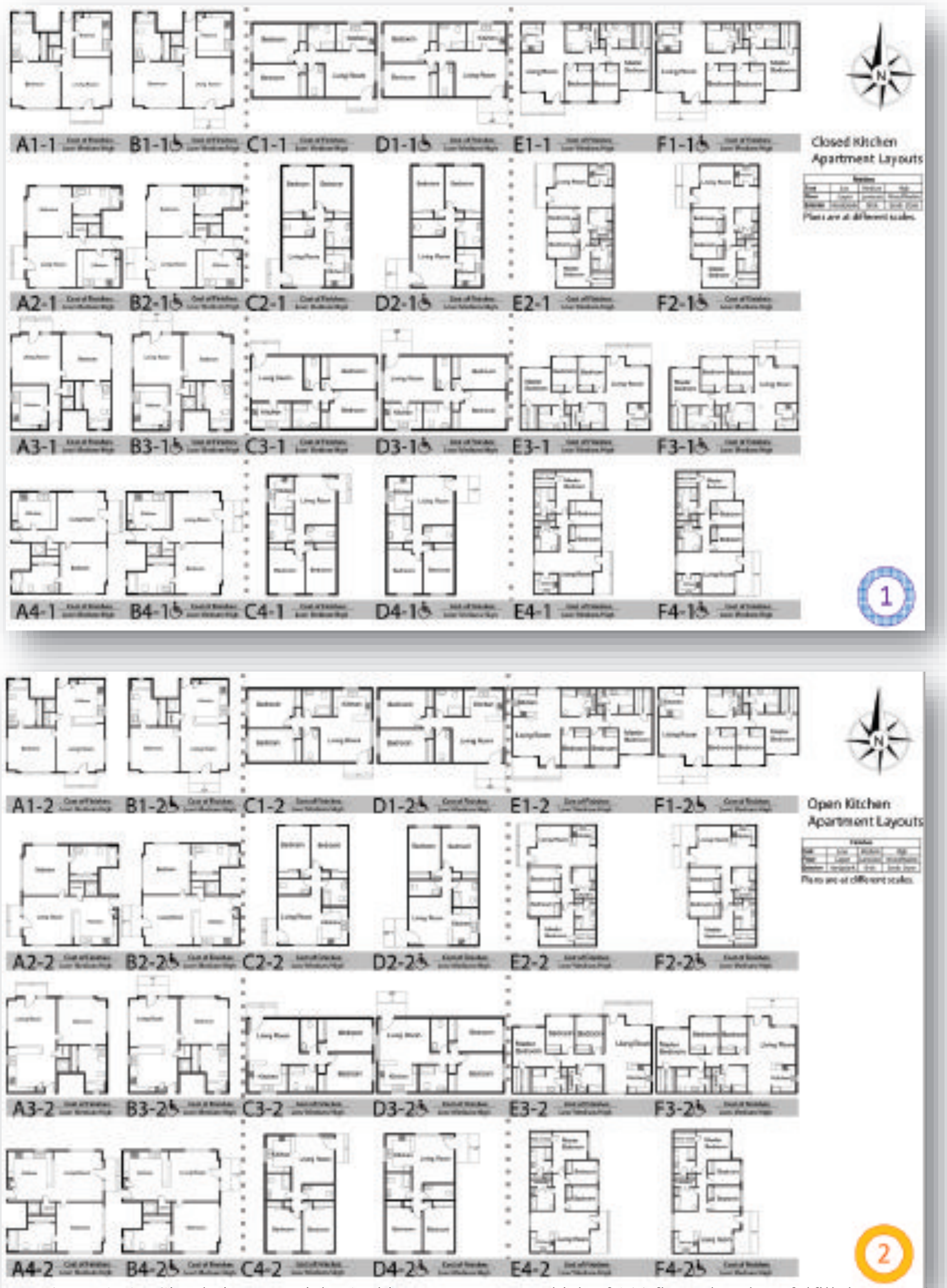


Figure 8. AP Simulation Materials: Architects must guess which of 144 floor plans best fulfill the owner's values (to be given to both owners and architects).

Sheets were numbered in color to clarify to players that the two sheets differ.

REFERENCE

Arroyo, P., Tommelein, I. D., and Ballard, G. (2013). “Using Choosing by Advantages to select ceiling tile from a global sustainable perspective,” *Proceedings of the 21st Annual Conference of the International Group for Lean Construction*, July, Fortaleza, Brazil, 309-318.

Ballard, G., and Rybkowski, Z. K. (2009). “Overcoming the hurdle of first cost: A case study in target value design,” *The 2009 Construction Research Congress*, Constr. Inst. of ASCE, Seattle, WA, 10 pp.

Cox, Robert F., R. Raymond Issa, and Heidi Collins. (1999). “Determining the Quantitative Return on Investment (ROI) of Craft Training.” Report to the National center for Construction Education and Research, University of Florida, FL.

Denerolle, S. (2013). *Technical Report: The application of Target Value Design to the design phase of 3 hospital projects*. P2SL:Project Production Systems Laboratory, Berkeley, CA.

KPMG. (2015). "Percentage of construction projects underperforming in FY 2014, by sector." Statista - The Statistics Portal <https://www.statista.com/statistics/526690/percentage-of-construction-projects-underperforming-by-sector/> (Oct. 2, 2018).

Kuriger, G. W., Wan, H. D., Mirehei, S. M., Tamma, S., & Chen, F. F. (2010). “A web-based lean simulation game for office operations: training the other side of a lean enterprise.” *Simulation & Gaming,* 41(4), 487-510.

Kuykendall C. J (2007). “Key Factors Affecting Labor Productivity in the Construction Industry,” thesis, presented to University of Florida at Gainesville, FL, in partial fulfillment of the requirements for the degree of Master of Science.

Mc-Graw Hill Construction (2012). *Construction Industry Workforce Shortages: Role of certifications, Training and Green jobs in filling the gaps smart market report.* Bedford, MA.

Morêda Neto, H., Costa, D., and Thomas, L. (2016). "Target Value Design Approach for Real Estate Development." *24th Annual Conference on Lean Construction,* The International Group for Lean Construction, (2016), Boston, MA, 63-72.

PMI and KPMG. (2013). "Reasons for cost overrun in construction projects worldwide, as of 2008." In Statista - The Statistics Portal <https://www.statista.com/statistics/526875/reasons-for-cost-overruns-in-construction-projects/> (Oct. 2, 2018).

Peña, W. M. and Parshall, S. A. (2001). *Problem-Seeking: An Architectural Programming Primer*, 4th Ed., Wiley, New York, 224 pp.

Rybkowski, Z. K., Munankami, M., Shepley, M. M., and Fernández-Solis, J. L. (2016). "Development and testing of a lean simulation to illustrate key principles of Target Value Design: A first run study." Proceedings of the 24th Annual Conference for the International Group for Lean Construction; July 20-22, 2016: Boston, MA, Sect. 4, 133–142.

Sanoff, H. (1992). *Integrating Programming, Evaluation and Participation in Design: A Theory Z approach,* Aldershot (Angleterre), Routledge, Brookfield (É.-U.), Avebury, England.

Sanoff, H. (2016). *Integrating Programming, Evaluation and Participation in Design (Routledge Revivals): A Theory Z Approach,* Routledge, New York, NY.

Schöttle, A., Arroyo, P., and Haas Georgiev, C. (2017). "Applying Choosing by Advantages in the Public Tendering Procedure," *Proceedings of the 25th Annual Conference of the International Group for Lean Construction* , Heraklion, Greece, 45-52.

Suhr, J. (1999). *The Choosing By Advantages Decision Making System*, Greenwood Publishing Group, Quorum, Westport, CT, 293 pp.

Venkataraman, R. R., & Pinto, J. K. (2011). "Cost and value management in projects." *John Wiley & Sons.*

Wan, H., Chen, F. F., & Saygin, C. (2008). "Simulation and training for lean implementation using web-based technology." *Int. Journal of Services Operations and Informatics*, 3, 1-14.

Whole Building Deign Guide. (2018). <wbdg.org/design-disciplines/architectural-programming> (Oct. 10, 2018).

Wouters, P., Tabbers. H. K., and Paas, F. (2007). "Interactivity in video-based models," *Educational Psychology Review*, 327-342.

Zimina, D., Ballard, G., and Pasquire, C. (2012). "Target value design: using collaboration and a lean approach to reduce construction cost." *Construction Management and Economics*, 30(5), 383-398.

STREAM 9: PLANNING AND WORKFLOW

Styrvold, M., Knotten, V., and Lædre, O. (2019). "Planning the BIM Process in AEC Projects." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 527–538. DOI: https://doi.org/10.24928/2019/0208. Available at: <www.iglc.net>.

PLANNING THE BIM PROCESS IN AEC PROJECTS

Marie Styrvold[1], Vegard Knotten[2], and Ola Lædre[3]

ABSTRACT

The architectural, engineering and construction industry (AEC Industry) needs to focus on the early design phases. The use of Lean Design Management and Building Information Model (BIM) can be used together for reducing uncertainty and improve communication. BIM requires new working methods, and the use of Level of Development (LoD) or model maturity is proposed as a key element to align the challenges in the design phase and to generate an enhanced design process.

This paper addresses these challenges and aim to answer three research questions. RQ1: What approaches to model maturity are used or attempted in the Norwegian AEC industry? RQ2: What experiences do the actors of the AEC industry have towards the use of model maturity? RQ3: How can model maturity be implemented in an AEC project?

The research method is based on a literature study and a study based on semi–structured interviews. This paper presents an analysis of the interviewees regarding the experiences the industry has with the use of model maturity. There is proposed a framework based on the results, about how to implement model maturity in construction projects. The framework is generic and can be adapted to different construction projects independent of contract form.

KEYWORDS

BIM, model maturity, design management, lean design, collaborative planning

INTRODUCTION

Research has highlighted the importance of the early design phase to reduce uncertainty, improve quality and consequently the overall performance in construction projects (El Reifi et al. 2013). The design process is important for creating successful construction projects (Bølviken et al. 2010).

Many contractors have successfully implemented Lean Construction for reducing waste in the production phase to improve productivity (Emmitt et al. 2004). This opens for using Lean Design Management in the early design phases (El. Reifi and Emmitt 2013). There

---

[1] MSc Student, Department of civil and environmental engineering, The Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway, Mobile +4748126153, marie.styrvold@gmail.com

[2] Associate professor II, PhD, Department of Architecture and Planning, NTNU. Head of BIM and Design management development (Veidekke), vegard.knotten@veidekke.no

[3] Professor, dr. ing, Department of civil and environmental engineering, The Norwegian University of Science and Technology (NTNU), ola.laedre@ntnu.no

is proven to be synergy effects between the use of Lean and BIM (Sacks et al. 2010a). The increased use of Building Information Model (BIM) requires a different design management strategy than a traditional 2D – CAD process (Abou-Ibrahim and Hamzeh 2017). Level of Development (LoD) was created for facilitating the use of BIM as a work process, to formalize the development of BIM models and authorize their possible uses (BIMForum 2018). The expected benefits of using LoD are improved productivity and efficiency in communication – and enhanced development of the model (Hooper 2015).

Due to the current usage of the LoD concept, many researchers and practitioners have raised several concerns about the LoD concept, due to how it is currently understood and used (Abou-Ibrahim and Hamzeh 2016). The Norwegian AEC Industry have made their own LoD framework, called Model Maturity Index (MMI). This framework aims to reduce the uncertainty around LoD and focus on improving the design processes (Fløisbonn et al. 2018). This framework is created as a collaborative effort between architects, consultants and contractors, and is supposed to be an agreed framework for all actors in the AEC Industry.

Achievements of the mentioned benefits could lead to an improved design process through improved utilization of BIM, and thus increased productivity. The literature points out the advantages of using BIM together with LoD. However, the planning of BIM process in the AEC industry with the use of LoD and Lean needs more attention. Therefore, this study will investigate the following research questions:

- **RQ1**: What approaches to model maturity are used or attempted in the Norwegian AEC industry?
- **RQ2**: What experiences do the actors of the AEC industry have towards the use of model maturity?
- **RQ3**: How can model maturity be implemented in an AEC project?

METHODICAL APPROACH

This study is divided into two parts, a literature study and qualitative study. The literature study aims to answer RQ1. RQ2 and RQ3 is answered by using the findings from the qualitative study supported with theory from the literature study.

The literature study was conducted by performing a scoping study, based on five steps made by Arksey and O'Malley (2005). Step 1 was to identify the research questions as presented in the introduction. Step 2 was to identify relevant studies. This was performed through systematic searches in digital databases. There was used different search words and combinations, that had relevance for the research questions. This search results were narrowed down by sorting out articles that wasn't based on the AEC Industry practice. In step 3 the remaining literature was evaluated, the evaluation was based on criteria regarding credibility, objectivity, accuracy and relevance of the article's topic. Furthermore, the remaining articles after the evaluation was used for performing snowballing. Snowballing uses the relevant literature to find more literature, by using the reference list in the article and by identify which articles that has used the article as a reference (Wohlin 2014). Articles that were found through snowballing was evaluated the same way as articles found in the scoping study. The next steps were charting the data, collecting, summarizing and reporting the results.

The qualitative study is based on eight performed semi structured in – depth interviews. The interviewees were chosen based on their experience with the use of BIM and LoD. Seven of the interviewees are employed at different constructors. Respectively the interviewees are three BIM managers, three design managers, one VDC responsible, and one production – and process manager. The last interview object is positioned at a consultant and is a design manager at a project where MMI was implemented. The interviews where recorded, transcribed and analysed. To ensure the rigor of qualitative analysis, the data was analysed by using an constant comparative method (CCM) (Corbin and Strauss 2008; Knotten et al. 2017).

THEORETICAL BACKGROUND

The theoretical background consists of two parts. The first part is about Lean Design management and how to plan the design process. The second part is about the use of model maturity, how it differs from LoD thinking, and how it is used in the Norwegian AEC Industry, answering RQ1.

LEAN DESIGN MANAGEMENT

There are numerous challenges that must be solved in the construction phase, primarily result of an ineffective communication and poor decision-making in the design phase. This results in some degree of uncertainty in the production phase, and this gives the production team little option but to confront the problem Therefore, Lean philosophy, with its focus on minimizing waste and maximizing value, should be applied as early as possible in the design phases to avoid this problem (Emmitt et al. 2004). Based on a literature review El. Reifi and Emmitt (2013) found that it appears to be four themes related to the reduction of waste and the enhancement of value in Lean design management:

- Briefing and client interaction
- Value and value stream mapping
- Lean culture and assembling the team
- Information flow

To ensure improved project quality, enhanced client relations, and savings in time and cost, it is important that requirements are clearly identified, and information must be well managed through the design process. This will lead to a significant improvement in the decision making (El Reifi et al. 2013). The use of BIM together with Lean Design Management can help the design manager ensure these elements. By using BIM, the content of design work can be visualized in a better way. BIM can improve value adding tasks by reducing the number of design cycles and design errors, which leads to faster, smoother and a more economic process. Further this leads to an increased value realization for the costumer (Arayici et al. 2011).

The benefits of using BIM are important to quantify, but it is equally important to identify what to include in BIM to achieve the expected value added by using BIM in a construction project (Leite et al. 2011). Due to, increased use of BIM in the construction industry, certain companies have found communication challenging trying to understand the maturity and reliability across disciplines and companies (Garcia et al. 2018). Tauriainen et al. (2016) recommended specifying the instructions and ways of action which are related to BIM in the beginning of the project and suggests that this is done by using LoD.

To improve the planning in design, Svalestuen et al. (2018) proposed three elements that could help the design manager to success: (1) Increased focus on the schedule during the design process, (2) BIM should be used collaboratively as a communication and development tool, and (3) LoD should be used in the planning process. Concluding, Svalestuen et al. (2018) purposed that the AEC industry should use Collaborative Planning in Design (CPD) and adapt the LoD definition to the context of each project. By using LoD as a planning tool, it could be easier to avoid unnecessary iterations, due to the complex tasks and the dependencies in the early phases of the design (Hamzeh et al. 2009).

Knotten (2018) argued for making a design management strategy and separated the design management process into three stages; an assessment-, initialization- and execution stage. In the assessment stage the design manager assesses the project, its objectives, the available resources and preform a self-evaluation. It is important to evaluate the projects purpose and goal in this stage. The initialization stage consists of planning and organizing the project goals, based on the previous assessment. In this stage it is important to address milestones, decision points and necessary output. The execution stage is about performing what's decided in the two earlier stages. In this stage there must be performed an evaluation of the design management process to see if it is developing as expected. If not, steps need to be taken to re-plan and re-organize in order to achieve the project goals.

MODEL MATURITY

The demand for a metric capable to assess the quality and reliability of the engineering models, has made different markets and regions to create their own guidelines to measure the model maturity (Garcia et al. 2018). Today several metrics are known, such as Level of Model Information (LOI), Level of Detail (LoDt), Level of Development (LoD) and now also Model Maturity Index (MMI). LoD has been criticized for being too advanced and complicated (Nøklebye et al. 2018). This is because LoD only reflects the modelling requirements of an individual object (Abou-Ibrahim and Hamzeh 2017) and therefore it doesn't measure the accuracy of graphical information (Garcia et al. 2018). The big variations in definitions and concepts regarding LoD indicates that the purpose of LoD is not fulfilled (Hooper 2015), and that there is a need for a standardized set of modelling definitions capable to streamline the communication process.

Therefore, the Norwegian AEC industry has created guidelines for how to use MMI as a planning tool for the design process. The MMI is supposed to be a common starting point for the use of model maturity in Norway and the main idea behind the MMI process can be seen in figure 1 (Fløisbonn et al. 2018).

Figure 62: Flow sheet made by Fløisbonn et al. (2018) that should work as a base for a design process using MMI in a Norwegian building project

Today, it is only the contractor Skanska that has taken MMI into use as a business strategy in Norway. Several Lean construction elements are implemented in their approach, such as the combination of Last Planner, BIM and ICE sessions (Fosse et al. 2017). The last element included in their VDC approach is MMI guidelines (Nøklebye et al. 2018).

The approach of using Skanska Norway's MMI strategy in design is: (1) Separate the model into different sections, (2) assign maturity to all geometry, managed by each discipline within each section, (3) coordinate the design team in ICE – sessions utilizing Last Planner for planning and control, (4) create milestones for different sections achieving MMI, and (5) illustrate the achieved MMI milestones by post – it – notes in Last Planner (Nøklebye et al. 2018).

Additionally, metrics for Last Planner (PPC, root cause trends, task completion rate, reliability per trade), BIM clash trends per area according to the MMI plan and ICE session evaluations (session efficiency, team preparations and involvements) is being continuously tracked and visualized on the wall in the Big Room, ensuring transparency and control of the project teams performance (Fosse et al. 2017).

FINDINGS

The findings section is based on the answers from the eight performed interviews of AEC professionals. The first part deals with the findings regarding which experiences the interviewees have made form using MMI, and this parts answers RQ2. The last part is dealing with what the interviewees thinks about the implementation of MMI in a construction project. This part together with the discussion answers RQ3.

EXPERIENCES

The interviewees have several positive experiences regarding the use of MMI. The design managers have experienced improved communication between actors in the design process. MMI offers a common language to communicate expectations, dependencies, interfaces and a way to plan the design process. MMI enhances the expectations for the timing for decision making and this makes it easier to understand when the last responsible moment is, for both the client, user, designer and producer.

According to the interviewees, the design team experienced an increase in inter-disciplinary communication by using MMI. This makes it easier to create a delivery plan for the design process. A more specific delivery plan for the design team, gives a more structured process which prevent unnecessary iterations to appear. Interviewees from the contractor points out, that a more structured design process makes it easier to coordinate with the production team. The effect of this is that the production drawings are finished at the right time, the BIM can therefore be in front of the production and can be used to do calculations and procurement in the production without the production team being uncertain about the reliability of the model.

One interviewee also tried using MMI for performing risk management. By giving the production manager a way to know exactly what's going to change in the model or drawing from one MMI level to the next. This makes it possible to evaluate the risk of performing a task before the production drawings have reached MMI 400.

Some of the interviewed design managers, experienced several challenges when they have started using MMI. First the design managers point out that there is a challenge to know at what MMI level the BIM and drawings are at, when they get the design material after the contract is signed. Because of this, in some project the design manager from the contractor must start the design from scratch and in other projects the design manager uses the delivered material, however uncertainty of the maturity and reliability in the previous BIM. The interviewees point out that this could be improved if all the actors in the AEC Industry used MMI on regular basis.

The last challenge that is pointed out, is the use of MMI on an object level, such as in LoD. The interviewed VDC responsible said that if MMI should be implemented on object level in BIM for each object, this will take so much time that it must be specified in the contract with the designers. Other interviewees also argued for the implementation of MMI at object level will not bring any value to the design process, only extra work.

Implementing Model Maturity Index

Start – up

The importance of a start-up meeting was mentioned by the interviewees as a first step to implement MMI, and they pointed out that the main actors in the design team should be represented. The agenda for the start-up meeting should according to the interviewees be first to create a strategy for the project, defining the project goal and who holds the different roles in the project. Then define the BIM – Use strategy. To set this goal is important to know the design team and their BIM skills. The design manager must evaluate which BIM competence there is in the project. Further, the experience and knowledge about MMI must be evaluated. It is also smart to assess what kind of goal the members of the design team individually have for the project. It is also important to clarify what kind of resources the actors in the design team have available to perform the project.

After deciding the strategy, goals, use of BIM and MMI in the project and the design team har gotten to know each other. As pointed out by the production and process responsible, the design team collaboratively should create the wanted MMI working process for the project. The working process should be customized to each building project, but all the interviewees agreed on that it should be based on the flowsheet from the MMI guidelines presented in figure 1. Discussing the flowsheet collaboratively, will according to interviewees give the team members a common understanding of the working process and ownership of what they are supposed to perform. When the team has agreed on a flowsheet, the next step for the team should be to define the MMI levels for the project.

The MMI levels can be very general or very specific, the interviewees pointed out that this should depend on the project and the team members.

The next step in the start – up meeting according to interviewees is to start considering the deliveries in the project. It was argued that this can be considered as the main job to take MMI into use. Each actor in the design team should define which design activities they shall perform on each MMI level. This practice will create a delivery plan that gives each actor a work package to perform on each MMI level. An example of this is presented in table 1. When creating this table, it is important to think about what do we need to do in this level, and why do we need this to be done at this level?

Table 25: Example of what a delivery plan can look like, this can for example also have a second division under each actor with each building part such as foundation, structure, facade and inner work

MMI	Contractor	Architect	Structural E.	Electrical E.	Plumbing E.	Mechanical E.
100						
200						
300						
350						
400						
500						

Planning the design process

After the start- up meeting it is time to create the design process plan. First, it must be clarified which dependencies there is between the different actors in the process of reaching the MMI levels. This should be done by using a Last Planner System™ tool for example in a post-it-note session. The post-it-note session makes a visual representation of the design plan and the dependencies, it is easy to understand, and the plan can hang on the wall, so all the team members gets reminded of the plan each time they go into the meeting room.

The plan should be made by creating design milestones for the model. The milestones should represent an MMI level. When creating this design plan, it is important that the plan relates to the production plan, so that the design team reach MMI 400 in time for the production to start as planned. A post - it - note plan can turn out to be quite big, so there could be enough to just put the most important design milestones in the plan and create a separate plan for all deliveries in the design process in some sort data program, such as Excel or MS Project.

Based on Lean thinking it is important to update the plan as the BIM develops. The BIM will develop in different places for each actor, but also for different parts of the building. The production team divides the building into smaller pieces for planning the production phase, in planning the design process the same pieces as in production should be used. These pieces could be divided in both zones and systems. This should be defined for each project, but in general a zone could be a floor, a room or a function inside a building, a system will be such as a HVAC system that goes through multiple zones.

Planning by using the same zones and systems as the production will ensure that the production drawings will be finished at the right time.

Table 26: Example of how a post – it - note plan can be formed

Week number	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Milestones										MMI 300		MMI 350		
Contractor												MMI 350		
Architect								MMI 300						
Structural E.							MMI 300					MMI 350		
Mechanical E.										MMI 300		MMI 350		
Electrical E									MMI 300			MMI 350		
Plumbing E.									MMI 300			MMI 350		

Control, measure and evaluation

The interviewees pointed out that there should be performed a control of the performed work, before an actor can move to next MMI level. Some interviewees pointed out that they use a control form that the design actors must deliver to the design manager for approval. If the performed work is satisfying according to what's expected in the MMI level, the design manager signs the scheme and the actor can continue to develop to model.

One design manager presented a way of controlling all deliveries in real time, where the delivered files gets tagged with the representing MMI level. In this way they always track the development, and they have a diagram that is updated automatically which shows the models MMI level. The design manager says that this gives a clear picture over the model maturity and because all files are tagged with an MMI-level, all participants at a project knows if the design material is finished and ready for use.

Some interviewees also played with the idea of using an automatic control in Solibri, using pre-defined rules. For this to work all objects must be marked with the MMI level in their original model. It is commented that with today's data programs the use of MMI on object level will not provide any value for the project.

DISCUSSION AND CONCLUSION

Today, very few actors use MMI in Norway. This may be due to uncertainty regarding use and implementation of MMI. Based on the findings from the theory and interviews, a framework is proposed in figure 2. The framework illustrates a way for implementing MMI in an AEC project and a way to structure the model maturity work in the design process. The framework is divided into three main stages, based on the framework made by Knotten

(2018). The use of the assessment and initialization stage will ensure that the project stakeholders know the project goals, client requirements, and plan and organize the projected based on this. The suggested assessments and initialization in these two stages, will make it easier to utilize the use of BIM, because it is created a common communication language, which is customized to the specific project and the actors of the project. The actor's knowledge and competence regarding the use of BIM, will influence how the MMI language is developed and used.

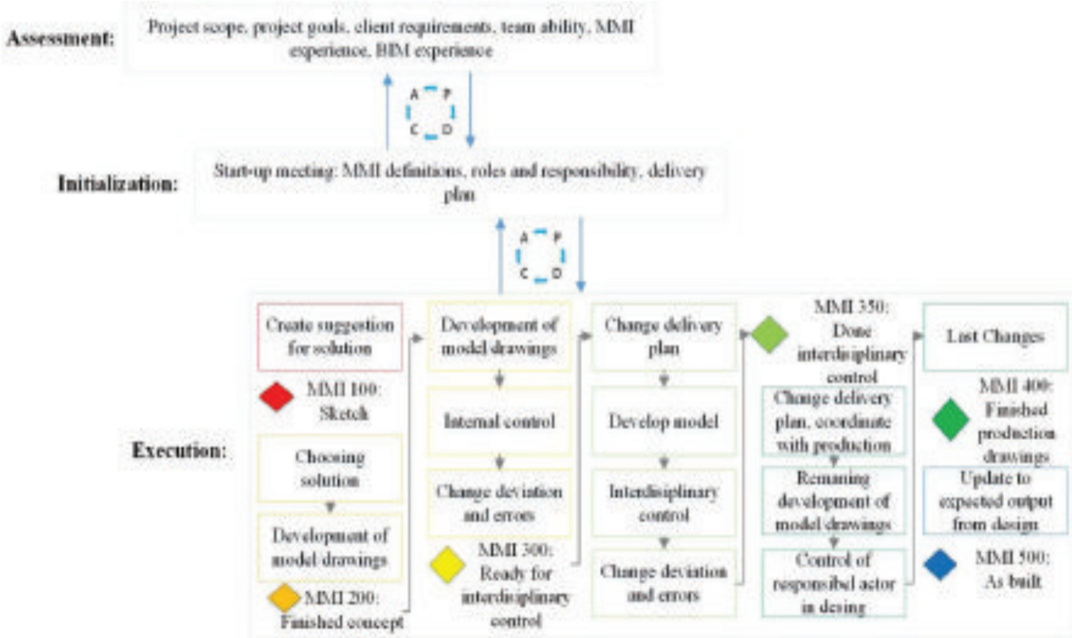


Figure 63: Framework for implementing MMI in a Norwegian building project

Both the initialization and execution stage must be evaluated against the decisions made in stage before. This is illustrated with an PDCA cycle between the stages. The PDCA cycle, also known as Demings cycle, consists of Planning – doing – checking – and acting. The planning is performed in the stage, and then the plans are executed. After or during the execution, there should be performed some sort of check or control. This will ensure that the project is reaching its goal and developing according to the plan made in the previous stage.

The flowsheet in the execution stage is based on the presented flowsheet in figure 1 and findings from interviews, and is developed with inspiration from a framework for the use of LoD created by Hooper (2015). The flowsheet presents activities that needs to be addressed in order to achieve the next MMI. The execution stage focuses on controlling and correcting (Act) the planning and doing of the previous stages. Figure 2 shows which controls should be performed at each MMI level, and that any deviations and errors that occurs must be corrected before the design team can reach the next MMI level. To reach a new MMI level, a BIM – coordinator or the design manager should approve that the expected work in the MMI level is performed and approved. After getting the approval of reaching a new MMI level, the design team can continue with developing the BIM according to the work packages decided for that specific MMI level. This working method will ensure continuous improvement, because a control between each level will make problems clear and there will be possible to correct errors before they are passed on. A control will also align the design progress in the BIM with the plan, and the delivery plan can be updated if necessary. This will support a leaner design-process, by removing unnecessary iterations and errors.

The framework with the flowsheet can be used in all contract forms and it doesn't matter which actor brings MMI into the project. It is a huge advantage if MMI gets implemented as soon as possible in the project, to ensure that the design members get an ownership to the working method and communication language. It can be argued that the development from MMI 0 to MMI 200 is missing some details in the flowsheet. The reason for this is that the guidelines created by Fløisbonn et al. (2018) is based on a need from the contractors in the detailed design phase. Therefore, it needs research into the early stages of design. Defining MMI in more detail up to MMI 200, will create a more structured process and give the design team better guidelines to work by.

This research is conducted in the Norwegian AEC Industry and based on Norwegian guidelines; however, the authors believe that the framework and flowsheet is applicable for international AEC projects as well. The framework is generic and needs to be incorporated in the project strategy, and the focus is the improvement of the design process. The design process is almost the same in all countries, as it is almost the same in all contract forms. Using this framework together with LoD will work just as well, because the main point is to improve the design process and not the graphical detail level in the BIM.

REFRENCES

Abou-Ibrahim, H., and Hamzeh, F. (2016). "Enabling lean design management: An LOD based framework." *Lean Construction Journal*, 2016, 12-24.

Abou-Ibrahim, H., and Hamzeh, F. "Design Management: Metrics and Visual Tools." *Proc., 25th Annual Conference of the International Group for Lean Construction*Heraklion, Greece, 465-473.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., and O'Reilly, K. (2011). "Technology adoption in the BIM implementation for lean architectural practice." *Automation in Construction*, 20(2), 189-195.

Arksey, H., and O'Malley, L. (2005). "Scoping studies: Towards a methodological framework." *International Journal of Social Research Methodology: Theory and Practice*, 8(1), 19-32.

BIMForum (2018). "Level of Development (LOD) Specification Part 1 and Commentary."

Bølviken, T., Gullbrekken, B., and Nyseth, K. "Collaborative design management." *Proc., Challenging Lean Construction Thinking: What Do We Think and What Do We Know? - 18th Annual Conference of the International Group for Lean Construction, IGLC 18*, 103-112.

Corbin, J. M., and Strauss, A. L. (2008). *Basics of qualitative research: techniques and procedures for developing grounded theory*, Sage, Thousand Oaks, Calif.

El Reifi, M. H., Emmitt, S., and Ruikar, K. "Developing a conceptual lean briefing process model for lean design management." *Proc., 21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013*, 325-334.

El. Reifi, M. H., and Emmitt, S. (2013). "Perceptions of lean design management." *Architectural Engineering and Design Management*, 9(3), 195-208.

Emmitt, S., Sander, D., and Christoffersen, A. K. "Implementing value through lean design management." *Proc., IGLC*.

Fløisbonn, H. W., Skeie, G., Uppstad, B., Markussen, B., and Sunesen, S. (2018). "MMI - Modell Modenhets Indeks." <http://eba.no/globalassets/dokumenter/mmi-utvalget/mmi-modell-modenhets-indeks.pdf>. (14.11, 2018).

Fosse, R., Ballard, G., and Fischer, M. "Virtual design and construction: Aligning BIM and lean in practice." *Proc., IGLC 2017 - Proceedings of the 25th Annual Conference of the International Group for Lean Construction*, 499-506.

Garcia, G., Golparvar-Fard, M., De La Garza, J. M., and Fischer, M. "Model maturity risk index framework for tracking progress in model-based engineering." *Proc., Construction Research Congress 2018: Construction Project Management - Selected Papers from the Construction Research Congress 2018*, 42-52.

Hamzeh, F. R., Ballard, G., and Tommelein, I. D. "Is the Last Planner System applicable to design? A case study." *Proc., 17th Annual Conference of the International Group for Lean Construction, IGLC17, July 13, 2009 - July 19, 2009*, National Pingtung University of Science and Technology, 165-176.

Hooper, M. (2015). "Automated model progression scheduling using level of development." *Construction Innovation*, 15(4), 428-448.

Knotten, V. (2018). "Building design management in the early stages." Degree of Philosophiae Doctor, NTNU, Trondheim.

Knotten, V., Hansen, G. K., Svalestuen, F., and Lædre, O. "Learning across disciplines - Use of the Constant Comparative Method." *Proc., Proceedings of the 9th Nordic Conference on Construction Economics and Organizations*, 273-284.

Leite, F., Akcamete, A., Akinci, B., Atasoy, G., and Kiziltas, S. (2011). "Analysis of modeling effort and impact of different levels of detail in building information models." *Automation in Construction*, 20(5), 601-609.

Nøklebye, A., Svalestuen, F., Fosse, R., and Lædre, O. "Enabling lean design with management of model maturity." *Proc., IGLC 2018 - Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers*, 79-89.

Sacks, R., Koskela, L., Dave, B. A., and Owen, R. (2010a). "Interaction of lean and building information modeling in construction." *Journal of construction engineering management*, 136(9), 968-980.

Svalestuen, F., Knotten, V., Lædre, O., and Lohne, J. (2018). *Planning the Building Design Process According to Level of Development*.

Tauriainen, M., Marttinen, P., Dave, B., and Koskela, L. (2016). "The Effects of BIM and Lean Construction on Design Management Practices." *Procedia Engineering*, 164, 567-574.

Wohlin, C. "Guidelines for snowballing in systematic literature studies and a replication in software engineering." *Proc., ACM International Conference Proceeding Series*

Styrvold, M., Knotten, V., and Lædre, O. (2019). "Planning the BIM Process in AEC Projects." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 527–538. DOI: https://doi.org/10.24928/2019/0208. Available at: <www.iglc.net>.

Daniel, E.I, Garcia, D, Marasini, R., Oshodi, O. (2019). "Improving Construction Management Practice in the Gibraltar Construction Industry." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 539–540. DOI: https://doi.org/10.24928/2019/0227. Available at: <www.iglc.net>.

IMPROVING CONSTRUCTION MANAGEMENT PRACTICE IN THE GIBRALTAR CONSTRUCTION INDUSTRY

Emmanuel I. Daniel[1], Daniel Garcia[2], Ramesh Marasini[3], Shaba Kolo [4], and Olalekan Oshodi[5]

ABSTRACT

Research has shown that 57% of activities in a construction project is non-value adding (waste) which contributes to the poor performance of the sector. While other countries of the world such the USA, UK, Brazil, Nigeria and Israel among others are seeking to understand this challenge and deploy innovative ways and modern techniques to improve it, limited studies have explored factors that contribute to non-value adding activities (NVA) in the Gibraltar construction industry. The current study aims to identify the factors that contribute to NVA on construction sites in Gibraltar and to present an outlook on how this could be minimised using Last Planner System(LPS).

A combination of quantitative and qualitative research approaches was used. Thirty-one questionnaire responses were analysed and seven semi-structured interviews were conducted. The investigation reveals that the development of unrealistic schedules, lack of adequate training, delayed approval process and work interruption due to the community are the key factors that contribute to NVA. The study found that the suggestions offered by construction professional for minimising NVA align with some LPS principles. The study concludes that some of the current practices, could serve as justification for the introduction of LPS in the construction sector of Gibraltar.

KEYWORDS

Last planner system, non-value adding activities, waste, workflow, Gibraltar.

INTRODUCTION

The construction industry is characterised with low productivity. In the existing literature, it was revealed that productivity has been growing at 1% every year and the efficiency of

[1] Lecturer, Department of Construction Management and the Built Environment, Solent University, Southampton. UK. emmanuel.daniel@solent.ac.uk

[2] BSc(Hons) Graduate, Department of Construction Management and the Built Environment, Solent University, Southampton, UK. dangarcia.official@gmail.com

3 Associate Professor, Department of Construction Management and the Built Environment, Solent University, Southampton. UK. ramesh.marasini@solent.ac.uk

4 Lecturer, Department of Construction Management and the Built Environment, Solent University, Southampton. UK. shaba.kolo@solent.ac.uk

[5] Post-Doctoral Research Fellow, University of Johanesburge, South Africa. os.oshodi@gmail.com

workers is about 40% in the construction sector (Prabhu & Ambika, 2013). The common causes of low productivity include mismanagement of construction materials, design errors, communication problems and inexperience of project team members, among others (Dai et al., 2007; Naoum, 2016). Based on the causes of low productivity, it is evident that poor management of site activities and pre-construction phase are the main reasons for low productivity.

While other countries of the world such the USA, UK, Brazil, Nigeria and Israel are seeking to understand this challenge and deploy innovative and modern management techniques such as Lean Construction, Building Information Modelling,and Offsite Construction to minimise wasteful processes (Khosrowshahi and Arayici,2012), the situation in Gibraltar is yet to be known. Gibraltar is a British Overseas Territory with a population of 34,571 people (Worldmeter, 2019). The Ministry for the Environment Government of Gibraltar report (2013) confirms that the waste in the Gibraltar construction industry is difficult to measure. The wastes considered in the report include both physical and process wastes. There is a lack of studies that explore factors contributing to wasteful processes (non-value adding activities) in the Gibraltar construction industry.

The term "non-value adding activities (NVA)" and "waste" is used interchangeably in this study. Waste in this study is limited to process waste. This study aims to identify the factors that contribute to non-value adding activities (waste) on the construction sites in Gibraltar and to present the prospect of minimising it through the use of Last Planner System (LPS). The LPS is a lean construction technique that focuses on supporting the flow of work through the project, builds trust and collaboration with a workforce and delivers a task safely (Ballard, 2000). From studies, the implementation of lean construction techniques such as the LPS has positive outcomes in construction process improvement and minimise waste (Fernando-Solis et al., 2012; Alarcon et al., 2011).

LITERATURE REVIEW

LEAN CONSTRUCTION AND THE CONCEPT OF WASTE

Waste in construction is defined in various ways. From a lean construction perspective, waste is any process that incurs a cost but does not add value to the project (Koskela, 2000). Waste occurs as a result of overproduction, waiting, inventory, defect, movements, processing and transportation (Alarcon, 1997; Shingo, 1998). Abdelrazig (2015) identified three more categories of waste which are time, people and bureaucracy.

Waste is also referred to as NVA and is defined as an "activity that takes time, resources or space but does not add value to a project" (Zhao & Chua, 2003). According to Koskela, (2000) value-adding activities convert material and information to the output which is required by the customer. Zhao and Chua, (2003) found that NVA is usaually influence by the work environment factors and project related factors. Examples of the project related factors are project features, design features among others while example of work environment features include equipment condition, sequencing, information among others. Additionally, Koskela, (2000) identified three factors that contribute to NVA which include; the structure of the production system, the way the production is controlled and the nature of the production system. All these shows the importance of paying attention to the designing of the production system so as to minimise the incidence of NVA on site.

However, only limited activities in the construction industry are value adding. Nagapan et al., (2012); Zhao and Chua, (2003) found that non-value adding activities could arise from poor site management, lack of adequate training, inadequate planning, unrealistic schedules, mistakes and errors in design, mistakes during construction, incompetent sub-contractor, rework and lack of coordination between parties. Diekmann et al. (2004) found from their study that 57% of activities in the construction industry is NVA; 33% support activity and 10% value adding. However, in the manufacturing sector, 62% of activities are value adding. This emphasises the need for the construction industry to improve by minimising NVA using an innovative approach like lean construction. Ingle and Waghmare (2015), found that the implementation of lean techniques in construction projects reduces the wastes generated from the traditional construction practices.

LAST PLANNER SYSTEM

The Last Planner System (LPS) is a technique within lean construction that focuses on supporting a smooth workflow through the development of collaborative relationship among project stakeholders (Ballard and Tommelein, 2017; Daniel et al., 2017; Ballard & Zabelle, 2000). The LPS consist of twelve interrelated principles (Ballard and Tommelein, 2016). Rusell et al., (2015); Gonzalez et al., (2010); Wambeke et al., (2011) found that the LPS supports the development of a reliable plan, reduce variation in a project, improve project performance because of its integrated approach. However, it should be noted that the benefits of LPS can only be achieved by utilising the main components in the LPS technique, which consists of master scheduling, phase scheduling, lookahead planning, weekly work planning (WWP), measurement and learning (Ballard and Tommelein, 2016).

Lindhard and Wandahl (2013) claim that the master schedule consists of uncertain variables, owing to the unpredictable the nature of a construction processes. However, this identifies the activities that should be accomplished and reveals milestones within a project (Ballard & Howell, 1994). Phase scheduling is known to be the “link between work structuring and production control” (Ballard & Howell, 2003). It ensures a thought through sequence and structure of work with different trades (Ballard & Zabelle, 2000)

The look-ahead and make-ready planning process identifies and removes constraints to the planned task sufficiently before its execution. The look-ahead planning is usually done within the 6 - 8 weeks window. The make-ready element focuses on ensuring smooth workflow during production activities on site by ensuring the identified constraints are removed (Koskela, 2000). However, Daniel et al., (2017) found that there seems to be a reluctance in implementing make-ready planning during the LPS implementation.

The WWP aims to identify scheduled commitments that would be completed the subsequent week, which creates an efficient workflow on projects (Koskela, 1999). It ensures only activities that are well sized, sequenced and sound are sent into the work phase. The last and the most crucial element of the LPS is measurement and learning. The measurements of percent plan complete (PPC) and the investigation of the reason for non-completion of tasks provide learning and improvement opportunity for the team on the project (Ballard, 2000). Learning in the LPS is made possible because production planning and production control form an integrated approach.

RESEARCH METHOD

A mixed research design that uses quantitative and qualitative approaches was adopted for the study. The quantitative method allowed research participants to rate the factors that contribute to NVA in the context of Gibraltar construction industry. A questionnaire survey was adopted as it enables the study to reach a large number of participants (Naoum, 2013). In addition, the interviews were used to collect the views and opinions of the research participants on the effective ways of minimizing NVA that they observed whilst working in Gibraltar rather than relying on information available in literature alone (Creswell, 2007).

RESEARCH DESIGN

A review of literature was done to identify the factors responsible for NVA. These factors were used to develop the survey instrument. The 11 factors that contribute to NVA identified from the literature review include; poor site management, lack of adequate training, inadequate planning, unrealistic schedules, mistakes and errors in design, mistakes during construction, incompetent sub-contractor, rework and lack of coordination between parties (Nagapan et al., 2012). Furthermore, to understanding the current practice that shows some resemblance with the LPS principles in Gibraltar, the concept of Last Planner Thinking introduced in Daniel et al, (2014) was used. According to Daniel et al, (2014), Last Planner Thinking are practices that show some resemblance with some of the LPS principles which could serve as a platform for implementing the LPS. Some of these practices include having weekly site meetings, identification of constraints, having coordination meetings among others (Daniel et al., 2014). The survey was designed with three sections. Section one focused on the background information of the respond2ents. Section two sort to identify how the eleven factors contribute to NVA in the Gibraltar construction industry on a five-point Likert scale. In section three, the respondents were asked to rate how often the identified Last Planner Thinking practice was observed in construction sites in Gibraltar. An open-ended semi-structured interview was used to gather evidence on how the NVA observed on the construction sites in Gibraltar could be minimised.

DATA COLLECTION AND ANALYSIS

The questionnaire was hosted online for three months using the SurveyMonkey®. The link was emailed to the prospective respondents and placed on other social media platforms meant for construction professionals in Gibraltar. According to HR Government of Gibraltar (2017), the population of the construction industry was 3,407. Based on this, a sample size calculator was used to determine the sample size for the study. With a confidence level of 90% and a margin of error of 10%, the sample size was determined to be Sixty-seven. However, it is important to note that over half of the population are frontier workers (HR Government of Gibraltar, 2017). Thirty-one responses were received from the questionnaire survey and this represented over 45% of the sample size. Seven semi-structured interviews were conducted and this number was deemed to be sufficient as no new issues were emerging after seven interviews which meant data saturation could have been attained (Francis et. al., 2010). The focus of the interview was to enable the respondent shed light on how the identified NVA could be minimised. The quantitative data were analysed using SPSS (V 23.0.0.0) while the qualitative data were analysed using thematic analysis. The participants who took part in the study included: project managers, directors, estimators, architects, construction managers, engineers, quantity surveyors and site managers, which shows the diverse range of professionals working in the construction industry in Gibraltar and justifies the validity of the study.

RESULTS AND DISCUSSION

RESPONDENT BACKGROUND INFORMATION

The respondents surveyed consisted of '29% Construction Managers', '23% Quantity Surveyors', '19% Project Managers', '13% Site Managers', '3% Technical Officer', '3% Chief Operations Officer', '3% Electrical Sub-contractor' and '3% Engineers'. The results suggest that the responses received cut across the relevant stakeholders who are involved in analysing the performance of a project and decision making on a day-to-day basis on a project. Furthermore, majority of the respondent have over 10 years experience in the construction industry. This showed the respondents have a sufficient experience in the construction industry in Gibraltar, and thus their response would be reliable.

FACTORS THAT CONTRIBUTE TO NON-VALUE ADDING ACTIVITIES ON CONSTRUCTION SITE IN GIBRALTAR

The results, as shown in Table 1, revealed the three top factors as: 'unrealistic schedules with a weighted average of 1.87', 'lack of adequate training with a weighted average of 2.19' and 'a delayed approval process with a weighted average of 2.45'. Mcgevna (2012) argues that scheduling is one of the most critical aspects of planning in a project. This means the introduction of the Last Planner System into the Gibraltar construction industry could minimize the most contributing factor to NVA currently observed on construction sites. According to Russell et al., (2015); Wambeke et al., (2011) and Ballard, (2000), the implementation of LPS focuses on reducing uncertainty which is inherent in the traditional approach to project management. There is a consensus that all the factors listed in Table 1 contribute to NVA on construction sites in Gibraltar, suggesting that considerations should be given to all 11 NVA factors.

Furthermore, the respondents identified a lack of adequate training as the second topmost factor which contributes to non-value adding activities (Waste). This factor was expected to have a high contribution in the beginning of the study, as Gibraltar's construction industry consists of cross-employment between Spain and unqualified workers. Contractors adopt this strategy in order to reduce labour costs in a project. However comparing this finding with previous studies on factors that contributes to NVA (Nagapan et al., 2012; Daniel et al., 2014), interruption from the local seems to be peculiar to the Gibraltar construction industry. This shows the need to pay attention to social value delivery in construction projects.

Table 1: Ranking of Factors that Contribute to NVA on Construction site in Gibraltar

Contributing Factors to NVA	Frequency	Weighted Average	Ranking
'Unrealistic schedule'	31	1.87	1
'Lack of training'	31	2.19	2
'Delayed approval process'	31	2.45	3
'Work interruption due to community'	31	2.58	4
'Poor site layout'	31	2.65	5
'Miscommunication between the workforce'	31	2.71	6
'Disagreements between contractors subcontractors and client'	31	2.71	7
'Lack of resources'	31	2.73	8
'Lack of team work'	31	2.74	9
'Delay payment'	31	2.77	10
'Lack of flow in construction'	31	2.84	11

Social value is what a community receives from an organisation from the execution of its business (Hunter, (2014). Conversely, when the organisation fails to give back to the community it could lead to conflict. Daniel and Pasquire, (2019) argued that construction organisations should consider the local community around their project as customers, this would enable them to be committed to improve the quality of life of the community around the project.

LAST PLANNER THINKING IN THE GIBRALTAR CONSTRUCTION INDUSTRY

To understand the concept of Last Planner Thinking in the context of Gibraltar, the respondents were required to identify current Last Planner Thinking practices on a five points Likert scale where one is very often and five is never. The study found that the 'identification of constraints' before any task is commenced and the 'holding of weekly coordination meetings' are common practices. This finding aligns with a similar study conducted in Nigeria where a weekly meeting was also reported to be observed often (Daniel et al., 2014). However, the occurrence of weekly meetings observed in both studies may be primarily due to its inclusion in the traditional contract. It could be argued that such weekly site meetings may not necessarily serve as a platform for collaboration as expected in the Last Planner System and are used for a limited scope.

Traditionally, weekly site meeting is more of an opportunity for subcontractors to receive instructions rather than make input into the decisions. Foley and Macmillan (2005) found that during a team meeting the input from subcontractors is only 2%. It is no surprise therefore, as shown in Figure 1, the managers rarely allow subcontractors to make input during the decision-making process in the Gibraltar construction industry. This is a dominant practice in the traditional approach to project management.

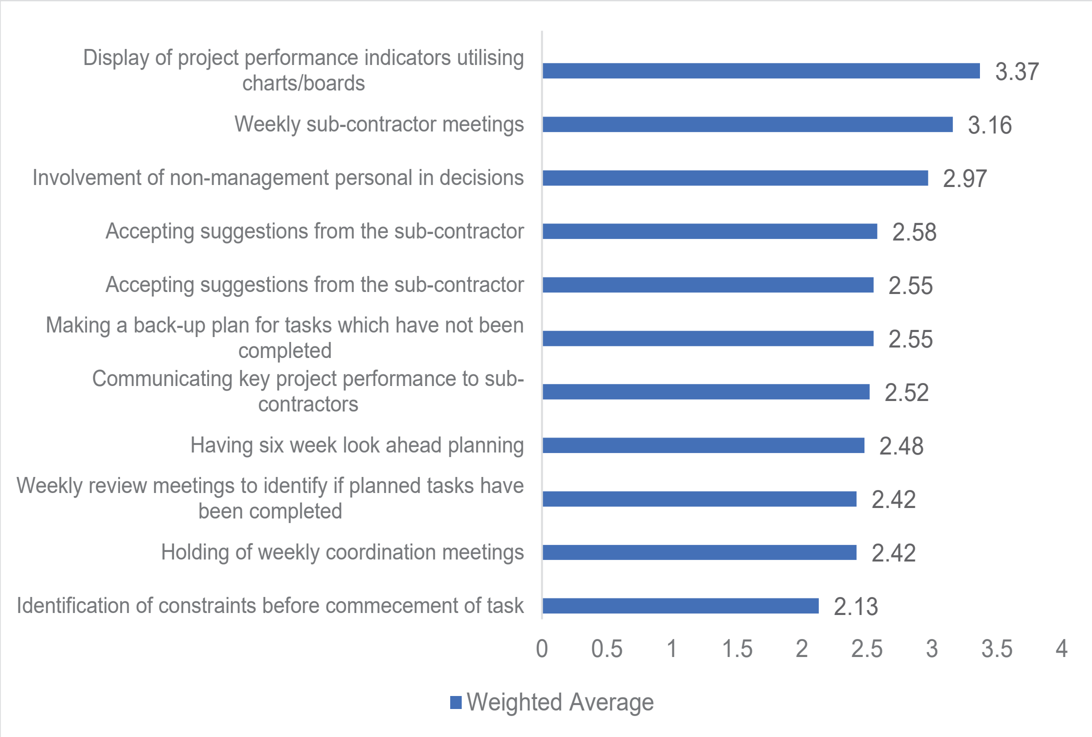


Figure 1 indicates some Last Planner Thinking within the Gibraltar construction industry.

In contrary, the LPS empowers the project stakeholders to make a promise of what they can do during the WWP (Ballard, 2000). While the current weekly site meeting may not necessarily follow the LPS principles completely, it could serve as a platform to implement LPS WWP principles. Furthermore, the practice of identification of constraint before the commencement of a task could serve as a foundation for make-ready planning practice in implementing the LPS in Gibraltar. The make-ready process enables the team to collaboratively identify constraint and implement a strategy for eliminating the constraint for a smooth workflow (Ballard and Tommelein, 2017).

The results highlight that ‘display of project performance indicators', ‘weekly sub-contractor meetings' and ‘involvement of non-management personnel in decision making' are the three least practised on sites in Gibraltar. This indicates there is no much collaboration between the sub-contractor and management which could negatively influence the implementation of the core principles of the LPS in the construction sector of Gibraltar. One of the core principles of the LPS is to allow the people who would do the work to be involved in the planning (Ballard and Tommelein, 2017). The non-involvement of the subcontractors in the decision and planning process would defeat the purpose of implementing the LPS. The current practice in Gibraltar could have been influenced by culture (Temple, 2016). Studies have shown that culture is an important issue to consider in the implementation of lean generally and the implementation of the LPS in particular (Johansen and Porter, 2003). In implementing the LPS in the Gibraltar construction industry, significant attention should be given to the cultural issues such as the outright sidelining of subcontractors from the decision-making process on site.

How to Minimise Non-Value-Adding Activities on Construction site in Gibraltar

The respondents were asked to suggest how non-value adding activities (Waste) could be minimised in Gibraltar's construction industry. Figure 2 shows the emerging themes from the analysis. It is evident that in addition to pre-planning and adequate training, most of the suggestions revolved around developing an active communication network and collaboration with the different stakeholders in the project. Some of the respondents stated that: *"In Gibraltar, proper training, planning ahead and communications between all parties involved in the projects would help to deliver the project effectively"* ***[R05 Construction Director]*** *"Allow all parties to meet regularly to discuss any occurrences that may be stopping the project from evolving"* ***[R01 Project Manager]*** "*Continued progress and coordination meetings with management/subcontractors and site foreman working hands in hands, so information has less of a chain to feed back to the workers*"**[R04 Electrical subcontractor]**

Again, all these shows the central role clear communication and active collaboration plays in minimising NVA on a construction project.

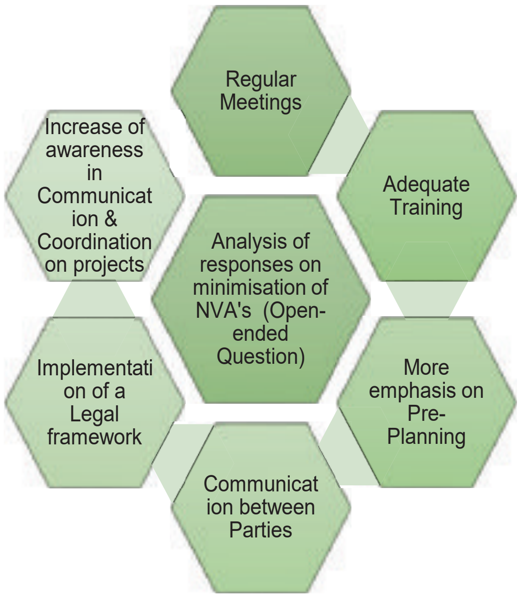


Figure 2: How to Minimise Non-Value Adding Activities on Construction site in Gibraltar

Construction management researchers have consistently argued communication breakdown between the various stakeholders on a project is one of the major contributors to project failure (Murray et al., 2007). For instance, poor communication between the construction manager, work package contractors and the client was responsible for both cost and time overrun in the case between Great Eastern Hotel and John Laing (Donohoe and Brooks, 2007). However, the LPS supports the development of collaborative conversation among different stakeholders on a construction project which supports effective and clear communication in a complex project environment (Rusell et al., 2015; Gonzalez et al., 2010). Arguably, the application of the LPS principles has the potential to address some of the suggestions for minimising NVA in Gibraltar made by the respondents as shown in Figure 2. For instance, the phase planning, lookahead planning, WWP and measure and learning in the LPS could address issues such as 'more emphasis on pre-planning' and 'regular meeting', project coordination' and communication between parties. This implies the use of the LPS could minimise the incidence of NVA in the Gibraltar construction industry. However, some of the respondent also believed that focusing on the critical activities would enable them develop reliable programmes. One of the respondent stated that: *"Identifying the critical activities would support the development of a clear and concise program"**[R07 Construction Manager].*** This view is contrary to the principles of Last Planer System where the focus is in understanding the interface between the different stakeholders that would be doing the work. This could mean the traditional approach is the dominant practice among the construction practitioners in the Gibraltar construction industry.

CONCLUSIONS

The current study aimed to identify the factors that contribute to non-value adding activities (waste) on the construction sites in Gibraltar and to present an outlook on how this could be minimised through the Last Planner System. The study found that the topmost factors that contribute to NVA in the Gibraltar construction industry include the development of unrealistic schedules, lack of adequate training, delayed approval process and work interruption due to the community. Although the factors that contribute to NVA in Gibraltar is not entirely different from those reported from other countries, the interruption from the local communities seems to be peculiar to Gibraltar construction context and this shows the need to pay attention to social value delivery in construction projects.

The investigation found that there are practices within the Gibraltar construction industry that mirror the Last Planner System thinking which include identification of constraints before commencement of tasks, having weekly coordination meetings and weekly review meeting. However, the current practice is not only rooted in the traditional approach to project management, but it is also unsystematic. For instance, subcontractor inputs were not considered in such meetings. Nevertheless, the current practice could serve as in route for introducing the LPS into the Gibraltar construction industry.

The study found that the suggestions offered by construction professional in the Gibraltar construction industry for minimising NVA such as an emphasis on pre-planning, regular meeting, better communication with the stakeholders, increase of awareness in communication & coordination on projects align with some LPS principles. This suggests the introduction of LPS has a significant potential to minimise NVA in Gibraltar. However, the top-down approach with the non-involvement of the subcontractor by the management in the decision making is seen as key a barrier. Thus, ways of involving subcontractors in the decision making should be identified and managed effectively during the introduction of the LPS into the Gibraltar construction industry. The current finding is based on the perception of the construction professionals; the actual implementation LPS could reveal more contextual issues in Gibraltar.

REFERENCE

Alarcon, L., 1997. *Lean Construction*. Print Edition ed. Rotterdam: A A Balkema

Abdelrazig, Y.E., (2015). Using lean techniques to reduce waste and improve performance in municipal construction project delivery. The University of Texas at Arlington.

Alarcón, L.F., Diethelm, S., Rojo, O. and Calderón, R., 2011. Assessing the impacts of implementing lean construction. *Revista ingeniería de construcción,* 23(1), pp.26-33.

Ballard G. and Zabelle T. (2000). "Lean Design: Process, Tools, & Techniques" White Paper #10, Lean Construction Institute.

Ballard, G. and Howell, G. (1994) Implementing lean construction: stabilizing work flow, *in Proceedings of the 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G., (2004). Competing construction management paradigms. *Lean Construction Journal*, 1(1), 38-45.

Ballard, H. G. (2000), *The Last Planner System of Production Control*. PhD. Thesis, University of Birmingham, Birmingham UK.

Creswell, J. (2013). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks: SAGE Publications.

Dai, J., Goodrum, P. M., & Maloney, W. F. (2007). Analysis of craft workers' and foremen's perceptions of the factors affecting construction labour productivity. *Construction Management and Economics*, 25(11), 1139-1152.

Daniel, E. and Pasquire, C. , 2019. Creating social value within the delivery of construction projects: the role of lean approach. *Engineering, Construction and Architectural Management*.

Daniel, E.I. , Pasquire, C. & Ameh, O.J. 2014, 'The Magic of the Last Planner® System for Nigerian Construction' In:, Kalsaas, B.T., Koskela, L. & Saurin, T.A., *22nd Annual Conference of the International Group for Lean Construction*. Oslo, Norway, 25-27 Jun 2014. pp 605-616

Daniel, E.I., Pasquire, C., Dickens, G. and Ballard, H.G., (2017). The relationship between the Last Planner® System and collaborative planning practice in UK construction. *Engineering, Construction and Architectural Management*, 24(3), pp.407-425.

Dave, B., Hämäläinen, J-P., and Koskela, L., (2015). "Exploring the recurrent problems in the Last Planer implementation on construction projects. *In: Proc. Indian Lean Const. Conference*, Mumbai, India.

Diekmann, J. E, Krewedl, M., Balonick, J., Stewart, T., and Won, S. (2004) *Application of Lean Manufacturing Principles to Construction,* Construction Industry Institute, Report No.191

Donohoe, S. and Brooks, L., 2007. Reflections on construction management procurement following Great Eastern Hotel Company v. John Laing. *Construction Management and Economics,* 25(7), pp.701-708.

Fernandez-Solis, J. L., Porwal, V., Lavy, S., Shafaat, A., Rybkowski, Z. K., Son, K., and Lagoo, N. (2012). “Survey of motivations, benefits, and implementation challenges of last planner system users”. *Journal of Construction Engineering and Management,* 139(4), 354-360.

Foley, J. and Macmillan, S., 2005. Patterns of interaction in construction team meetings. *CoDesign,* 1(1), pp.19-37.

Francis, J. J., Johnston, M., Robertson, C., Glidewell, L., Entwistle, V., Eccles, M. P., & Grimshaw, J. M. (2010). What Is an Adequate Sample Size? Operationalising Data Saturation for Theory-Based Interview Studies. *Psychology and Health, 25*(10), 1229-1245. doi:10.1080/08870440903194015

González, V., Alarcón, L.F., Maturana, S., Mundaca, F. and Bustamante, J., (2010). “Improving planning reliability and project performance using the reliable commitment model”. *Journal of Construction Engineering and Management,* 136(10), pp.1129-1139.

Halligan, D.W., Demsetz, L.A., Brown, J.D. and Pace, C.B., (1994). Action-response model and loss of productivity in construction. *Journal of Construction Engineering and Management,* 120(1), pp.47-64.

HM Governemnt Gibraltar (2017). Employment 2017 | Government of Gibraltar. [online] Available at: https://www.gibraltar.gov.gi/new/statistics-topic-area/2017/employment [Accessed 15 Feb. 2019].

Hunter, M. (2014), “Social enterprise is good for design, Design Council”.[Online] Available at: http://www.designcouncil.org.uk/news-opinion/social-enterprise-good-design [Accessed: 09 March 2017].

Ingle, A. & Waghmare, A. P., 2015. Advances in Construction: Lean Construction for Productivity enhancement and waste minimization. *International Journal of Engineering and Applied Science*, 2(11), pp. 19-23.

Khosrowshahi, F. and Arayici, Y., 2012. Roadmap for implementation of BIM in the UK construction industry. *Engineering, Construction and Architectural Management*, 19(6), pp.610-635.

Koskela, L. J., Stratton, R., and Koskenvesa, A. (2010). “Last Planner and critical chain in construction management: comparative analysis”. *In Proceedings of the 18th Annual Conference of the International Group for Lean Construction*, National Building Research Institute, Technion-Israel Institute of Technology, 538-547

Koskela, L., 2000. An Exploration towards a *production theory and its application to construction*, Finland: VTT Publications.

Lindhard, S., and Wandahl, S.(2013). Looking for Improvement in the Last Planner System: Defining Selection Criteria. *In ICCREM @ Construction and Operation in the Context of Sustainability*, 27-35. ASCE.

McGevna, V., 2012. The Importance of a Realistic Schedule. [Online] Available at: http://www.pmsuccess.com/Articles/Importance_of_Realistic_Schedule.pdf[Accessed 25 April 2018].

Merrell, J. M., 2016. 6 Ways to Leaders Can Improve Employees’ Quality of Work and Life. [Online]. Available at: https://workology.com/6-ways-to-leaders-can-improve-employees-quality-of-work-and-life/[Accessed 26 April 2018].

Murray, M., Dainty, A. and Moore, D., 2007. *Communication in construction: Theory and practice.*London: Routledge.

Nagapan, S., Rahman, I.A., Asmi, A., Memon, A.H. and Zin, R.M., 2012. Identifying causes of construction waste–case of Central Region of Peninsula Malaysia. *International Journal of Integrated Engineering*, 4(2).

Naoum, S. G. (2016). Factors influencing labor productivity on construction sites: A state-of-the-art literature review and a survey. *International Journal of Productivity and Performance Management,* 65(3), 401-421.

Naoum, S., 2012. *Dissertation research and writing for construction students*. London: Routledge.

Prabhu, G. P. & Ambika, D., 2013. Study on the behaviour of workers in the construction industry to improve production efficiency. *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development*, 3(1), pp. 2249-6866.

Russell, M.M., Liu, M., Howell, G. and Hsiang, S.M., (2014). "Case studies of the allocation and reduction of time buffer through use of the last planner system". *Journal of Construction Engineering and Management,* 141(2), p.04014068.

Shingo, S., 1988. *Non-stock production: the Shingo system of continuous improvement.* USA: CRC Press.

Temple, G., (2016). Medieval practices in the construction industry. [Online] Available at: http://gibraltarpanorama.gi/14775/243114/a/medieval-practices-in-the-construction-industry [Accessed 25 April 2018].

Wambeke, B.W., Liu, M. and Hsiang, S.M., 2012. Using last planner and a risk assessment matrix to reduce variation in mechanical related construction tasks. *Journal of Construction Engineering and Management,* 138(4), pp.491-498.

Woetzel, J., Sridhar, M. & Mischike, J., 2017. The construction industry has a productivity problem — and here's how to solve it. [Online] Available at: https://www.marketwatch.com/story/the-construction-industry-has-a-productivity-problem-and-heres-how-to-solve-it-2017-03-04 [Accessed 25 April 2018].

Worldmeter, (2019). Population of Gibraltar (2019 and historical). [Online]. [Available at: http://www.worldometers.info/world-population/gibraltar-population/]. [Accessed: 12 Feb. 2019]

Zhao, Y. and Chua, D.K., 2003. Relationship between productivity and non value-adding activities. *In Proceeding of the 11th annual conference of the international group for lean construction,* Blacksburg, Virginia, USA.

Matthias Helgi Gardarsson, Ola Lædre, and Fredrik Svalestuen (2019). "Takt Time Planning in Porsche Consulting, The Boldt Company and Veidekke". In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 551–562. DOI: https://doi.org/10.24928/2019/0232. Available at: <www.iglc.net>.

TAKT TIME PLANNING IN PORSCHE CONSULTING, THE BOLDT COMPANY AND VEIDEKKE

Matthias Helgi Gardarsson[1], Ola Lædre[2] and Fredrik Svalestuen[3]

ABSTRACT

In recent years takt time planning has been a more and more utilized method in construction projects. In 2010 the Norwegian contractor Veidekke started their first takt project and have since carried out several projects with the method. The results of these has been wavering from breakdowns of the takt system to great success. It is therefore interesting to see how takt is used by different companies internationally and which experiences these have compared to Veidekke.

Through literature reviews, interviews and case studies the paper looks at takt as practiced by Porsche Consulting, The Boldt Company and Veidekke. Their practical applications have a lot in common, but are distinguished – among other things – by the way to involve subcontractors, the types of projects that they use takt on, and how they divide the project into zones. Currently, takt seems to be dependent on key persons familiar with the method, and there is a need for a guideline for takt so more projects can benefit from use of the method.

KEYWORDS

Takt time planning (TTP), lean construction, production planning, work flow, buffer

INTRODUCTION

The contractor Veidekke has in recent years used takt time planning in some projects. Takt is a relatively novel method for the Norwegian construction industry, and Veidekke is one of few contractors that have applied it. The practice of takt varies between countries, companies and even within the same company. The method seems to depend on key persons in the project that are familiar with the method. To some extent, the management staff and the foremen on-site have been the same across takt projects. However, the results of using takt have varied between the projects. Some projects have experienced success,

[1] MSc, Student, Department of Civil and Environmental Engineering, NTNU – Norwegian University of Science and Technology, Trondheim, Norway, +4790120191, mhgardarsson@gmail.com

[2] Professor, Department of Civil and Environmental Engineering, NTNU, Trondheim, Norway, +4791189938, ola.ladre@ntnu.no

[3] Researcher, Department of Civil and Environmental Engineering, NTNU/Department Manager, Veidekke, Trondheim Norway, +4798673172, fredrik.svalestuen@veidekke.no

and some have experienced failure-like outcomes. Based on that, there is a need to find out how using takt in construction can lead to success. Therefore, this study maps experiences with takt in Norway and abroad. The research questions:

- What types of takt are used today?
- What are the experiences with takt?

The study's novel contribution lies in the comparison of how takt is practiced in by the companies Porsche Consulting, The Boldt Company and Veidekke. Veidekke has cooperated with both Boldt and Porsche Consulting, so their use of takt is known in by Veidekke employees. The paper mainly takes interior work into consideration, even though its also used for concrete and exterior work.

THEORY

Takt is German for "beat" and refers to the manner takt time planning is carried out in production. Takt is a lean-tool that has a goal to reduce waste and increase value by creating a stable environment for implementing Last Planner (Frandson et al., 2014). Takt was first used in traditional industry, like the automotive industry, where products move down an assembly line with a set takt time at each work station. Each station has to finish their work before the item is moved along to the next work station (Hopp & Spearman, 2008). Fabrication shops and construction industry are similar because the sequencing and pace of the work is driven by labor instead of machines (Linnik et al., 2013). The difference is that the product in construction is fixed at one place and cannot be sent between the workstations. Instead the workers have to move from station to station, or zone to zone, in a set time followed by a new group of workers. Each group consist of workers of preferably one trade that complete a set of activities without interference from other trades. This is what we call takt. Takt is often illustrated as a train with several wagons moving through a construction site. The wagons are the different groups of workers that complete their set of tasks before moving to the next area followed by another wagon that will complete their set of tasks. Together they make up the train that leaves a finished construction when the last wagon finishes.

Different trades need different time to complete the distinctive zones. For each zone the trades set an upper-bound time they need to complete their activities. Since everyone moves with the same pace some trades will work with lower capacity then what is possible (Frandson et al., 2013). The capacity for each wagon is the amount of work that is possible to do within the takt time with a given number of workers. In takt project most wagons will work under capacity while the bottleneck activities will set the pace. When the takt time is set high many trades will have idle time. If the takt time is low, then many trades will have issues finishing on time. This can be solved by increasing or decreasing staffing dependent on of the task is working under and over capacity. Idle crew can work on workable backlogs, rigging, improvement work, etc. For wagons exceeding the takt time they can, in addition to increase crew size, use different means-and-methods, change set-up for the work or increase the use of prefabrication.

Frandson et al. (2015) describe four possible buffers that construction planners can use; time, capacity, space and workable backlogs. Frandson (2015) argues that takt projects can use all except time. This is because the activities in takt are closely connected with little room for adjusting the timetable without interfering with the entire project line. Instead the capacity can be adjusted through increasing or decreasing the number of workers in each wagon as described above. Space as a buffer in takt are parts of the zone that are finished by one trade so the following trade can start their work without interfering. This can for example that the first trade has completed three out of four apartments within the takt time. The next trade can start with the three apartments while the first trade completes the last apartment. Some areas are uneven in the amount of work for the different trades. Therefore, it might be better to do these areas off-takt as a workable backlog. Workable backlog can give and receive workers from over- or understaffed zones.

METHODS

The methods used in this study include a literature review, case studies, interviews and a document study. The paper has a set goal of helping Veidekke to improve on takt time planning. Therefore, most of the research is done on Veidekke's projects to understand how they utilize takt and how it can be improved. Research on Porsche's and Boldt's projects is done in order to compare them with Veidekke's projects.

The existing literature on takt in Norway and abroad is reviewed. The literature review was inspired by Arksey and O'Malley's (2002) paper on scoping studies. Google Scholar, Oria and the IGLC.net were used in this review. Google Scholar has a wide range of papers and is easy to navigate in. It is not the most reliable database, so the sources' reliability was double checked. Oria is NTNU's database with an extensive specter of research papers, articles, books and dissertations. IGLC's web page contains all previous IGLC conference papers and recent research on takt time planning.

The literature review has been conducted to get an overview of the existing literature within takt and answer research questions. Takt is a relative novel method, especially in Norway, so the amount of relevant literature is limited. Abroad The Boldt Company has participated in multiple papers, and Veidekke has in collaboration with NTNU published master thesises and research papers about takt projects. Mordal (2014) wrote about the housing project Horneberg B3 and Smiseth (2013) wrote about the Knowledge Centre at St. Olav's Hospital in Trondheim. In addition to this, Solem (2013) and Andersen (2012; 2013) wrote research rapports about the construction of the Knowledge Centre. Porsche Consulting delivers commercial services with takt to contractors and developers, so literature from them has been hard to find. However, some documents and course presentations from Porsche Consulting have been acquired and used in this paper.

The three companies chosen in this study are Porsche Consulting, The Boldt Company and Veidekke. Porsche Consulting originates from the car producer Porsche. Porsche Consulting provides training and consulting in takt time planning for contractors, but does not conduct construction projects themselves. After being nearly bankrupt in the 1990s, Porsche implemented takt time principles inspired by Toyotas Just-In-Time methods with huge success (Nash, 1996). They did this by manufacturing the cars with a set finishing time for all activities down the assembly line. This increased flow and reduced waste. Porsche transferred this principle from car production to construction projects. By using the same principles of series of set tasks finishing at the same time, with the worker moving around at the building site instead of the car moving down the assembly line, Porsche Consulting achieved a similar success.

The Boldt Company is an American contractor with over 2000 employees located in multiple states across the US. They offer services like construction management, design, real estate development and technical services. Their department in Sacramento, California is one of the leading construction firms in takt.

Veidekke is one of Scandinavia's largest contractors and property developer with over 8,000 employees. Veidekke has been using takt in some of its projects since the Knowledge Center in Trondheim was built in cooperation with Porsche Consulting in 2010. Since then Veidekke has incorporated takt into its own Lean Construction Initiative Collaborative Planning and started a partnership with Boldt where knowledge and experience regarding takt is exchanged. Takt has been implemented in a handful of projects and they are now working on a guideline for use of takt in Veidekke.

These three companies were chosen because they have different approaches to takt, they have come far with takt in their local market, and information was available for both theory and cases. Four cases have been used to illustrate takt in Porsche, Boldt and Veidekke. Three of the selected cases were in Norway and one in the US. In 2010 Porsche Consulting consulted Veidekke in implementing takt in the new Knowledge Center at St. Olav's Hospital in Trondheim, Norway. This was the first takt project for Veidekke and it was therefore heavily influenced by Porsche Consulting and hence defined as a Porsche Consulting project in this study. The project had a budget of 32 million euros, was built over three years and was the first hospital building in the world with passive house standard. Solem (2012), Smiseth (2013) and Andersen (2012; 2013) conducted interviews and research on this project. It has therefore been possible to see what was implemented by Veidekke and Porsche Consulting. The second case was Sutter Health Anderson Luchetti Women´s and Children's Center (WCC). It is a nine-story hospital with 242 sleeping accommodations in Sacramento, California and was built with takt by The Boldt Company. The case is described by Linnik (2013). Veidekke's Moholt 50/50 – the third case – was a student housing project with 5 nine-story buildings where every floor, except the main floor and basement, have the exact same design. In addition, a parking basement, a library and a kindergarten were built and the whole project had a budget of 46 million euros. Only the living areas of the student housing was built with takt. The case is scarcely described in the literature and the information largely comes from interviews with key persons in the project. The cases were chosen to exemplify some of the differences found between the methods. While the three other case projects finished several years ago, there have also been done a case study of a project under construction in 2019. The project Nærbyen in Trondheim is a project with apartment and commercial areas, where the interior phase in the apartment's areas are built with takt. The initial findings about takt in Veidekke has been verified through interviews with project managers and foremen at this project.

6 Project managers from Veidekke, 2 project managers from and The Boldt Company, as well as 3 foremen from Veidekke were interviewed. The authors did not find representatives in Porsche willing to be interviewed, but some of the representatives from Veidekke have worked with Porsche in the Knowledge Centre. Most of the interviews were with representatives from Veidekke, who were easy to get in touch with due to geograpichal location. In addition, one of the authors is employed by Veidekke and the main author has had vacation job positions there. The interviews done for this thesis were semi-structured and inspired by Yin´s (2009) 5 traits of a good interview. The interviews were conducted to supplement and confirm the actual findings from the literature review. This was important since the existing literature is limited and that the method, especially in Norway, where the method so far is used by few people.

RESULTS AND DISCUSSION

The three methods of takt time planning of Porsche, Boldt and Veidekke have in common that they promote a stable flow in production through clear interfaces between the different activities, predictable task management and a steady number of crew. This section presents the differences between the methods one by one, based on the two research questions about 1) what types of takt are used today and 2) what are the experiences with takt. Finally, the section presents the similarities.

EARLY INVOLVEMENT OF SUBCONTRACTORS DURING PLANNING

Zoning, sequencing and constraint analysis

There are different practices on involving the subcontractors between the methods. Porsche has little involvement of the subcontractor early in the planning and scheduling. The general contractor and project manager develop a production schedule with zoning, takt time and trade sequence. Subcontractors gets the chance to adjust the plan late in the process. Porsche has a top-down management approach which is common in industries and German construction projects. This is unlike Norway where a bottom-up version is more common. Boldt and Veidekke involve their subcontractors in planning zones, sequencing activities and constraint analysis. Zones in takt are designated areas where trade activities move through. Constraint analysis identify causes of uncertainties in the workflow of the construction and how this can be solved to improve the reliability of the plan (Shen and Chua, 2005). Involvement in Veidekke and Boldt is done through a series of workshops with the subcontractors and project management before construction starts. Veidekke use their own Lean initiative, *Collaborative Planning*, to facilitate the planning of takt.

It is believed, especially in Veidekke, that the foremen are the ones that know their field and team best and therefore are most capable to accurately assume work load, decide the optimal trade sequence and predict uncertainties in production. Also, Boldt puts great emphasis on making a collaborative environment for planning.

On the Knowledge Center the subcontractor delivered information about expected work load for each area of the project. The project management used this information to divide the project into zones and set the takt time. In Solem´s (2012) master theses about the project the participants said that takt in Porsche was not adjusted for Norwegian work culture. They felt ignored in the planning process and meant that the timetable did not take into consideration their actual needs for completing each zone on time. They did not feel any ownership to the plan and did not participate in a constraint analysis which led to problems that could have been avoided (Smiseth, 2013).

A critical success factor for takt time planning is the involvement of subcontractors. Involvement of the subcontractor at Moholt 50/50 created ownership of the plan among the foremen. They managed to sell the plan to their teams and actively contributed in solving problems that appeared throughout the project, often without needing to involve the project management. They felt ownership to the plan they participated in making and felt a responsibility to follow it. The predictability of what to do each week and every day combined with the repetitive design of the buildings meant that needed workhours was cut throughout the project. Construction errors were reduced and absence due to sickness almost eliminated.

Takt time and design phase

Veidekke prefers the takt time as a weekly takt time with start up on Mondays and handover to the next activity on Fridays. This is often a set part of takt in Veidekke and the subcontractor seldom can change this. Boldt and Porsche is more flexible with the length of the takt time for the project, but Boldt let the subcontractor take part in the decision.

In Norway it's normal to procure the subcontractor after getting the project while Boldt does this earlier in the project. This enable Boldt to involve the subcontractor in the design phase. This helps the project designers to find solutions that will make the construction easier to build.

PROJECT TYPES

Using takt on complex projects

Veidekke have had success with apartment complexes and student housing when using takt while Boldt and Porsche have had success with more complicated projects like hospitals. Boldt has used takt since the late 2000's and have today a more sophisticated method compared to Veidekke. In Norway takt is a new method that have been used on few projects. The method is therefore unfamiliar for most of the industry.

For takt to become a consistently successful it is vital that more contractors and subcontractors get sufficient training and understanding of the method. It is therefore essential that the project manager uses enough time in the beginning of the project to make sure that all the subcontractor understand the principals and their role in the project. Using the same subcontractors in multiple projects will give benefits for the contractor in the long run. For Veidekke a guideline should also be easy to use and adjust for different projects in such a way that it is possible to use takt without any prior experience.

Veidekke has only implemented takt in interior work and at some degree in exterior work. Porsche and Boldt uses takt for the entire production, which also involves exterior work as well as concrete work.

Varying takt time and zoning throughout the project

Boldt changes the zoning and takt time depending on the phase they are in. For example, with an office- or hospital building the first phase would be an overhead phase where MEP (Mechanical, Electrical and Plumbing) racks, ductwork and tubes are installed. These activities span over large areas and the zones are therefore large compared to the following phases. A framing phase usually follows with tasks like framing and firestopping which are more labor intensive per square meter of building which means that the zones get smaller or the takt time longer. After this follows a drywall phase and then a finishes phase.

To be able to split the project into phases and do separate takt for each zone you will need more planning and it is more demanding to control during building than project that runs with the same zoning and takt time. The benefit is that the trades are given the optimal area to work most efficient.

VARIES TAKT TIME FROM PROJECT TO PROJECT

Takt time is an essential part of the takt projects. Veidekke use almost exclusively weekly takt time with startup on Mondays and handover on Fridays. They have experienced good results with this at Moholt 50/50 and Nærbyen. The craftsmen highlight predictability with the weekly takt as the biggest advantage with the method. There is always a clear plan for where they are going to be and what is expected to be done.

The weekly takt time also fits well with Veidekke meeting structure in Collaborative Planning which has set meetings throughout the week. In Collaborative Planning, there are a series of meetings on different levels of the project hierarchy, at set intervals, with their own agenda for the meeting. The different meetings have different time windows they plan for. Wednesday there is a meeting where the trades have to report if they will finish on time or what they will do to finish on time. One or more wagons within the same trade usually have a team meeting at the start or at the end of a week to discuss next week's work. There are weekly meetings between the foremen in each train and at Nærbyen they have started to take these meetings on the construction site while walking through the zones. Here the foremen talk together, solve problems and adjust ways of production to optimize production in the train. By trains the author means a series of activities that follow each other through certain zones with a set takt time for each zone. In one of the meetings the project management and the foremen of the project meets and discuss the plan for upcoming weeks and problems discovered on the foremen meeting. Here potential changes in the takt can be discussed and agreed upon and problems from the foremen meeting discussed and solved with the project management.

A five-day-cycle that is used by Veidekke leads to large areas of the zones not being under production. For example, will an apartment building with three apartments in each zone have only one apartment in production at any time. This means that only a third of the construction site is under construction at any time. This works as a buffer since it allows the next activity to start in one part of the zone while the previous finishes at another part. This buffer can be avoided to reduce production time and cost by decreasing takt time and the size of the zones, but then the risk of propagating the delay increases.

With a weekly takt time the trades have the option to work overtime in the weekend if they are behind schedule. It is also sufficient time to adjust staffing with status meeting on Wednesdays. With shorter takt time there is less room to adjust for delays. At the same time, there is little room for improving takt when you are obliged to plan within one week. There might be projects where another takt time is more ideal, and when takt as a method evolves it might be to smaller more compact zone to ensure that more of the project are under construction at any time.

DIVIDING IN ZONES

An important part of setting up the takt plan is to divide the project into zones. What criteria this is based on is different for the three companies. Porsche Consulting start their process by identifying areas that are repeatable and non-repeatable. Repeatable areas are for example offices, hotel rooms and front claddings while non-repeatable areas can be lobbies, technical rooms and kitchens. The repetitive areas are divided into construction sections, usually floors, and then into smaller subsections if necessary. One subsection can be a set number of hotel rooms. The non-repetitive areas are either used as backlog areas or divided into different types of buildings, e.g. shops, bars and restaurants in a commercial area. Then these areas are further divided into subsections to fit the needed workload into a given takt time. After this the trade sequence is defined before each trade required work duration for the different subsection is calculated. From this the required staffing is calculated to complete the trade on the set takt time.

The Boldt Company base their zoning on the scope of work for each trade. They use a lot of time understanding the scope early on in the project before they start to divide the project into zones and decide the trade sequence and takt time. As mentioned Boldt change their zoning and takt time throughout the project in different phases. To do this it is important to truly understand the scope.

Veidekke use both scope of work and architecturally defined areas to divide their project. Architecturally defined areas are naturally defined areas in the project like floors, classrooms or areas within fire walls. On Moholt 50/50 it was natural to divide the project into floors since each floor was identical so the workload for the different trades would be the same every week. Other projects, like Nærbyen, have divided the project into floors for the different towers of the building. Here the apartments within the towers are different and therefore the scope varies from floor to floor. Variation in workload means that staffing has to be adjusted from week to week. This can reduce the predictability for the craftsmen and frequent transfer of staffing will reduce the continuous improvements gained by having steady teams. This also reduce the craftsmen ownership to their wagon’s completion time in the project. The benefit of having areas defined by architecturally defined zones is that it is more transparent and therefore easier for everyone to understand the zoning. It also makes rigging and transportation easier. By having all production in one floor workers don’t have to move up and down with materials and equipment.

SIMILARITIES

All three companies use multiple trains in their projects. When there are multiple trains this means that there are two or more unconnected series of activities that move through a separate area of the project. This usually is done in project where the content of the building varies greatly from area to area which makes it difficult to balance the workflow. This can for example be buildings with large amount of technical rooms, wet rooms, laboratories or office areas. It is also used in big projects where it makes sense to use multiple trains instead to increase workflow. In Veidekke there is a split opinion among the project leaders about using multiple trains. Some think multiple trains should be used depending on the building type. Others believes this will create more variation in workload which can accumulate at times and create delays. The chance of total halt is reduced since the risk is divided between the trains, but it is more demanding for the project management to control the production.

The interview objects said that buffer for takt projects often are workable backlogs, overstaffing and using areas as buffers. Also, Frandson (2015) describe workable backlogs, overstaffing and areas as buffers that can be used in takt project. Veidekke always start their takt projects with overstaffed wagons so it can withstand problems that haven’t been detected and solved in the constrain analysis. After a while when the initial problems are solved, and the workflow is stabilized the staffing is reduced. The extra staff is sent to other wagons in the train, workable backlogs or other projects.

In Moholt 50/50 there was an increase in work flow throughout the whole project as the workers learnt better ways to streamline the production. The extra work hours that were gained was used on workable backlogs that where not planned in takt. When there was delays workers from workable backlogs was called in to help. Moholt 50/50 got issues in the end because the project management and subcontractors used to much time and focus on planning and following the takt that the backlog areas was neglected.

Takt is especially vulnerable for delays in the plan during construction compared to traditional planning. There are direct links between all the activities so delays in one can lead to delays for all the following activities if measures are not implemented. This means that drawings and materials must be delivered on time in addition to sufficient staffing to complete the task. A change in the timetable must be approved by all subcontractors because it affects everyone. When problems occur in one of the wagons it’s hard to change the plan much more than one or two days without it having negative impact on the following wagons. Postponing the deadline for a wagon is therefore not an option.

All three companies involve their subcontractor during production to adjust the schedule for changes. Porsche Consulting uses a takt control board to control production. Several of these boards are placed around the project with updated information about the HSE-status, construction sequence and completion status for the different wagons. The foremen and project managers have frequent meetings by the boards to update and give status. If they expect to finish on time the activity is marked in green, if it will be finished with extra work/overtime the activity is marked in orange, and if the wagon can only be finished through non-planned activities and extra cost the activity is marked with red. Porsche Consulting also have a defined restart system with the objective to come back to the planned takt after shutdown as soon as possible. The site manager and subcontractors identify all delayed activities and work required for each trade to get back on the plan. From this a new plan is made. Veidekke used the takt control board in the Knowledge Centre but have since gone away from this method. Instead they use methods from Collaborative Planning to control and adjust production in their takt project. Boldt have daily check-ins and weekly meetings to discuss the progress for each trade and systems in place for restarting the takt plan. Takt is, when implemented right, a self-regulating transparent system, meaning that the subcontractors are controlling and pushing each other to complete on time more compared to projects with more traditional scheduling. The transparency also makes it easy to control progress and quality of work. The activities that are struggling are spotted early and measures to increase their productivity can be implemented.

CONCLUSION

The paper answers two research questions; what types of takt are used today and what are the experiences with takt. The paper looks at takt time planning in Porsche Consulting, The Boldt Company and Veidekke. Their application differs regarding what types of projects where they use takt, if they use takt on the entire project or not, and how the subcontractors are involved. Subcontractor involvement is – according to many of the interview objects – one important reason for success with takt time planning. Boldt changes their zones and takt time through different phases of the project, while Veidekke uses the same weekly takt time for all their projects. The companies base their zoning on different criteria. Veidekke and Boldt run their own projects, while Porsche Consulting only takes the role as a consultant. Table 1 illustrates the differences.

Table 27: Illustration of differences between application of takt-time planning

	Porsche Consulting	**The Boldt Company**	**Veidekke**
Involving subcontractors early in production planning of:			
Zoning, sequencing activities and constraint analysis	No	Yes	Yes
Takt time and design phase	No	Yes	No
Type of projects			
Using takt successfully in complex projects	Yes	Yes	No
Varying takt time and zoning throughout the project	No	Yes	No
Uses takt on the entire project	Yes	Yes	No
Varies takt time from project to project	Yes	Yes	No
Divide zones primarily based on:	Repeatability	Scope of work	Scope of work Architecturally defined areas
Type of business	Consultant	Contractor	Contractor

There are also many similarities between the application of takt-time planning. All three companies use multiple trains in their projects, they involve subcontractors in planning and rescheduling during production, and they use much of the same types of buffers.

To let more projects benefit from takt time planning, its necessary to develope guidelines. With guidelines, the use of takt will not depend on individual persons familiar with the method. The guidelines should contain principles for takt and examples from practical application without being too detailed. The guidelines should be flexible enough to let the method be adjusted to each individual project.

REFERENCES

Andersen, L. (2012). *Organisering av prosjekterings- og byggeprosessen St. Olavs hospital, Kunnskapssenteret [Organisation of design and construction process St. Olavs hospital Knowledge Centre]*, 1st Ed., Helsebygg Midt Norge, Veidekke og YIT, Trondheim, Norway

Andersen, L. (2013). *Samhandling i prosjektering og bygging. Kunnskapssenteret. St. Olavs Hospital [Cooperation in design and construction. Knowledge Centre. St. Olavs Hospital]*, 1st Ed., Helsebygg Midt Norge, Veidekke og YIT, Trondheim, Norway

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International journal of social research methodology*, 8(1), 19-32.

Fiallo, M. and Howell, G. (2012). "Using Production system Design and Takt Time to Improve Project Performance." In Proceedings of the *20th Annual Conference of the Inerantional. Group for Lean Construction*, San Diego, CA, USA.

Frandson, A., Berghede, K., & Tommelein, I. D. (2013, August). Takt time planning for construction of exterior cladding. In Proceedings of the *21st Annual Conference of the International Group for Lean Construction*. Fortaleza, Brazil.

Frandson, A., Berghede, K., & Tommelein, I. D. (2014, June). Takt-time planning and the last planner. In Proceedings of the *22nd Annual Conference of the International Group for Lean Construction. Group for Lean Construction* (pp. 23-27).

Frandson, A. G., Seppänen, O., & Tommelein, I. D. (2015). Comparison between location-based management and takt time planning. In Proceedings of the *23rd Annual Conference of the International Group for Lean Construction* (pp. 28-31). Perth, Australia.

Linnik, M., Berghede, K & Ballard, G. (2013). An experiment in takt time planning applied to non-repetitive work. In Proceedings of the *21th Annual Conference of the International Group for Lean Construction*. Fortaleza, Brazil.

Nash, N. C. (1996). *Putting Porsche in the Pink*. New York Times accessed February 16, 2017.

Shen, L. J., & Chua, D. K. (2005). Key constraint analysis: achieve lean processes with the application of TOC. In *Construction Research Congress 2005: Broadening Perspectives* (pp. 1-10).

Smiseth, S. (2013). *Taktplanlegging, en god måte for å gjennomføre produksjon i byggeprosjekter? [Takt time planning – a good method for production in construction projects?]* Master theses, Norwegian University of Science and Technology, Trondheim, Norway.

Solem, A. (2012). *Involvering av bygg-/produksjonsleddet i prosjekteringsfasen. St. Olav's Hospital. Bygging av Kunnskapssenteret [Involving production in the design phase of St. Olavs Hospital. Building the Knowledge center]* 1st edition. Norwegian University of Science and Technology, Trondheim, Norway.

Velarde, G.J., Saloni, D.E., van Dyk, H., and Giunta, M. (2009). "*Process flow improvement proposal using lean manufacturing philosophy and simulation techniques on a modular home manufacturer*." Lean Constr. Journal, 5 (1) 77-93.

Yin, R. K., (2009). *Case study research methods*, 4th Ed., SAGE Publications, Inc. New Delhi, India

David Grau,, Amin Abbaszadegan, and Rizan Assanair (2019). “Takt Time Planning in Porsche Consulting, The Boldt Company and Veidekke”. In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 563–572. DOI: https://doi.org/10.24928/2019/0197. Available at: <www.iglc.net>.

PROCESS VERSUS OPERATIONS WORKFLOW – MAKING THE CASE FOR CONTINUOUS MONITORING OF CONSTRUCTION OPERATIONS

David Grau[1], Amin Abbaszadegan[2], and Rizan Assanair[3]

ABSTRACT

This article argues that an opportunity to leverage operations flow in construction exists. Operations flow represents the flow of work within a unit of production such as a worker or workstation. To date, construction has mostly neglected operations flow and solely focused on process flow. Process flow represents how the flow of work on a product moves through workstations or tasks. For example, the Last Planner System (LPS) exemplifies a successful approach to plan for tasks with resolved constraints, so that production units (e.g. crews) can flow smoothly through the built product or project. In order to spark a discussion in the construction community, this article provides a theoretical review of process and operations flow concepts and practices. In addition, interviews with subject matter experts in the automobile industry are leveraged in order to unveil how work and information flows are monitored in assembly lines. Based on the previous insights, a model for the continuous monitoring of operations in construction with the support of advanced technologies is discussed. The model is partially implemented in a healthcare project.

KEYWORDS

Project controls, variability, work flow, process flow, operations flow, value, takt-time planning.

INTRODUCTION

Flow stability is an indispensable characteristic of efficient and effective production (Sacks et al. 2010). In construction, however, the traditional focus of management has targeted the completed product or project outcome (Grau et al. 2014; Grau and Back 2015;

[1] David Grau, Assistant Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (480) 727-0665; email: david.grau@asu.edu

[2] Amin Abbaszadegan, Ph.D., School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (416) 347-7547; email: aabbasz1@asu.edu

[3] Rizwan Assainar, MS, School of Sustainable Engineering and the Built Environment, Arizona State University, 660 S College Avenue, Tempe, AZ 85281, USA, Phone +1 (480) 727-0665; email: ruizwan.assanair@asu.edu

Grau et al. 2016; Grau et al. 2017). Thus, management techniques were developed to target the conversion of outputs from inputs while neglecting the production process required to achieve those outputs (Howell and Ballard 1996, Koskela 2000). In doing so, the quality of work during execution or construction has been historically obviated (Kim and Ballard 2000; Seppänen 2009). For instance, the critical path method devises a project as the interrelation of tasks through start and finish type of relationships and thus simplistically assumes a constant flow of work through those tasks. Such project management focus fails to acknowledge other constraints with a likely impact on the flow of work (Koskela 2000). Indeed, multiple efforts have quantified the negative impact of workflow variability on craft labor productivity and project performance measures (Thomas 2000; Hamzeh 2009; Brodetskaia 2013; Seppänen 2009; Liu et al. 2011; Abbaszadegan and Grau 2015; Arashpour and Arashpour 2015).

Lean construction claims that efficient and effective production must satisfy the three fundamental axioms of transformation-flow-value (TFV) (Koskela 2000). The transformation of outputs based on inputs reflects the traditional management focus on the finished product (Olli Seppänen 2009). As previously explained, such transformational management focus has obviated the quality or flow of work during construction. The value aspect of production aims at optimizing the amount of value delivered to the final customer. For instance, the design and delivery of a high performing building in terms of energy consumption, maintenance, or functionality with a reduced cost is an example of high customer value. Finally, the flow aspect of production aims at the minimization of non-value added steps or the simplification of production with the overall objective to eradicate waste. The fluctuation or variability of workflow is an example of waste. An integral aspect of Toyota's total production approach is the maintenance of a smooth flow of product through assembly lines. In construction practice, the Last Planner System (LPS) (Ballard and Tommelein 2016; Ballard 2000) has become a mainstream planning and controls technique aiming at the improvement of workflow and minimization of variability and waste. LPS aims at the completion of lookahead and weekly work tasks as initially planned. In doing so, LPS assumes a constant workflow within each task and in-between them. At the end of the planned timeline (e.g. one week), the success of the plan is quantitatively assessed with the metric of percent plan complete (PPC). PPC quantifies the percentage of completed tasks over the total number of tasks that should have been completed. Since its development in the early 1990s, LPS has become a mainstream lookahead planning tool and has positively impacted construction. Yet, opportunities to improve production in construction exist.

Indeed, even though the tremendous success of LPS, opportunities for improvement are discussed in this paragraph. First, weekly work plans fail to support continuous learning and improvement. Despite PPC was conceived to support continuous improvement and learning, the reality is that, as Sacks (2010) pointed out, "the pressures of day-to-day construction make recording of success for learning (both within and beyond the current project) impractical." In reality, the causes for incomplete planned tasks are often not sought, recorded, or analyzed due to pressure and consequent lack of time. Second, the transfer of workflow in-between tasks or activities is still inefficient. According to PPC values, nearly 20% of planned tasks or activities are either not completed or, more frequently, not even started. This lack of completion of planned tasks indicates that the transfer of work between tasks fails at similar percentages. Third, controls is still a reactive endeavor and fails to address variability fluctuations as these happen. The assessment of planning success at the end of the week can only provide a past perspective on performed work and thus fails to resolve unexpected constraints on time. On the contrary, a proactive or immediate controls strategy could detect interruption or alterations of workflow as these happen and thus result in immediate mitigation actions. Indeed, Sacks et al. (2010) argue that a continuous or at least frequent flow of information and work status enables pull planning since such information enables work prioritization "in relation to signals from downstream demand." Finally, an opportunity to stabilize workflow through production units exists. Research and practice with a focus on workflow stabilization have targeted the smooth flow of work between tasks and activities but neglects the adverse effect of flow variability *during* those tasks (Sacks 2016). The stabilization of the pace of work in production units (e.g. crews) presents a latent opportunity to enhance the reliability of the planned work. Indeed, the maintenance of a stable pace of work eventually guarantees that each task will be completed on time and thus that the flow of work transfers to successor tasks as planned.

In response to such shortcomings, the study presented in this article details a theoretical technology-enabled monitoring model with the objective to stabilize workflow at production unit level, and leverage the accumulation of historical and fine-grained data to enhance the accuracy of planning and thus minimize discrepancies between expected and actual production rates.

CONTROLLING VARIABILITY

The reduction of variability and the stabilization of the flow of work has been a major cornerstone in production since the second half of the XX century. In manufacturing, Schonberger (1986) unambiguously states that "variability is the universal enemy." In construction, flow variability negatively impacts project performance measures (Thomas 2000; Hamzeh 2009; Arashpour and Arashpour 2015) and productivity (Brodetskaia 2013; Seppänen 2009; Liu et al. 2011). Previous research in construction based on simulation techniques provided further evidence of the negative impact of workflow fluctuations, as documented by Tommelein et al. (1999), Bashford et al. (2005), and Sacks and Golding (2007). Brodetskaia et al. (2013) have discussed a workflow management model for construction. Such model relies on three thrusts in order to ensure a smooth flow of work: design of a production system in consideration of the constraints that can cause fluctuations; proactive planning based on work-readiness and readiness of subsequent trades to accommodate work; and continuous reduction of variability during the production of individual activities. Complementarily, Koskela (2000) proposed 7 techniques for the design, control, and improvement of a production system in construction: minimization of non value-adding activities (waste); variability reduction; production time reduction; simplification; flexibility, and; transparency. Among them, the transparency and continuous control aspects towards the reduction of variability are of particular interest in this study since the communication of accurate and timely production information is essential for the stabilization of flow (Formoso et al. 2002; Rusell et al. 2009; Gurevich and Sacks 2014; Matthews et al. 2015). Information flow is critical for a smooth flow of work (Dave et al. 2010; Sacks et al. 2010).

As previously stated, LPS presupposes the stabilization of workflow between tasks or activities in lookahead or weekly work plans. LPS also transfers the accountability of the weekly work plan to those in charge of execution (i.e. last planners). During planning meetings, last planners collaboratively work to identify and resolve constraints (such as predecessor tasks or availability of space or other resources) before a commitment towards the execution of a task is made. At the end of the planned timeline (e.g. one week), PPC indicates the reliability of the proposed plan. Introduced late in the XX century, LPS represented a leap in the practice of construction with a focus on production systems design. Recently, LPS has been supported with advanced sensing and computing technologies (Sacks et al. 2010; Jongeling and Olofsson 2007; Gurevich and Sacks 2014; Matthews at al. 2015).

Actually, recent research and practice efforts have analyzed how advanced sensing, computing, and information technologies can support planning, execution, and controls. For instance, a 4D (3D model + schedule) approach resulted in the visual representation of line-of-balance execution progress in comparison to the planned work and enabled the visualization and analysis of actual vs. planned workflow (Jongeling and Olofsson 2007). Also, Building Information Modeling (BIM) tools were leverage to enable LPS and the communication of timely and accurate planning information among project team players (Sacks et al. 2010). The BIM+LPS approach enabled the visualization of the planned tasks in the object-oriented 3D model and ensured the consistency of schedule/planning changes by means of the automated propagation of such changes through the model. The influence of this approach on the work sequencing decisions by the last planners was determined (Gurevich and Sacks 2014). In order to alleviate the flow of production information that could alert of workflow variability, a theoretical model with commercial technologies was proposed by Matthews at al. (2015). The qualitative analysis of interviews from subject matter experts elicited the integration of project documents as a critical factor. Finally, a theoretical approach to integrate and visualize product and process information and extend it through the project life-cycle was recently proposed by Dave et al. (2016).

PROCESS VS. OPERATIONS FLOW

The flow of processes and the flow of operations coexist in any production system (Shingo and Dillon 1988). On the one hand, process flow represents how the flow of work on a product moves through workstations. Ideal production aims at meeting customer's demand rate with a steady process flow or takt time. On the other hand, operations flow represents the flow of work within a unit of production such as a worker or workstation. In this regard, the optimization of individual production units does not necessarily result in an optimal production system. For instance, an optimized operation unit may increase the rate of production and generate and out-of-sync demand from upstream operation units and supply to downstream operations units, and thus generate intermediate buffers and prevent takt-time production. In contrasts to manufacturing, Sacks (2016) observed in the construction literature a convoluted understanding of these two expressions of flow, even though Koskela (2000) and Koskela et al. (2007) had previously noted them. Sacks argues that such confusion results from the batch type of production in construction -as opposed to continuous production in manufacturing and assembly lines. In construction, the production units (such as crews) move through the built product at discrete intervals of time and result in a batch production mode. Despite these fundamental differences, as suggested by the later authors, this article maintains the semantics and thus refers to process workflow as the flow of work exerted on the building product by multiple production units (e.g. trades, crews) and to operations flow as the flow of work delivered by individual production units (at distinct work locations).

The different perception of flow between manufacturing/assembly and construction is mirrored in their control techniques. In manufacturing, monitoring focuses both on process and operation flows. For this discussion, the authors have interviewed subject matter experts in the automobile manufacturing industry in order to gain insights on their monitoring goals, practices, and techniques. The discussion on the rest of this paragraph is based on the analysis of such interviews. A real-time and continuous monitoring exists in order to detect and eradicate variability as it happens and at the source, and thus avoid the propagation of such variability into upstream and downstream operations. Thus, a worker in car assembly is not only empowered but also required to stop the line when the worker cannot finish the work within a marked stretch within the assembly line. Stopping the flow of production enables the elimination of variability right at the source and minimizes the unbalance of the entire assembly system. Such empowerment of the worker is a lean manufacturing strategy to respond in real-time and minimize the propagation of variability. In addition, such empowerment builds worker's accountability, such that the worker becomes an actor that must respond to variabilities in flow, quality, or other production issues. Such real-time communication of information also triggers management decisions. For instance, the late delivery of automobile parts in a just-in-time supply for an assembly line automatically activates contingency supply mechanisms. Thus, the continuous monitoring of the production system and its components results in a real-time flow of information that aims at the generation of corrective actions as soon as events occur.

In contrast, though, construction has invariably focused on process flow and neglected operations flow. LPS exemplifies a basic effort to plan tasks with a smooth flow of work between them. However, the reader should notice that while the planning focus in LPS is process flow, its weekly control informs on the reliability of the planned flow (i.e. PPC) after the weekly transformation cycle, i.e. from the perspective of the transformed work or output. This shortcoming is understandable since controls in shorter communication cycles could not have been realistically conceived with the state of technology in the early 2000s. As discussed in the previous section, recent studies have envisioned the support of advanced sensing, computing, and information technologies to address such shortcomings. However, these and other previous efforts have unequivocally focused on the planning and stabilization of process flow.

This lack of attention to operations flow in construction contrasts with the real-time monitoring of operations in lean manufacturing. Such contrast provides further motivation for the study presented in this article. Indeed, an opportunity exists to leverage advanced technologies for the exploration and stabilization of operations flow with a real-time feed of information. Within a production unit, fluctuations in workflow imply that resources are either underused or overused. Such fluctuations can eventually disrupt the smooth transfer of work in-between activities. The opportunity to stabilize operations flow is latent for finishing activities due to their short durations and multiple and varying dependencies on information, preceding tasks, and equipment, which cannot be guaranteed in advance (Brodetskaia et al. 2011).

MODEL FOR THE CONTINUOUS MONITORING OF CONSTRUCTION OPERATIONS

The model presented in this section builds on the previous theoretical insights and proposes the continuous monitoring of construction operations with the support of advanced technologies. Such fine-grained production data is accumulated into a historical database. Figure 1 illustrates the model. The fundamental idea is that fine-grained production records hold value and that such value can be leveraged to support estimating, planning, and execution based on the analysis of records from previously completed and similar projects. For example, precise execution work-hours can be populated by dividing the takeoff quantities extracted from the BIM model by previously recorded production rates in similar projects. Fine-grained production records can be leveraged to support additional project functions, such as pre-qualification of subcontractors based on past performance. Besides, such dataset could be mined in search for hidden patterns and correlations or correct predictions. Advanced sensing and computing technologies are envisioned in support of the data collection of fine-grained operations data in real- or near real-time. Similar to manufacturing, the analysis of real-time information can be leveraged to trigger corrective actions.

Indeed, the continuous monitoring aspect of the model was tested during the construction of a healthcare facility by a sophisticated contractor company. The reader can find the insights and results from the real-time collection of operations records and corrective actions in support of the healthcare project in Cruz-Rios et al. (2015) and Tang et al. (2014). The test actually combined the utilization of the proposed model in order to stabilize flow within operations with the Last Planner approach in order to ensure the flow of work between tasks. In regards to operations flow, the test proved that 1) sensing, mobile, and computing technologies enabled the collection of fine-grained operation records, and that 2) such continuous feed of fine-grained operations information enabled corrective actions that effectively stabilized workflow. Thus, test results proved the feasibility of the model and the potential to leverage operations workflow in order to stabilize production and reduce waste. The test also indicated that the continuous collection of vast amounts of labor productivity data should be resolved with the automation of the data gathering process.

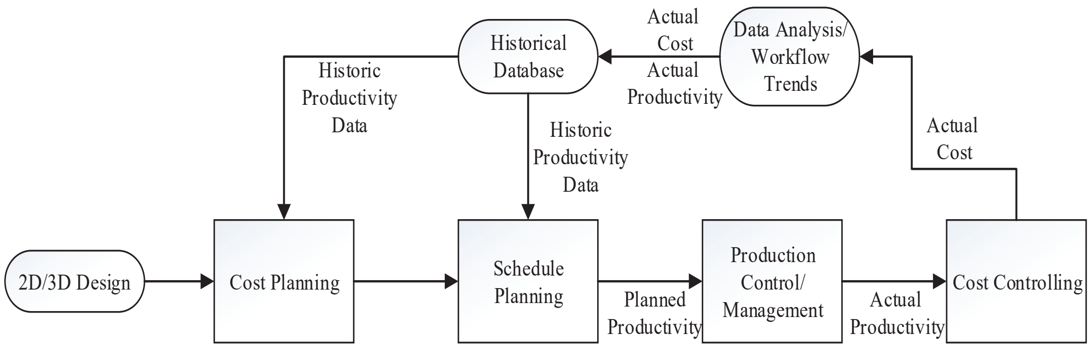


Figure 64. Continuous Monitoring Model

CONCLUSIONS

This article argues that an opportunity to leverage operations flow in construction exists. To date, construction has invariably focused on process flow and neglected operations flow. In reality, the construction literature shows a convoluted understanding of these two expressions of workflow. Such confusion likely results from the batch type of production in construction -as opposed to the continuous production in manufacturing and assembly lines.

For the purpose of this study, the authors interviewed subject matter experts in the automobile manufacturing industry in order to gain insights on the controls of an assembly line. The analysis of the interviews unveiled how car makers leverage the real-time control of the assembly line for the stabilization of workflow and reduction of variability.

Based on such insights, a model for the continuous monitoring of operations in construction with the support of advanced technologies was detailed. The fundamental idea is that fine-grained production records hold value and that such value can be leveraged to support estimating, planning, and execution based on the analysis of records from previously completed and similar projects. As proof of concept, the continuous monitoring aspect of the model was tested during the construction of a healthcare facility by a sophisticated contractor company. Test results proved the feasibility of the model and the potential to leverage operations workflow in order to stabilize production and reduce waste. Further studies should investigate the stabilization of operations and process flows for effective production management.

REFERENCES

Abbaszadegan, A., and Grau, D. (2015). "Impact of Real-Time Project Control on Capital Cost and Schedule Performance." *University of Zagreb, Organization, Technology & Management In Construction: An International Journal*, 7(2), pp. 1289-1294

Arashpour, M., & Arashpour, M. (2015). "Analysis of Workflow Variability and Its Impacts on Productivity and Performance in Construction of Multistory Buildings." ASCE, Journal of Management in Engineering, 31(6), 04015006.

Grau, D., and Back, W.E. (2015). “Predictability Index – A Novel Metric to Assess Cost and Schedule Performance.” ASCE, Journal of Construction Engineering and Management, 04015043-1 to -8.
Grau, D., Back, E., Abbaszadegan, A., and Sirven, R. (2014). “The Predictability Index – A Novel Project Performance Metric to Assess the Early Prediction of Cost and Time Outcomes.” Conference Proceedings, Construction Research Congress 2014, pp. 2306-2314, Atlanta, GA, May 19 – 21, 2014.
Grau, D., Back, W.E., and Aguilar, G.M. (2017). “Organizational Behavior Influence on Predictability.” ASCE, Journal of Management in Engineering, 33(5), pp. 04017027-1 to -8.
Grau, D., Back, W.E., and Hossain, N. (2016). “Influence of Risk and Change Events on Cost, Schedule, and Predictability Performances.” ASCE, Journal of Professional Issues in Engineering Education and Practice, 04016006-1 to -9.
Ballard, G. (2000). The Last Planner System of Production Control. PhD Thesis. The University of Birmingham, Birmingham, UK.
Ballard, G. and Tommelein, I.T. (2016). Current Process Benchmark for the Last Planner System, Project Production Systems, University of California, Berkeley, CA.
Bashford, H.H., Walsh, K., and Sawhney, A. (2005). “Production system loading–cycle time relationship in residential construction.” ASCE, Journal of Construction Engineering and Management, 131 (1), 15–22.
Brodetskaia, I., Sacks, R., & Shapira, A. (2013). Stabilizing Production Flow of Interior and Finishing Works with Reentrant Flow in Building Construction. ASCE, Journal of Construction Engineering and Management, 139(6), 665-674.
Brodetskaia, I., Sacks, R., and Shapira, A. (2011). “A workflow model for finishing works in building construction.” Taylor and Francis, Construction Management and Economics, 29(12), 1209–1227
Cruz-Rios, F., Grau, D., Rizwan, A., Ganapathy, R., and Diosdado, J. (2015). “Stabilizing Craft Labor Workflow with Instantaneous Progress Reporting.” In: Seppänen, O.,
González, V.A. & Arroyo, P., 23rd Annual Conference of the International Group for Lean Construction, pp. 43-52. Perth, Australia, July 29-31, 2015.
Dave, B., Kubler, S., Främling, K. & Koskela, L. (2016). “Opportunities for enhanced lean construction management using Internet of Things standards.” Elsevier, Automation in Construction, 61(C), 86-97.
Flyvbjerg,B. (2006). "From Nobel Prize to Project Management: Getting Risks Right." Project Management Journal, 37 (3), pp. 5-15.
Formoso, C.T, Santos, A.D., and Powell, J.A. (2002). “An Exploratory Study On The Applicability Of Process Transparency In Construction Sites.” Journal of Construction Research, 3 (1), 35–54.
Gurevich, U., & Sacks, R. (2014). “Examination of the effects of a KanBIM production control system on subcontractors' task selections in interior works.” Elsevier, Automation in Construction, 37, 81-87.
Hamzeh, F. (2009). “Improving Construction Workflow - The Role of Production Planning and Control.” Civil Engineering, UC Berkeley, CA.

Howell, G., and Ballard, G. (1996). "Can project controls do its job?." IGLC Proceedings, 4th Annual Conference of the International Group for Lean Construction, 1996.
Jongeling, R., and Olofsson, T. (2007). "A method for planning of work-flow by combined use of location-based scheduling and 4D CAD." Elsevier, Automation in Construction, 16(2), 189-198.
Kim, Y.W. and Ballard, G. (2000) "Is the earned-value method an enemy of work-flow?." In Ballard, G. and Chua, D. (eds.) GLC Proceedings, 9th Annual Conference of the International Group for Lean Construction, Singapore, 2000.
Koskela, L. (1992). "Application of the new production philosophy to construction." Technical. Rep. No. 72, Center for Integrated Facility Eng., Dept. of Civil Eng., Stanford University, Stanford, CA.
Koskela, L. (2000). "An exploration towards a production theory and its application to construction." D. Tech, Helsinki University of Technology, Espoo.
Liker, J.E. (2003). "The Toyota Way." McGraw-Hill, New York, 2003.
Matthews, J., Love, P.E.D., Heinemann, S., Chandler, R., Rumsey, C., and Olatunj, O. (2015). "Real-time progress management: Re-engineering processes for cloud-based BIM in construction." Elsevier, Automation in Construction, 58(C), 38-47.
Liu, M., Ballard, G., Ibbs, W. (2011). "Work Flow Variation and Labor Productivity: Case Study." ASCE, Journal of Management in Engineering, 27(4), 236-242.
Mulva, S.P. and Dai, J. (2012). "Performance assessment." Construction Industry Institute, Austin, TX.
Russell, A.D., Chiu, C.Y., and Korde, T. (2009). "Visual representation ofconstruction management data." Elsevier, Automation in Construction, 18 (8), 1045–1062.
Sacks, R., & Goldin, M. (2007). "Lean Management Model for Construction of High-Rise Apartment Buildings." ASCE, Journal of Construction Engineering and Management, 133(5), 374-384.
Sacks, R. (2016). "What constitutes good production flow in construction? Construction Management and Economics." Taylor and Francis, Construction Management and Economics, 34(9), 641-656.
Sacks, R., Radosavljevic, M. and Barak, R. (2010). "Requirements for building information modeling based lean production management systems for construction." Elsevier, Automation in Construction, 19, 641–55.
Seppänen, O. (2009). "Empirical research on the success of production control in building construction projects." Ph.D., Helsinki University of Technology, Espoo, Finland.
Shingo, S. and Dillon, A.P. (1989). "A study of the Toyota production system: from an industrial engineering viewpoint (Produce What is Needed, When it's Needed)." Taylor & Francis, New York, NY.
Tang, P., Grau, D., Ganapathy, R., Diosdado, J., and Abbaszadegan, A. (2014). "Workflow Stabilization with Fine-Grained Work Packaging and Near Real-Time Progress Monitoring." Proceedings from 22nd Annual Conference, International Group for Lean Construction, pp. 739-750, Oslo, Norway, June 25 – 27, 2014.
Thomas, H. (2000). "Schedule Acceleration, Work Flow, and Labor Productivity." ASCE, Journal of Construction Engineering and Management, 126(4), 261-267.

Tommelein, I.D., Riley, D.R., Howell, G.A. (1999). "Parade game: impact of workflow variability on trade performance." ASCE, Journal of Construction Engineering and Management, 125 (5), 304–310.

Wong, J., Wang, X. Li, H., Chan, G., and Li, H. (2014). "A review of cloud-based BIM technology in the construction sector." Journal of Information Technology and Construction, 19, 281–291.

STREAM 10: NOVEL DESIGN CONSIDERATION

Ghanem M., Albanna R., Hage R., and Hamzeh F. (2019). "Comparing Lean Management Principles and Evolutionary Design in Nature" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 573–582. DOI: https://doi.org/10.24928/2019/0229. Available at: <www.iglc.net>.

COMPARING LEAN MANAGEMENT PRINCIPLES AND EVOLUTIONARY DESIGN IN NATURE

Malek Ghanem[152], Rania Albanna[153], Ralph I. Hage[154], and Farook R. Hamzeh[155]

ABSTRACT

Evolutionary design is defined as a gradual process in which something changes into a different and usually more complex or better form. This process is apparent in nature where it is evolving towards the optimum solution. Lean is defined as a philosophy that aims at eliminating waste in production processes without compromising value. The two concepts appear in the literature as independent with little attempts to study a possible relation between them. The purpose of this paper is to explore synergies between the two seemingly distinct systems. This is performed by studying each notion on its own through breaking it down to its dynamic functional systems, and comparing the functions of each against one another. Findings reveal that the development of lean since its inception is comparable to the natural mechanisms of evolutionary design in nature. Findings suggest that lean is the natural course of evolution of construction management systems towards more optimal systems.

KEYWORDS

Lean construction, evolutionary design, nature, workflow, optimization, design science.

INTRODUCTION

Project management in general has been practiced since the establishment of humanity. From the first human settler tents in the heart of the African continent, to the Stonehenge monument in England, it helped -and continues to help- provide an environment which enables people to work together to reach a mutual objective. This long existence is proven by massive successfully built ancient projects such as The Pyramids of Giza, the Great Wall of China, and the Coliseum, among others. These enormous projects required innovative planning and detailed execution, accompanied with large workforce and scope,

[152] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Beirut Riad El-Solh 1107 2020, Lebanon, mng08@mail.aub.edu

[153] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Beirut Riad El-Solh 1107 2020, Lebanon, rma138@mail.aub.edu

[154] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Beirut Riad El-Solh 1107 2020, Lebanon, rih16@mail.aub.edu

[155] Associate Professor, Civil and Environmental Engineering Department, University of Alberta, Canada, hamzeh@ualberta.ca

and many years of execution. In the world of today, where societies have built their own grand and complex structures such as the Empire State building, Burj Khalifa, and the Eiffel Tower, there has been a vast increase in complexity in construction management – as construction management has evolved since humans first discovered how to build shelter.

LITERATURE REVIEW

EVOLUTION OF CONSTRUCTION MANAGEMENT

Unfortunately, there are only a few instances of documentation that show the construction strategies and techniques that existed in the far past. This scarce information is thought to be caused by various reasons such as that upper-classes of society focused more on the final structure than the construction aspect, and most importantly, craftsmen kept execution details secret among their tribes to preserve their specialization (Symour and Hussein 2014).

Throughout history, man has been working on improving and refining practices of project management until reaching the advanced systems known nowadays (Symour and Hussein 2014). The use of systematic project management techniques and tools to complex projects started around half a century ago. Prior to the 1960s, project management was moving from craft system to human relations administration. This was aided by technological advancement that helped in shortening project schedules. For instance, vehicles helped in resource transportation, telephones increased in the speed of communication, etc. Besides, the Gantt Chart was invented, and job specification was spread which became a basis for Work Breakdown Structure (WBS) later on (Kwak 2003).

Then, in the late 1950s until late 1970s, significant technology advancement was used to develop new project managing techniques and tools. For instance, Xerox invented the first paper copier, which helped mainly in documentation. Moreover, computer systems, programming languages, and the first email software were introduced in this era. In addition, some major project management tools were presented as well, such as CPM/PERT, Work Breakdown Structure (WBS), Material Requirement Planning (MRP), etc. Then in the 1980s, as a part of technology advancement, a revolution in Information Technology (IT) was observed. This uprising shifted managers from using mainframe computers that are not easy to use, into multitasking personal computers, which increased the efficiency and helped in managing large complicated projects. Besides, Internet in the mid-80s helped researchers and developers, and Ethernet technology became more commonly used (Kwak 2003). Moreover, an important management philosophy was introduced, the Theory of Constraints (TOC) (Symour and Hussein 2014).

In the 1990s, technology continued to develop, where internet had a major role in facilitating organizations' business and management, increasing their productivity and efficiency (Symour and Hussein 2014). Moreover, after having all these advanced tools that made complex project management much simpler, managers and researchers were thinking of new and updated concepts and strategies rather than tools. The aim was to reduce waste without affecting value. This was the main goal of what is called Lean Construction. Lean Construction has its origin from Lean Production System that was developed by Toyota that was led by Engineer Taiichi Ohno (Howell 1999). Lean theories were applied to construction at first by Glenn Ballard, Gregory Howell, and Lauri Koskela, and are still in continuous evolution. More importantly though, is how one initially approaches this new management system – and the correct way of doing so can be characterized in the following section by a quote from one of the most brilliant minds of recent history, Albert Einstein, when he says, "Fundamental ideas play the most essential role in forming a physical theory. Books on physics are full of complicated mathematical formulae. But thoughts and ideas, not formulae, are the beginning of every physical theory. The ideas must later take the mathematical form of a quantitative theory, to make possible the comparison with experiment" (Einstein and Infeld 1938).

The fact that Lean management started with efforts directed at the Toyota vehicular manufacturing process lead to many managerial features accredited by Toyota Production System (TPS) such as just-in-time inventory organization technique. This meant requiring less warehouse space, a smaller quantity of forklifts and superfluous spaces. Once the workflow is free of disturbances, materials taking up space, re-work and of inefficient re-looping, waste can be abolished – but more importantly, to be lean is to strive for endless improvement in all areas of work (Liker 2004). So as to improve the work of the die-press and decrease waste, Shigeo Shingo taught his workers the TPS principles, and requested that the workers think. He dared them to be pioneers, and to find ways to quicken the process as a whole by abolishing unnecessary activities. The workers who worked the press and changed the dye operated as a team and collectively overcame obstacles and pursued development. It was the hands-on workers, who were working on-site, and who had more valuable opinions, experience, and expertise than those who do not work hands-on, who experimented, observed the data, and learned from the actualities (Liker 2004).

Lean Management comprises this system of improving the work process by those executing the work hands-on. The example of Shingo asking the team to think, to test, and to learn from the data, is the model of lean management. This idea was rapidly copied by Honda and other Japanese corporations and has now evolved into the world-class standard in manufacturing and in management systems in all types of work environments. While lean management principles have been compared to some natural mechanism such as stigmergy (Khaddaj et al. 2016), this paper discusses how the evolution of Lean Management relates to evolutionary design in nature.

Evolutionary design in nature and Lean Management Principles are two independent systems. The first describes the mechanisms of change; whereas, the second describes principles that could be applied in processes, products, and collaborative activities. Although the two are separate systems, there are synergies that go beyond their basic definitions. But to what extent is the Lean Management System a natural evolution and optimization construction management, as compared to the natural evolutionary mechanisms in nature? What can evolution and optimization in nature tell us about the implementation of Lean principles? Before developing the answers, it is necessary to study the established ideas of both systems in the circles of academics and researchers.

METHODOLOGY

The objective of this paper is to derive a correlation between two seemingly independent concepts: Lean and evolutionary design in nature. In order to achieve the objective of this research, the following method was devised and followed: 1) define and understand evolution in nature and Lean as two independent dynamic systems 2) compare and contrast the two mechanisms 3) deduce the correlations 4) present the practical implications of the correlation.

LEAN PHILOSOPHY

Lean Management can be most completely understood as a way of life rather than a specific technique or method. Lean philosophy, attitudes, and culture can be summarized the fourteen principles of TPS that are to be mentioned in Figure 2, and may be described in the following set of statements.

Lean Management is a philosophy that aims at constant improvement practiced at all levels of the organization and by every team and team member, through studying work processes and systems and applying scientific methods of experimentation. Moreover, it is about respecting people, customers' needs, and those who do the work hands-on, who have more valuable opinions, experience, and expertise. Lean is the endless pursuit after removing waste in all its different forms, the capability to differentiate between work that adds value to the system and work that does not. It works towards having a work setting that guarantees the quality and safety of the work taking place for both the clients and the staff. It is focused on improving the process of work and not on blaming people or building fear and is a philosophy of teamwork, shared responsibility, and ownership that cuts through organization the many wasteful levels of bureaucracy. There are three pleasures of buying, selling and making the product. In relation, lean is a lifestyle that brings back the joy to work, and with this, the best work is produced. Lean is flow; it is, as much as possible, a disturbance free process that flows from start to finish without interruptions (Liker 2004).

EVOLUTIONARY DESIGN IN NATURE

Evolutionary design implies design modifications through time. The answer for the phenomenon of this design is explained through the Constructal Law accredited to Adrian Bejan. The Constructal Law states that flow systems should progress and optimize over time such that they provide better and easier access to the currents flowing through them. Constructal theory provides a broad coverage of “design” everywhere, from engineering to geography, biology, social sciences, animal design, technology and social organizations. So flow systems are everywhere, and they are governed by two properties: The current that flows (fluid, heat, mass, services, people, etc.) and the design through which this current flows. These properties are outlined in Figure 1. Flow systems exist with purpose, and once one realizes what is flowing through a system, one can think more clearly of what shape, structure, design, configuration, rhythm or architecture should emerge in order to help facilitate that flow. The design evolves over time to make flow easier, to make better designs, to increase flow access, to better achieve its purpose, to be more efficient, to enhance performance, and to offer greater and faster access to movement – this is what Bejan calls Constructal Law flows. This Constructal Law governs any system, anytime, anywhere and at every scale. It targets the inanimate such as rivers and lightning bolts, the animate such humans, trees, and animals, technological design such as cars, ships, and engines among others, and cultural concepts such as knowledge and language (Bejan 2016).

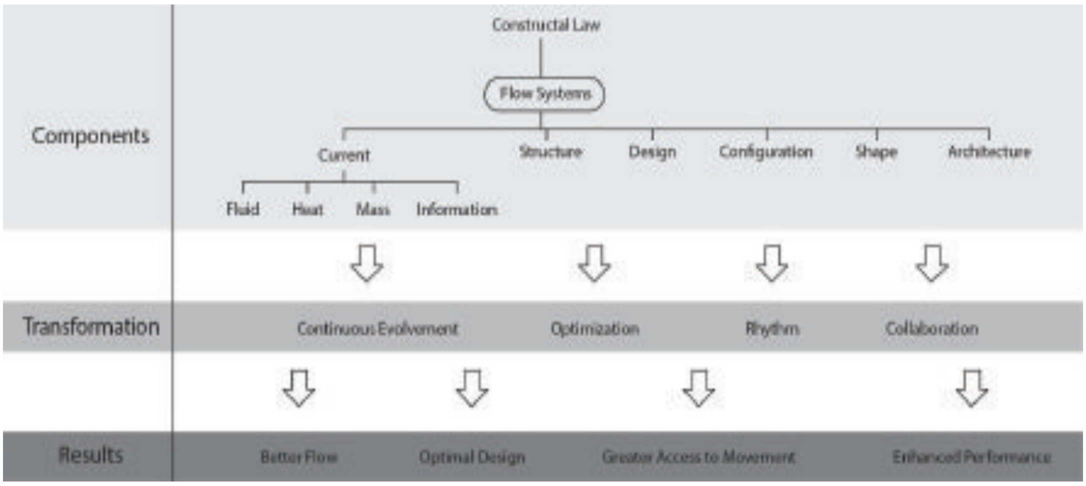


Figure 1: Constructal Law in nature.

Evolutionary design in nature is explained through the Constructal Law. The Constructal Law explains how the flow system generates its configuration in time and what mechanisms mark this flow system. For example, in evolution of sports, the mechanism of doing so is training, recruitment, mentoring, selection and rewards (Bejan and Lorente 2013). The phenomenon of evolutionary design is a global phenomenon. It is a naturally occurring phenomenon that is based on the Constructal Law, thus it is predicted and not descriptive and is apparent to the human senses. The design generation and evolution are macroscopic free movements that can be named: organization, configuration, architecture and change. The flow of this design runs in such a way that the existing pattern and organization are replaced by easier flowing configurations (Bejan 2016).

For example, the emergence and evolution of river basins shows that they are naturally and continuously replaced by forms that flow more smoothly. A river basin evolution produces an architecture (tree-like structure) that moves water (current) from the plain (area) to the river mouth (point). Over time, the river basins exhibit the hierarchical flow of large channels together with many small channels. Thus, it calls for a design with maximum flow access and optimal configuration. Treelike structures can be found as well in the air passage in lungs (a flow system for oxygen), the passage of electricity in the lightning bolt (a flow of electricity) and the transportation routes (a flow system for moving people and goods). Although tree-like structures are very common in nature, they are not the only manifestation of the Constructal Law. In addition to rivers, human beings are part of other, much larger, flow systems on Earth. When one gets into his car, he enters the flow of traffic. When one goes to work, he enters the flow of work related information. All these flow systems are morphing and evolving to facilitate the human movement; thus serving a much bigger picture: enhancing the global flow (Bejan 2016).

Constructal Law provides us with a perspective about the concept of evolution and the direction of these evolutionary changes with time. The continuous evolution of everything is never out of control. Plotting the history of the covered territory against time shows an

S-shaped curve. Every spreading flow has an S-shaped history of growth. It starts with an initial slow growth, followed by a much faster growth and a slow growth again.

Global optimization, rhythm and renewal, adaptation to nature or one's surroundings, collaboration and optimism are key features of evolutionary design. All of these are explained by the Constructal Law. Global optimization is observed through attaining the optimal structure, shape, design, configuration or architecture. This is not achieved by chance, but through continuous improvements for better performance and better results over time. Optimization is about choosing between the different alternatives that arise within the framework of set of constraints and resistance. It is based on the freedom to make the decision and replace the old existing configuration with a new configuration after a certain change has been done. The new configuration and as observed in most aspects is a more superior alternative in comparison to the older version, as observed for example in car manufacturing. Global optimization is a purpose driven process. It emerges after one is able to understand and realize the architecture of how the parts flow together; thus predicting the design and performance of the whole (Bejan 2016).

Rhythm is one of the features of evolutionary design. Everything in nature, from rivers to lungs, flows in patterns and rhythms. The pattern of evolutionary design follows a rhythm of continuous improvement. The mechanisms by which the flow systems achieve their goal mark the rhythm of the Constructal Law. The natural design is in the rhythm of systems, as it governs respiration, discretion, blood circulation, and other periodic body functions (Bejan 2016).

Collaboration is another feature of evolutionary design. Collaboration comes from labor, which means work, and work requires movement. In collaborating, entities are free to move, develop, change and find superior ways of flowing. Collaboration aims to help individuals flow together. Collaboration is a form of movement. It enhances the individual and the overall performance of the entities (Bejan 2016).

Evolutionary design has an optimistic vision towards life. Life is a universal tendency in nature. The positive outlook towards life goes hand in hand with making choices of purpose. When flow and movement stop, life ends. For example, when the current of information, materials and products stop flowing in a business, business would stop; thus reaching a dead end. When the configuration does not have the freedom to evolve and find better flow designs, the flow system stops. Evolutionary design never ends. The goal was and will always to be towards more life, better efficiency, greater movement, more access, increased flow, more freedom, longer life, greater wealth, and shorter paths (Dodds et al. 2015).

THE RELATION BETWEEN LEAN AND EVOLUTION IN NATURE AND PRACTICAL FINDINGS

Lean Production is based on the Toyota production system (TPS), which has emerged from unplanned results of separate enhancements (Fujimoto and Miller 2007) through following inductive methods to improve production systems. This subscribes to Aristotelianism (or Empiricism); an epistemology started by Aristotle (384 -322 BCE), who believed that scientific knowledge is based on perception (Lauri Koskela et al. 2019). According to

Koskela 2019, lean production (including lean construction) falls within Aristotelian Epistemology, whereby empirical reality has been used while following effective methods to extract knowledge completing the knowledge cycle that starts with deductive reasoning as stipulated by Platonism.

Going further with Aristotelian Epistemology, comparing lean to evolution in nature and trying to find their mutual constituents is a way for observing relations between them and seeking explanation which can be applied to particular cases, and then generalized to explain new observations.

Defining Lean principles and evolutionary design in nature each as a dynamic system allows their comparison. The two systems have common constituents and environments that interact dynamically with each other. Based on this initial relation between Lean and evolutionary design in nature, we will additionally relate the two based on their definition, features and through examples.

Despite being seemingly different concepts, Lean and evolutionary design in nature are comparable. It was deduced that the two systems are related and that evolution in nature can describe and justify the formation and use of Lean in the construction industry today. We will discuss how Lean and evolutionary design in nature are related through a few examples as categorized by definition, features and examples.

IN TERMS OF DEFINITIONS:

The phenomenon of evolutionary organization facilitates accessing everything that flows, evolves, spreads and is collected: technology, atmospheric and ocean currents, river basins, animal life and migration, besides other systems that fit within the evolution of the human and machine species, wealth and everything else that encompasses human life (Bejan 2016). In relation, lean principles aim to create "process" flow, and continuous improvement and development, which are related to evolution in nature as shown when river basins are ever changing to find optimum routes, or when migration patterns are optimized for shortest duration.

IN TERMS OF FEATURES AND EXAMPLES:

Lean applies the concept of standardizing tasks for continuous improvement – for example, the Lungs are the best organs at what they do because they do so consistently and do not change their function, the same can be said in lean – when each worker is assigned a standardized task, he will perform it better than a worker who works haphazardly. Lean principles linked to features and examples from nature may be summarized in Figure 2.

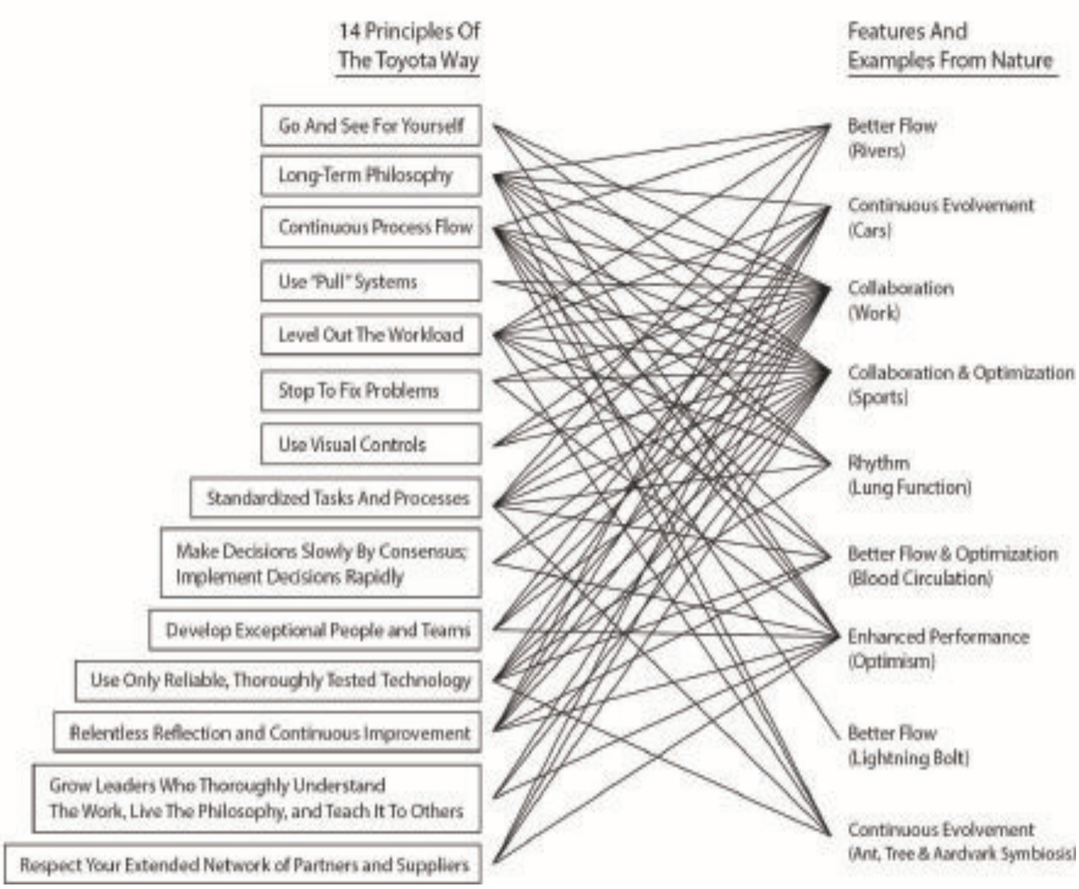


Figure 2: Lean principles as compared with features and examples from nature.

Optimism also goes hand in hand with making choices of purpose and can be found in nature in the will to survive, and in Lean in the principles of continuous development. Lean identifies one of its principles as identifying value and purpose in the eye of the customer – this is similar to natural selection in nature which identifies dominant and more resistant, or valuable, genes, as opposed to the recessive or one with less value in terms of survival. Optimization is attained by making changes and deciding between different options. To opt means to make a choice - or to have the ability to choose. Freedom of decision and capability to enhance, change, and develop the existing design define the major approaches toward change. Then comes the decision to choose between the alternatives that develop after the change. “To opt is not a one-punch boxing match. It is a relentless fight, because to find better choices after a change is good” (Bejan 2016).

Collaboration as found in nature is related to the Lean principles of seeing for oneself, developing exceptional people and teams, relentless reflection and continuous improvement among others. Examples in evolutionary design include the development of cars, and philosophies which govern sports. Another example found in nature is that of the symbiosis of the ants, trees, aardvarks, and river basins. Initially, a mound is full of termites. Aardvarks then dig around the mound and destroy it in order to reach the termites. However, the termites rebuild their galleries again. The target behind this three-way symbiosis is so that the fourth, most important member, the circuit of water, can benefit and flourish as a result of the ever-changing mound architecture. Just like lean, all of these factors are necessary. Without the water flow, the ants, trees and aardvarks would die – this relates directly to the lean principle of long term thinking and looking at the big picture. Without the first three, the water flow dies locally and moves to another mound, another nursery system – which is seen in lean in the form of bottlenecks, and that if the problem is not dealt with accordingly and at the source, bottlenecks will transfer from one area to another and persist. This example happens naturally without any interference; it always aims towards ease of flow in nature which relates directly to the Lean principles of continuous self-reflection, self-improvement, and continuous process flow.

Rhythm as found in nature is related to the lean principles of continuous process flow, levelling out the workload, standardizing tasks and processes, and in using only reliable technologies among others. Examples in nature include the functioning of the lungs and blood flow - each of which operate rhythmically and are assigned standardized tasks to undertake.

Continuous Evolvement as found in nature is related to the lean principles of relentless self-reflection and continuous self-improvement. Examples from nature include the flow of river basins which flow until they are at their optimum shape, in the migration patterns of birds which evolve to reach the shortest, most efficient route, and in the development of cars and ships which are continuously evolving to give the client maximum value.

Lean construction came as a new alternative for construction projects. It is a choice that is based on complete freedom. Lean principles demand continual organizational learning. Lean is the current "best" alternative, in the future, it may continuously improve to morph into another superior "best" concept.

CONCLUSIONS AND RECOMMENDATIONS

This paper explores synergies between the two seemingly distinct concepts of evolutionary design in nature and Lean management principles. This is performed by studying each notion on its own through breaking it down to its dynamic functional systems, and comparing the functions of each against one another. Findings reveal that the development of lean since its inception is comparable to the natural mechanisms of evolutionary design in nature.

Evolutionary design evolves over time to make flow easier, to make better designs, to increase flow access, to enhance performance and offer greater access to movement. Lean, on the other hand, represents a philosophy based on a long term thinking. Lean principles aim at optimizing the whole and not the parts to produce the desired value needed by the customer. This paper discusses how the two independent systems are related to one another. The division of each concept into its elements or principles help us realize that Lean is the natural evolution of construction management through relating it to evolutionary design in nature. The mere realization of the natural evolution of construction management into Lean can cast Lean in a new light, lend the system as more credible, and become conscious of construction system's continuous development and progress. Through the examples and figures provided, this paper shows how similarities exist between Lean and evolutionary design in nature both in theory and in execution. Timeless principles in Lean such as constant improvement, respect, removal of waste, quality and safety, not blaming people or building fear, teamwork, shared responsibility, flow, and positivity will always be present in future advancements of lean construction systems and methods.

Future research can possibly observe what nature's age-old wisdom can teach us, and see how we can apply its principles in advancing Lean. Further research may also consider further comparisons between evolutionary design and lean management.

REFERENCES

Bejan, A., (2016). The Physics of Life: The Evolution of Everything. New York: St. Martins Press.

Bejan, A. and Lorente, S., (2013) "Constructal Law of Design and Evolution: Physics, Biology, Technology, and Society," Journal of Applied Physics 113: 151301; Bejan, A., Entropy Generation through Heat and Fluid Flow (New York: Wiley, 1982), viii.

Dodds et al., P. S. (2015) "Human Language Reveals a Universal Positivity Bias," PNAS 112, no. 8: 2389–2394.

Einstein, A. and Infeld, L. (1938) The Evolution of Physics (New York: Simon and Schuster, 291.

Fujimoto, T., and B. Miller. 2007. Vol. 22 of Competing to be really, really good: The behind-the-scenes drama of capability-building competition in the automobile industry. Tokyo: International House of Japan.

Howell, G. A. (1999). What Is Lean Construction. International Group for Lean Construction (IGLC-7). Berkeley, California, USA.

Khaddaj, M.B., Kachouh, H., Halaby, B. and Hamzeh, F.R. (2016). "Lean Management Principles and Stigmergy." In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.7, pp. 23–32

Koskela, L., Ferrantelli, A., Niiranen, J., Pikas, E., & Dave, B. (2019). Epistemological Explanation of Lean Construction. Journal of Construction Engineering and Management, 145(2), 04018131.

Kwak, Y. H. (2003). Brief History of Project Management. In E. G. Carayannis, Y. H. Kwak, and F. T. Anbari, The Story of Managing Projects. Quorum Books.

Liker, J.K. (2004). The Toyota Way- 14 Management Principles from the World's Greatest Manufacturer. New York: McGraw Hill.

Symour, T., and Hussein, S. (2014). The History of Project Management. International Journal of Management and Information Systems, 223-240.

Steuer, D., Oprach S., Sonnabend F., and Haghsheno, S. (2019). “The General Contractor Response to Platform Ecosystems.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 583–594. DOI: https://doi.org/10.24928/2019/0211. Available at: <www.iglc.net>.

THE GENERAL CONTRACTOR RESPONSE TO PLATFORM ECOSYSTEMS

Dominik Steuer [1], Svenja Oprach [2], Felix Sonnabend [3] and Shervin Haghsheno[4]

ABSTRACT

Platforms enable value-creating interactions between producers and customers by mediating between their users. Supported by digitization, platforms use large datasets and integrated production systems to enhance the customer and producer experience. The platform's business model is expanding in the economy as digitization increases. In the context of the completion of building projects producers and customers find themselves in a complex tender and order process. On the producer side, the aim is to use resources as efficiently as possible and on the customer side to process orders as efficiently as possible. Digital platforms offer the potential to simplify the interaction between producers and customers and challenge the status quo of the classical general contractor (GC) business. Therefore, this paper investigates the impact on GCs by analysing expert interviews regarding business model implications for GCs through the development and emergence of digital platforms.

KEYWORDS

Business Model, Digital Platform, Network effects, Efficiencies

INTRODUCTION

"Firms that fail to create platforms and don't learn the new rules of strategy will be unable to compete for long" - with this statement van Alstyne et al. (2016) clarify which direction competition will take in the future.

Currently, van Alstyne and Parker (2017, p. 27) observe that platforms aggressively and disruptively penetrate existing markets - that is, platforms destroy existing structures and systems in the markets. The best-known examples of disruptive platforms are Airbnb in the hospitality and Uber in the transport industry. According to Parker et al. (2016, p. 2 f.), the networked business model is the driving force of the success behind the platforms. The networked business model is essentially based on supporting interdependent users in

[1] Research fellow, Karlsruhe Institute of Technology, Germany, +49-721-608-44122, dominik.steuer@kit.edu

[2] Research fellow, Karlsruhe Institute of Technology, Germany, +49-721-608-43650, svenja.oprach@kit.edu

[3] M. Sc. Student, Karlsruhe Institute of Technology, Germany, +49-721-608-44122, dominik.steuer@kit.edu

[4] Professor, Karlsruhe Institute of Technology, Germany, +49-721-608-42646, shervin.haghsheno@kit.edu

creating value by enabling direct interactions between them. According to Amit and Zott (2001, p. 495), this business model increasingly replaces traditional brokers of products and services. Parker et al. warn that basically any industry can be the target of these disruptive platforms. Especially chaotic and fragmented markets are prone to be disrupted by platforms (Choudary, 2017b).

With regard to the construction industry, Koskela (1992, p. 4) describes the existing fragmentation of work as the biggest problem. This places the construction industry directly in the focus of the platforms. For the construction industry, Alhava et al. (2017, p. 575) therefore predict a disruptive process in two steps:

1. Efficient companies will replace inefficient companies.
2. Networked business models will replace traditional business models.

In the long-term, as seen in other industries, competition will no longer take place between products, services and processes, but between business models (Gassmann et al. 2017; Choudary et al. 2013). Therefore, companies will need to focus on the development of business models to stay competitive in the future (Pekuri 2015, p. 48; Chesbrough 2007, p. 12). Gassmann et al. (2017) even see this as an additional potential for innovation, which in many industries has not yet been tapped.

LITERATURE OVERVIEW

The broad interest for business models just started around the turn of the millennium with the internet emerging (Teece 2010, p. 174; Morris et al. 2005, p. 727). Also, the first scientific paper regarding platforms was published in that period. In 2003 Rochet and Tirole investigated the business models of companies from the telecommunication industry and with their findings shaped the concept of the platform business model.

Despite the developments in other industries, within the construction industry Pekuri et al. (2013) state that business models receive too little attention. As a result, Pekuri published four publications by 2015. There he examines the understanding of managers in the construction industry regarding the concept of business models and shows how business models can be used to analyze and control the value added in construction companies. He also dealt with the role of business models in the selection of projects and the lean transformation of companies in the construction industry.

Laine et al. put forward the first publication that links construction, business models and platforms in 2017. They describe the failure of classical business models and the potential of digital platforms in the construction industry. However, they also find that their results need to be tested. Alhava et al. (2017) published the next article on platforms in the construction industry in the same year. Their aim is to highlight the differences between network and traditional business models and the maturity of business models in the construction industry. They come to the conclusion that business models in the construction industry follow traditional patterns and therefore there is a great potential for disruption. Consequently, they call on the players in the construction industry to promote the development of their business models. They also recommend developing digital platform within the construction industry before aggressive forces outside the market bring about disruptive change.

RESEARCH OBJECTIVE

Building on the work of Laine et al. (2017) and Alhava et al. (2017) this paper investigates the implications of digital platforms and the reaction of GCs. The general contractor was chosen because they are filling the role of the classic intermediaries for services and information in the construction industry (Laine et al. 2017, p. 177). They match the demand of the client with the competences of subcontractors, but don't allow any direct interactions between them. Therefore, they are particularly at risk of being subject to competition from networked business models. In order to thrive in future competition, general contractors must therefore address networked business models to develop knowledge and a strategy themselves. The aim of this research therefore is to evaluate the challenges and opportunities of digital platforms and the new business models for the GC to formulate recommendations for action. In order to do so, three major research questions are addressed:

1. How is the understanding of the concept of business models in the construction industry?
2. What is the status quo business model of the GC in the German market?
3. What are the potentials and challenges concerning platforms in the construction industry?

METHOD

Data was collected through seven interviews with industry experts from the German construction market. The experts were selected focusing on their role and market understanding. The interviewees have different professional backgrounds from project control, consulting, GC and client construction department. It is important to mention, that this sample does not consist of all the stakeholders of a construction project – i.e. planers, subcontractors and authorities were not interviewed.

The interview partners (IP) are employed in roles from a construction manager to a CEO level. The average work experience is above 15 years (15,71 years). The first contact was established via email. The interview itself was conducted in person or via Skype. Since the amount of available data for the underlying question is very low, the aim is to give a first orientation in the field. Therefore the authors decided to focus on explorative and speculative interviews to gather opinions and interpretations of the experts.

Table 1 provides and overview of the interview structure. Following the research questions, the interviews was divided in three main sections, (A) Understanding of Business Models in the Construction Industry, (B) the Business Model of GCs and (C) Potentials of digital platforms in the construction industry. Every section is divided into categories. This enabled the authors to analyse and compare the data in a matrix. For the evaluation of the expert interviews the authors applied a qualitative content analysis. For this the statements of the experts were assigned to one of the categories. The categories for Section A and B have been developed deductively, whereas the categories for Section C were developed inductively. To set a common data base and understanding of the concept of business models, in section B the business model of a GC was put together collaboratively using the Business Model Canvas (BMC) developed by Osterwalder and Pigneur (2011). According to them a business model defines the logic of how a company creates, delivers and captures value. In order to create a framework to enable structured communication and analysis of business models, they created the BMC, which consists of nine elements to describe the underlying business model of a company.

Table 28: Interview structure

NR.	CATGEGORY	DEFINITION
	SECTION A: UNDERSTANDING OF BUSINESS MODELS IN CONSTRUCTION	
A.1	Experience	Experience gained through working career
A.2	Association	Free thoughts in regard to business models
A.3	Elements	Elements of business models
A.4	Function	Function of business models
	SECTION B: GC'S BUSINESS MODEL	
B.1	Customer segments	Elements that define a business model according to the Business Model Canvas framework of Osterwalder and Pigneur (2011).
B.2	Value Proposition	
B.3	Channels	
B.4	Customer relationships	
B.5	Revenue stream	
B.6	Key resources	
B.7	Key activities	
B.8	Key partner	
B.9	Cost structure	
	SECTION C: POTENTIAL OF DIGITAL PLATFORMS IN CONSTRUCTION	
C.1	Potentials for building industry	Digital platform incentives for the industry
C.2	Potentials for companies	Digital platform incentives for companies
C.3	Potentials for clients	Digital platform incentives for clients
C.4	Requirements	Special requirements regarding the construction industry
C.5	Risks for GCs	Risk for displacement by digital platforms

RESULTS

SECTION A – UNDERSTANDING OF BUSINESS MODELS IN CONSTRUCTION

As already seen by Pekuri et al (2013, p. 9), Section A put forward the thesis that there is no common understanding of the concept of business models in the construction industry. In their interviews, they found that managers in the construction industry claim to have an understanding of business models. However, they also found out that each of these managers has their own understanding of the concept of business models. The interviews with experts conducted in the context of this work confirm this finding.

Section B – The Business Model of the General Constructor

The results of the evaluation of Section B are shown in figure 1. As described by Laine et al. (2017) the GCs business model follows a linear logic (pipes). Value is created upstream and consumed downstream. According to the interview partners, the main value proposition of GCs is to reduce the complexity of the building project. Additionally, they take over the risks in terms of time, costs and quality. Through value engineering GCs also offer the customer optimized solutions.

Figure 1 shows, that in order to compete in their market, the emphasis of the GCs business model is on the price. Consequently, the GCs focus is to reduce cost to achieve cost leadership in the market. In the logic of the GC business model this is achieved through project specific procurement of capacities. This way they ensure, that their internal resources are fully occupied. To realize better prices, GCs trie avoid direct competition and try to receive orders directly, i.e. in the form of follow-up projects. Nevertheless, the core business of GCs seems linear, their structure and organisation show characteristics of a network business model. One of the key resources of the GC's business is their network regarding subcontractors and supply chain, but since this network is not transparent to the client, GCs act as inefficient gatekeepers.

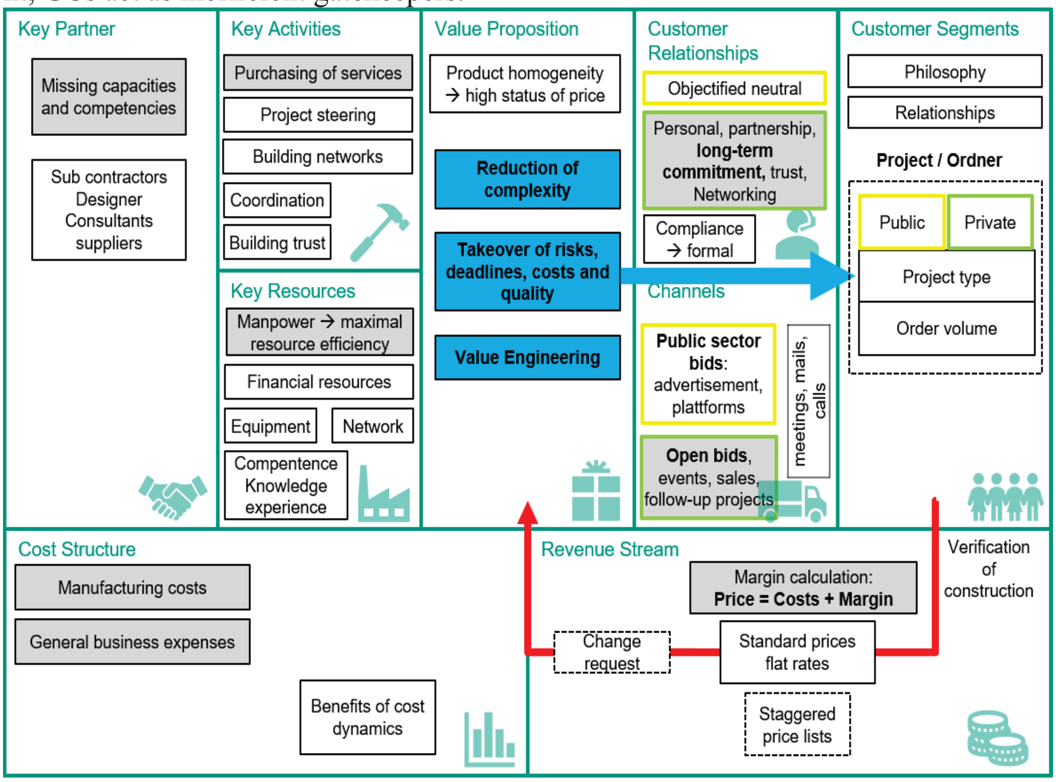


Figure 65: GC's business model based on BMC

Section C – Potentials of Digital Platform in Construction

In Section C all the findings regarding the potentials of digital platforms within the construction industry was gathered. As potential users of the platform all IP name the clients on the tendering side and a selection of project participants on the bidding side. In the interviews, the experts were asked about the potential of a digital platform in their own environment. The potentials for the construction industry, construction companies and owners were queried in detail. The categorisation of the statements by means of qualitative content analysis led to two central approaches: potentials with regard to tendering and awarding of contracts and potentials with regard to the provision of a production system.

The potential of a digital platform in the construction industry for the processes of tendering and awarding contracts is mentioned by all interview partner. This potential is closely related to the key activity of digital platforms to connect and enable interaction between the users.

IP 5 states that contracting authorities can benefit in particular from the standardisation of tender documents. This makes it easier and faster to compare offers. IP 7 also claims that through standardisation digital platforms can save clients time in research and competition enquiries and thus directly save costs. IP 1 sees the greatest potential for clients in the evaluation of contractors. He claims that every company on the platform is interested in positive evaluations and therefore, in addition to saving time, a general increase in quality can be expected. IP 2 also sees great potential for builders in evaluation systems. In his opinion, a transparent evaluation system creates a self-levelling system that drives performance and quality and thus added value for the customer. Furthermore, he explains that building owners can make faster and better decisions, because the system allows to distinguish more easily between good and bad contractors. IP 1 therefore not only sees an increase in quality, but also a decreased time span for clients to place an order. According to IP 3, providing a simple way of commissioning high-quality companies saves costs. IP 4, on the other hand, sees the benefit for clients not only in the reduction of their own costs for processing tenders, bids and awarding contracts, but in the reduction of the bid price. He justifies this through the fact that with transparency and evaluation systems, the competition between contractors will become more professional and pressure on cost leadership increases further.

According to IP 5, the other side of the platform – the bidding side - also benefits from standardisation. For companies, the transparency of the required documents makes the bid preparation process easier. This gives them additional security when bidding. According to IP 7, companies can thus acquire orders more quickly. But evaluation systems also have advantages for the bidding companies on the platform. For example, IP 1 explains that the evaluation of building owners can give entrepreneurs information about their payment loyalty. IP 2 also claims that evaluation systems reduce the relevance of the size of businesses and make smaller businesses more competitive. Platforms therefore give small businesses a fair chance to win more contracts for good performance. Instead of good performance, IP 1 speaks of competition over quality. IP 3 also sees evaluation systems as a potential for companies and in this respect, continues to argue that evaluation systems also make it possible to take soft skills into account when awarding contracts. Additionally, IP 3 sees the possibility for companies to show their presence on the platform and use it for marketing purposes.

At this point it must also be noted that four of the seven interview partners take a critical view on evaluation systems. IP 3, for example, warns about paid (unregular) evaluations. The IP thus draws attention to the fact that mechanisms have already been developed in existing digital platforms to manipulate rating systems. IP 7 also questions the significance of rating systems. He justifies this with the danger that rating systems can be leveraged by collusion. As an example, he cites an entrepreneur who waives a certain supplementary sum for a positive rating. IP 5 also questions which criteria are used for the evaluation or selection. He doubts the potential of evaluation systems and questions their significance analogous to IP 3 and IP 7 with regard to manipulation possibilities. He sees references from resilient sources as an approach for a reliable rating system. IP 7 considers the same approach necessary for an evaluation system in the construction industry. In his opinion, a rating system can only work if it is objective, fair, transparent, reliable and not anonymous. IP 4 also highlights the benefits of rating systems in question. In his opinion, in the end the cheapest alternative is chosen and quality is neglected. He therefore fears that competition for the best price will become tougher for companies, but that customers will be rewarded with lower prices.

Four of the seven experts see the potential of a digital platform to set up a production system for its users. IP 2 stresses that the coupling of users to the platform alone is not enough. Furthermore, according to him, the digital platform must coordinate its users by providing them with a production system. The setting up of a production system is closely related to the key activity of platforms to reduce resistance in interactions.

Three of the seven IPs explain that the benefits for users of providing a production system through a digital platform lie in particular in the standardisation of service delivery processes. IP 1 explains in more detail that digital platforms provide transparency because they require simple and clearly defined processes. He explains that there is no room for interpretation within digital platforms, as in the digital world only true and false can be distinguished.

For service providers, this means that they are given transparency over the building owners planning and decision-making processes. According to IP 1, the resulting common understanding of the processes and procedures ultimately leads to service providers being able to work more efficiently - thus optimising their value-added process. IP 7 adds that process transparency helps to eliminate uncertainties and allow providers to set deadlines early. This means that vendors can better schedule their resources and use them more efficiently. In this context, IP 7 is designing the vision of a product configurator on the part of the building owners - similar to the one used by the automotive industry for the individual configuration of vehicles. In his opinion, such a product configurator in combination with other technology can be used to create a virtual experience of the end product. In addition to the purely visual experience the configurator also provides information on price and dates based on stored standard processes and data. This improves the decision-making basis for building owners.

IP 5 and IP 6 also see a special added value for the users in the integrated handling of the project in the production system of the digital platform. This shortens information paths and makes data more accessible. Users can access all data regarding costs, deadlines and qualities over the entire life cycle of the property. According to IP 7, the collected data will enable the foresighted generation of information on prices, construction processes and deadlines. According to IP 6, the data can be used directly during the project to map the effects of changes on deadlines and construction processes in real time. Looking back, IP 5 also sees the possibility of cost monitoring and controlling by connecting the platform to a platform on the client side. IP 7 also states that, similar to the commissioning of general contractors, building owners have a central contact person via the platform. Four of the seven IP explicitly see a potential for digital platforms in the construction industry in the support of communication. According to IP 7, clear communication can be achieved with a digital platform. According to IP 3, the usual tactics in meetings to optimise one's own interests can be prevented. In this regard, like IP 5, he mentions digital project rooms in particular, in which a project file with access rights for all participants exists. This reduces information asymmetries and builds trust.

SECTION C – CHALLENGES OF DIGITAL PLATFORMS IN CONSTRUCTION

In addition to the potentials, all IP also see special characteristics and obstacles in connection with the development of a digital platform for the construction industry. According to IP 7, the characteristics of the construction industry in particular pose challenges for the implementation of a digital platform. In his opinion, the characteristics of the building industry strongly differentiate it from other industries in which digital platforms have already established themselves. Some of these characteristics will be examined in more detail below. The potential to achieve a common understanding of the product and the processes is critically questioned by IP 1 with regard to the high complexity in the construction industry. IP 5 and IP 7 also see complexity as a challenge for the development of a digital platform for the construction industry. According to IP 5 and IP 7, the high level of complexity is accompanied by the usually high investment sums for construction products. According to IP 7, this leads to long financing terms in the construction industry. He therefore believes that the value of products also plays a more decisive role in the construction industry than in other sectors. IP 5 cites an analogy to Amazon in this context. An error in an order at Amazon usually has no consequences due to a customer-friendly right of return. However, a building in which an error is made in the order cannot simply be returned without consequences. This analogy is linked to another characteristic of the building industry, which IP 7 regards as a challenge for the development of digital platforms: In the construction industry there are construction contracts for each project. This means that each product is a prototype. IP 7 explains that the constant production of unique products hinders the learning curve in terms of process efficiency. He compares the automotive industry with the construction industry and finds that the automotive industry also needs several years to produce its prototypes. However, as soon as they manufacture the products in series, the learning curve leads to an enormous increase in efficiency. This extreme learning curve, which is also based on standardization, cannot be achieved in this way by the engineer-to-order oriented construction industry. IP 7 also explains that disturbances are always to be expected in construction projects. In addition to the complexity, this is due to the fact that production takes place on site. Because of the disruptions, he believes that a high level of social competence is always necessary to solve problems in construction projects. Similarly, IP 6 states that the basic prerequisite for a digital platform in the construction industry is human monitoring. This has to identify problems and risks and communicate them, especially during the construction phase. According to IP 1, IP 4 and IP 7, a special degree of trust is also necessary, particularly because of the high investment volume. IP 1 and IP 7 consider the establishment of trust between the users of the platform (client and project participants) to be particularly necessary. IP 4 also emphasises that users should also be able to trust the platform with regard its liability. In contrast to IP 1, IP 4 and IP 7 rating systems take a critical view of building trust.

	Status Quo - GC	Potential for digital platforms in the construction industry		Challenges for digital platforms in the construction industry	Recommended action for GC
		Tender, award, contract	Provision of a production system		
Customer Segment	Professional client who wants to realize complex projects order / project specific categorization: Public / private Project content / industry project scope Farther: Basic philosophy / relationships				Consciously perceive that both the client and the key partners from the status quo represent customers. Definition of the sides of the platform (including preview of potential sides).
Value Proposition	Reduction of complexity. Taking risks for deadlines, costs and qualities. Value engineering. Value offer is perceived very homogeneously by the customers, therefore the significance of the price is high.	Enable direct interaction	Simplify direct interactions		Focus on enabling direct interaction between users. Start with the tendering, assignment and order processes creating the basis for further interactions. Value offerings from the status quo of the GC are taken over, but must be reinterpreted (elimination of friction by providing a production system).
Channels	Public client: Public tenders, submission of tenders, placing of orders (open and transparent competition according to VOB). Private client: Classic sales work: building relationships, maintaining networks, organizing events. Follow-up contracts. After placing the order, communicate via regular meetings, e-mail traffic and telephone calls.	Order brokerage via platform	Integral handling on platform: Platform as digital project space is central processing point → Short information paths. Throughout the lifecycle there is the possibility to access all data of the building in terms of cost, deadline qualities → Predictive, real-time and retrospective planning and control of costs and deadlines.	Disruptions are unplanned and can not be predicted. Legal Challenges in the award of public services.	Open channels and drop gatekeeper function. Define role as mediator. Enable the collection of data (→key ressources) Initially exclude public clients.
Customer Relationship	Public client: formal and neutral. Private client: Shaped by personal cooperation, partnerships, long-term relationships, building trust. Formality due to compliance regulations.	Rating Systems: Create transparency and trust. Simple decision-making basis for builders. Clients processes become more time and cost efficient. Orders are awarded at lower asking prices but with better quality. Information about payment loyalty. Increase the competitiveness of smaller businesses. Competition over quality. Consideration of soft skills at assignment.		Due to the high level of investment, a particularly high degree of trust is necessary. Users must trust each other but also trust the platform itself to be responsible. Rating systems do not create enough confidence because they are susceptible to manipulation. Construction projects require a high level of social competence to solve problems. Human surveillance is a prerequisite. A new kind of contract becomes necessary.	Become aware that the focus is in developing community. Rethinking from acquisition of projects to acquisition of users. Strong control of the offered service by the platform operator. For example, regular on-site inspections of specially trained staff of the platform (→ key resources). Build the rating system on references from reliable sources. Ensure liability of the platform through banks and insurance companies (→ key partner). if applicable with own fortune. Maintain human component. Specialists take care of problem solving in conflict situations. Establish contracts for users of the platform in the form of codes of conduct. Implement intensive feedback loops to evaluate these rules.
Revenue Streams	Source of income: client. Price: Cost plus surcharge. Revenues: after proof of performance.			High investment volume for the products.	Start with small orders or partial orders. Plan the monetization strategy: Potential source of income: all sides. Price: Define price level and price structure according to the added value for each page. Revenue streams: transaction-dependent and / or independent.
Key Ressources	Staff → Focus on maximum utilization equipment network Competence, knowledge, experience Financial ressources				Retrain specialist staff. Make expertise, knowledge and experience available in the form of data for the platform. Tap existing networks and make them available for the platform. Development of the technical infrastructure.
Key Activities	Purchase of service Building networks Building trust coordination project management	Standardization: Offers become more comparable. Building owner processes become more time and cost efficient. Transparency and understanding of documents to be submitted and evidence of offer. Creation of offers is simplified. Acquisition of orders becomes more time and cost efficient.	Standardization: Product configurator enables virtual experience of the product and provides real-time information about costs and deadlines. Creating a common understanding as builders, planning and decision-making processes become more transparent. Appointments can be fixed early. This eliminates uncertainties and resources can be optimally planned. More efficient work is possible.	Due to the high complexity of the construction industry, a common understanding is questionable. The peculiarity of the construction industry is that every building is a prototype. Standards for unique items are only possible on an abstract level. Construction processes are exposed to external disturbances that can not be controlled and planned.	Start with standardization of tendering, assignment and order processes. Gradual standardization of planning and execution processes from simple to highly complex processes. Clear definition of the interfaces. Excessive data collection. Implement feedback loops to evaluate and optimize the standardized processes.
Key Partners	Acquisition of missing capacities and competencies: subcontractors planners consultants Suppliers				Understand that key partners from status quo in the platform represent customers. Winning partners with a focus on reducing frictions in the interactions. For example: Banks for financing. Insurance for liability. Authorities for qualification certificates of companies.
st ucture	Cost of production General business costs Great momentum especially in the manufacturing costs				Invest in acquisition of users and development of technical infrastructure.

Figure 66 – Recommended actions for GC

In addition, there are still a number of challenges with regard to legal issues. IP 3 and IP 6, for example, mention the Federal Procurement Act. This obliges contracting authorities to publish in public media. This means that the potential of a digital platform in terms of tendering, awarding and contracting processes is initially not accessible to public developers. According to IP 2 and IP 5, cooperation in digital production systems on digital platforms continues to require a new type of contract. According to IP 2, the first approaches towards new contracts have already been made with Alliancing and the Integrated Form of Agreement.

DISCUSSION

The matrix in figure 2 links the findings of sections B and C and derives recommendations for actions. All results in this matrix are related to the BMC. The first column represents the starting point for the definition of the recommendations for action. It therefore reflects the status quo of the GC's business model (section B). The next two columns show the potentials with regard to tendering and awarding contracts as well as the provision of a production system (section C). The potentials were also assigned to the elements of the BMC. For this purpose, the potentials were broken down into their approaches and assigned to the BMC elements. The next column shows the challenges that digital platforms will face in the construction industry (section C). These are also assigned to the individual elements of the BMC, analogous to the potentials.

The recommendations for action for general contractors are derived from the status quo, the potentials, the obstacles and the general principles of networked business models. These recommendations are made for each element of the business model to develop the GC's business logic in the direction of networked business models. Based on this GCs can formulate concrete measures for the elements of their business models. This is the first step in transforming their business model towards a platform. It was found that there is potential for a digital platform in the construction industry, in particular with regard to the tendering and awarding of contracts and the provision of a production system. The added value of these potentials lie on the one hand in the fact that direct interactions are made possible and on the other hand in the fact that these are simplified. With these first potentials, the central value proposition behind the logic of the networked business models is implemented. The second potential focuses on the key activity of networked business models to reduce resistance. The potentials are based on three approaches: standardization of processes and documents, establishment of evaluation systems and integration of interdependent processes. In addition, the interviews have shown that challenges lie above all in the characteristics of the construction industry. The high complexity of building projects, which leads to high investment costs and therefore requires a special degree of trust, is to be emphasized in this connection.

LIMITATIONS

This research paper gives a first brief look into the GC's awareness of the challenges and transformations they face. In consideration of the fact that the underlying sample is limited to depicting a part of the German construction industry, further research and in-depth analysis are needed to gather more data and examine the impact on the GC's business model and their ability to adapt to the changing market conditions.

REFERENCES

Alhava, Otto; Laine, E.; Kiviniemi, Arto (2017). „Construction Industry needs an Airbnb of its own!" ResearchGate.

van Alstyne, Marshall W.; Parker, Geoffrey G.; Choudary, Sangeet Paul (2016). „Pipelines, Platforms, and the New Rules of Strategy." Harvard Business Review.

van Alstyne, Marshall; Parker, Geoffrey (2017). „Platform Business: From Resources to Relationships." Platform Business 9(1), S. 24–30. DOI: 10.1515/gfkmir- 2017-0004.

Amit, Raphael; Zott, Christoph (2001). „Value creation in E-business." Strat. Mgmt. J. 22(6-7), S. 493–520. DOI: 10.1002/smj.187.

Chesbrough, Henry (2007). „Business model innovation: it's not just about technology anymore." Strategy & Leadership 35(6), S. 12–17. DOI: 10.1108/10878570710833714.

Choudary, Sangeet Paul (2013). „Why Business Models Fail: Pipes vs. Platforms." WIRED. Available online at https://www.wired.com/insights/2013/10/why- business-models-fail-pipes-vs-platforms/, last checked on 07.02.2018.

Choudary, Sangeet Paul (2017b). „The future of competition Platform Strategy." Pipes to Platform. Available online at http://platformed.info/the-future-of- competition/, last checked on am 21.12.2017.

Gassmann, Oliver; Frankenberger, Karolin; Csik, Michaela (2017). „Geschäftsmodelle entwickeln: 55 innovative Konzepte mit dem St. Galler Business Model Navigator." Hanser, München.

Koskela, Lauri (1992). „Application of the new production philosophy to construction." Stanford University Press, Stanford.

Laine, Enni; Alhava, Otto; Peltokorpi, Antti; Seppänen, Olli (2017). „Platform Ecosystems: Unlocking the Subcontractors' Business Model Opportunities." 25th Annual Conference of the International Group for Lean Construction, S. 177–184. DOI: 10.24928/2017/0325.

Morris, Michael; Schindehutte, Minet; Allen, Jeffrey (2005). „The entrepreneur's business model: toward a unified perspective." Journal of Business Research 58(6), S. 726–735. DOI: 10.1016/j.jbusres.2003.11.001.

Osterwalder, Alexander; Pigneur, Yves (2011). „Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers." Wiley.

Parker, Geoffrey; van Alstyne, Marshall W.; Choudary, Sangeet Paul (2016). „Platform Revolution: How Networked Markets are Transforming the Economy-and How to Make Them Work for You." Norton & Company, New York.

Pekuri, Aki (2015). „The role of business models in construction business management." Universitatis Ouluensis.

Pekuri, Aki; Pekuri, Laura; Haapasalo, Harri (2013). „Business models in construction companies - construction managers' viewpoint." International Conference on Technology Innovation and Industrial Management TIIM2013.

Rochet, Jean-Charles; Tirole, Jean (2003). „Platform competition in two-sided markets." Journal of the european economic association 1(4), S. 990–1029.

Teece, David J. (2010). „Business Models, Business Strategy and Innovation." Long Range Planning 43(2-3), S. 172–194. DOI: 10.1016/j.lrp.2009.07.003.

Torp, O. (2019). "How Stochastic Cost Estimates Could be Applied in Relation to Target Value Design." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 595 - 606xx. DOI: https://doi.org/10.24928/2019/0239. Available at: <www.iglc.net>.

HOW STOCHASTIC COST ESTIMATES COULD BE APPLIED IN RELATION TO TARGET VALUE DESIGN

Olav Torp[1]

ABSTRACT

Approaches like Target Value Design (TVD) has gained more and more attention in the Construction Industry. Critical issues with these principles are how the cost targets are set, how shared profit is agreed upon and made transparent, and how production costs are steered towards the target costs and tracked. Research has shown positive applications of TVD, but also remaining challenges with the approach. This paper will focus on the process of setting the cost targets in TVD. In traditional design processes, the costs are estimated based on the finalized design. In TVD, design and construction is steered towards the constraints, while maximizing the value for the costumer. Based on the client value, Allowable Cost are set. In Scandinavian countries, stochastic cost estimation methods have been applied to estimate project costs and to set cost targets for projects over many years. The cost targets are set prior to detail design. The purpose of this paper is to discuss how stochastic estimates could be applied in TVD. The method used is a literature review, in combination with a case study of cost estimation principles in two Norwegian public agencies. Findings show that stochastic cost estimates could be used both as input to set Allowable Cost and to estimate the Market Cost.

KEYWORDS

Target value design, target costing, stochastic cost estimation, cost target

INTRODUCTION

Target Value Design (TVD) has gained increased attention in the construction industry over the latest years. Successful application of TVD in construction has been reported (e. g. Ballard and Reiser 2004; Ballard and Pennanen 2013; Tillmann et al. 2017). Still, it seems like the application of TVD with the support of Integrated Project Delivery (IPD) principles some projects struggle to meet their target costs (Tillmann et al. 2017).

Tillmann et al. (2017) report that factors that influence the ability to deliver a project to target costs are 1) how cost targets are set and market price is estimated, 2) how shared profit is agreed upon and made transparent and 3) how production costs are steered towards the target cost and tracked, so risks can be identified and mitigated. This paper focus on

1 Associate Professor, Norwegian University of Science and Technology, Trondheim, Norway, +47 934 226 73, olav.torp@ntnu.no.

the first aspect mentioned above, more specifically challenges related to how to set the cost targets and estimate market price in Target Value Design.

All cost estimates and targets are forecasts and uncertain numbers. Particular cost models are developed to address variability and uncertainty, e.g. stochastic cost estimation methods (Nguyen et al. 2008; Lichtenberg 2000). In the Scandinavian countries, stochastic cost estimation methods are widely used to estimate project cost and as a basis for setting cost targets. The purpose of this paper is to discuss how to apply stochastic estimates in TVD. To achieve the purpose of the paper, we address the following research questions:

1. How are cost targets set in TVD?
2. How are cost targets set with stochastic cost estimates?
3. How can stochastic cost estimates contribute to TVD?

RESEARCH METHOD

To address the research questions, a literature review and a case study was performed. The literature review aimed for a general overview of the literature on Target Value Design, and was applied to answer the first research question. The case study aimed to answer the second research question. To answer the last research question, results from the literature review and from the case study were used to discuss opportunities to use stochastic estimates in TVD.

The literature review was performed by searching for literature in databases like the university database Oria, Google Scholar and at iglc.net to find previous IGLC-conference papers. Search words like Target Costing, Target Value Design and Target Value Delivery were used. Search on Target Costing resulted in over 1000 hits in Google Scholar and 300 in Oria, most of them related to manufacturing and industry. Search for Target Value Design resulted in around 100 hits in Google Scholar and around 50 in Oria. Some relevant articles were picked based on these searches. Search for Target Value Delivery gave 16 hits in Google Scholar and 5 hits in Oria, all relevant. The literature was scanned and relevant sources were analysed for content on how targets are set and applied in TVD.

The case study approach proved a sound research method for studying how cost targets are set in two Norwegian public agencies. The method contributes to extending our knowledge and understanding about the phenomena, and is according to Yin (2014), a preferred method for answering 'how' research questions. The public agencies Norwegian Public Roads Authority and Statsbygg, the Norwegian public builder and building owner, were chosen based on their extensive experience with stochastic cost estimates. The case study was performed by document study of internal routines for cost estimation and cost management. This provided a convenient source of insight into the particular phenomena studied (Fellows et al. 2015). Furthermore, the use of documents provided some essential advantages as a mean of collecting data, as documents are non-reactive and a stable source of data, i.e., unaffected by the research process (Bowen, G.A 2009).

TARGET VALUE DESIGN, CONCEPTUAL COST ESTIMATES AND SETTING TARGETS

Target Value Design (TVD) is a management practice in which the design and construction are steered towards the project constraints while maximizing customer value (Ballard, 2011). TVD was adopted from Target Costing (TC), a management practice that has been widely used in the new product development and manufacturing industries to ensure predictable profit planning (Cooper and Slagmulder, 1997; Feil, Yook and Kim, 2004). In Target Costing, the cost is an input in the design stage rather than an output of it (Do et al. 2015). In Target Value Design, the customer Value, rather than the costs, serves as input to set the cost targets. Target Value Design focus on setting targets, design to targets and build to targets (Zimina et al. 2012).

TVD is based on conceptual cost estimates prior to design, based on programmatic data (Ballard and Pennanen 2013). Programmatic data includes what is wanted (functionalities, capacities, and features of the desired asset), where the asset is to be located and when it is to be produced. The Allowable Cost is cost the costumer finds acceptable; i.e., they are willing and able to pay that amount and are assured that they will receive in return what they want. The costumer set Allowable Cost. The Market Cost is output from the cost model and estimated by the project team. Uncertainties related to market fluctuations and how escalations will play over the years seems to be the first challenge for teams implementing TVD (Tillmann et al. 2017). Pennanen and Ballard (2008) developed the following process steps for setting the target costs.

1. Assess the business case
2. Determine stakeholder values and define specifications of the project
3. Determine the Allowable Cost
4. Determine the Expected Cost
5. If Expected Cost is bigger than Allowable Cost then modify the specifications
6. Go to Step 3
7. When Expected Cost is equal to or less than the Allowable Cost, start project delivery by setting a target cost equal to or below Expected Cost.
8. Launch design phase
9. Decompose product level target cost to component level target cost

CONCEPTUAL COST ESTIMATION IN TVD

In Target Costing, the cost is to be estimated directly from the client's requirements rather than from designs offered to satisfy those requirements (Pennanen and Ballard 2008). Pennanen and Ballard (2008) present a method of determining Expected Cost from client requirements. Performance, specifications and target cost should be defined before conceptual design (Tanaka, M. 1989). Two cost perspectives can be used to determine target cost in construction (Ballard 2006 and Ballard 2007):

2. The customer defines Allowable Cost. It is a cost that the customer is willing and able to pay for a facility with defined performance. The project business plan should specify Allowable Cost.

3. The project team defines the Expected Cost. It would be the cost if the facility with determined performance were provided at current best practice.

STOCHASTIC COST ESTIMATES

Nguyen et al. (2008) discuss different types of cost models, from parametric cost estimates to unit price estimates, based on resources and operations. Cost estimates are forecast of cost and they are always uncertain. Given the uncertainty and structural complexity, the use of deterministic historical cost database to estimate the cost of construction is not justifiable (Nguyen et al. 2008). Love et al. (2015) state that a base estimate (deterministic) plus the contingency figure typically form a project's estimated costs. *Contingency* can be defined as "the amount of funds, budget, or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable for the organization" (PMI 2011).

Particular cost models are developed to deal with variability and uncertainty, like stochastic cost estimation methods (Nguyen et al. 2008; Lichtenberg 2000). Fortune and Cox (2005) found that these new models were not widely used in the UK. These kinds of approaches are commonly used in infrastructure projects in the Nordic countries, especially stochastic cost estimation methods (Lichtenberg 2000; Torp and Klakegg 2016; Klakegg and Lichtenberg 2016). Stochastic methods are used for decades to estimate project cost, mostly in the front-end of projects (Lichtenberg 2000; Klakegg and Lichtenberg 2016; Torp and Klakegg 2016), but also in the design phase and after design to calculate the cost for the chosen design prior to construction. Lichtenberg (2000) introduced the successive principle, saying that when estimating cost for projects, one should use a top-down approach, include everything, focus on uncertainty and use subjective estimation. Torp and Klakegg (2016) show this approach applied for estimating the costs of demolition and decommissioning of a Nuclear Power Plant. Torp and Klakegg (2016) discuss some challenges with the approach, and how to overcome some of the challenges. The main challenges seem to be the composition of the estimation team, the level of detail in the estimation model, lack of focus on opportunities, underestimation of uncertainty and underestimation of the Expected cost.

Stochastic cost estimates are presented as an Expected Cost (mean value) for the facility with the variability given as standard deviation (Lichtenberg 2000). The results are presented in a probability distribution for the total cost for the facility, as shown in Figure 1 (Johansen et al. 2014). Based on the probability distribution of the total project cost, the client could set the cost limit at a chosen level of probability. Figure 1 shows an example of a probability distribution. Often the probability distribution could be represented by a normal distribution. Then Expected Cost is at the probability level of 50 %, meaning that it is 50 % probability of ending up below Expected Cost. The size of the standard deviation decides the steepness of the probability distribution. Cost targets could be set at a higher probability level than 50 %. The Norwegian Ministry of Finance have decided that the upper cost frame, defined as the budget, for large Norwegian investment projects should be set at 85 % probability, meaning that it is 85 % probability of keeping to budget (Lichtenberg 2016), defined as C in Figure 1.

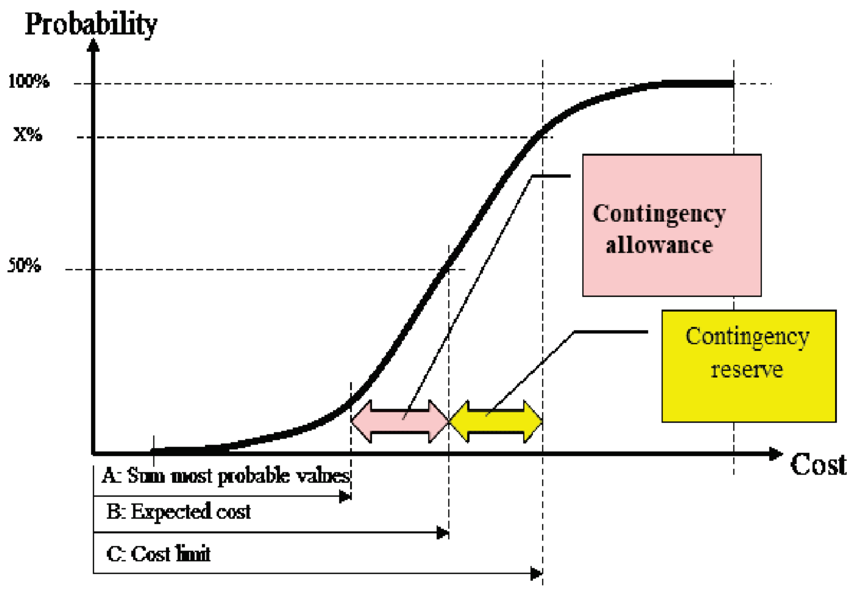


Figure 1. Probability distribution of the cost estimate for a project (Johansen et al. 2014).

HOW TO SET TARGETS WITH STOCHASTIC METHODS

The Public sector in Norway has applied stochastic methods to estimate costs and to set the cost targets for many years. The Norwegian Ministry of Finance has developed a guideline on how to do cost estimation for large public Norwegian investment projects (Norwegian Ministry of Finance 2008). The guideline states that a deterministic cost estimate should be followed by an uncertainty analysis, including a stochastic cost estimate (Norwegian Ministry of Finance 2008). The guideline is applied in most large Norwegian public construction projects, like building, road and railway projects. The cost targets include a cost limit, or the upper-cost frame which should be set at a probability level of 85 %, also called P85. This means that when setting the cost limit, it should be 85 % probability for the project having enough money.

The Norwegian Public Roads Administration (NPRA) use stochastic cost estimation methods (NPRA, 2015). NPRA has developed a cost estimation model and guidelines on how to set cost targets (NPRA 2018). Before the final decision to start the project, the cost limit is set at P85, according to the rules from Ministry of Finance. NPRA get P50 as their cost target. In addition, a steering goal for the project manager is set at probability level of 45 %, being the project manager's cost target. NPRA has traditionally not used Target Costing or Target Value Design principles. However, a new system implemented, applying a change log from the front end all through the project, together with defined cost targets will increase focus on cost estimation and control, and drive them towards thinking like TVD. In the front-end, cost-benefit analyses are performed to decide whether the project is profitable or not, and at what cost it is profitable.

Statsbygg is the Norwegian government's principal advisor in construction and property affairs, building commissioner, property manager, and property developer. Statsbygg is a public sector administration company responsible to the Ministry of Local Government and Modernisation (KMD). Statsbygg provides appropriate, functional premises to public sector enterprises, as well as realising principal socio-political objectives concerning architecture, governmental planning interests, preservation of heritage sites and the environment. In some cases, Statsbygg acts as a builder during the planning and construction, and then the building is transferred to a public organization who will own and facilitate the building. In other cases, Statsbygg also owns and facilitate the building for the lifetime. The building is then leased to public sector users. In these cases, Statsbygg has applied principles similar to TVD for years, where the value is set prior to design, based on an agreement on level of the tenancy, and the tenancy is used as a constraint for the design and construction. For other types of buildings, Statsbygg has not applied principles like TVD.

The Ministry of Local government and Modernisation developed a guideline for front-end management of large public building projects (KMD 2017mainly to improve cost control. The guideline applies to building projects in Statsbygg and states that Design to Cost principles should be used, followed by implementation of a change log. This is similar to the new rules for NPRA. The end of the pre-project stage should be followed by a decision by the Government about a steering goal and cost limit for the project. The cost limit is decided to be at the level of P85, while the steering target for the project management is at the level of Expected Cost.

Lichtenberg (2016) shows results from 40 Danish road construction projects using stochastic cost estimates. The results shows that far more projects were under the Expected Cost compared to those that exceeded it. The average savings related to Expected Cost were approximately 5 %. Data from 78 large Norwegian public investment projects applying stochastic estimates, mainly road, building and railway projects but also including some ICT projects shows that around 50 % of the projects end up below Expected Cost and around 80 % end up below upper cost frame (Welde 2017). The total budget of the 78 projects is NOK 124.5 billion. The total final costs is NOK 117 billion. In other words, the portfolio of projects turned out to be NOK 7.5 billion (6%) cheaper than budgeted. These results prove superior to what is documented in similar international studies. Morris and Hough (1987) show cost overruns on from 40 – 200 %. Flyvbjerg et al. (2002) show average cost overruns on 28 %, based on a study of 258 road and railway projects.

DISCUSSION - HOW CAN STOCHASTIC COST ESTIMATES CONTRIBUTE TO TVD?

This section will adress research question 3, how stochastic cost estimates could contribute to TVD. The basis for this discussion is the literature review and the case studies.

Not much literature was identified on how cost targets are set in TVD. Pennanen and Ballard (2008) present a model designed to set targets, based on a building information cost model. The model was developed to support a dialogue between Allowable Cost and Expected Cost, though it is not very specific on how the cost targets are set in TVD. The costumer should define Allowable Cost, what he is willing and able to pay. The project team should estimate the Market Cost, as Expected Market Cost. Target cost should be set below Expected Cost.

With stochastic estimates, Expected Cost and standard deviation are calculated, constituting the basis for the probability distribution of the total costs. Cost targets are set from the probability distribution, including contingency to reduce the risk of overruns of project objectives to a level acceptable for the organization. Both the NPRA and Statsbygg set their cost targets prior to design based on stochastic cost estimates. The Norwegian Ministry of Finance has decided that the cost limit should be set at a probability level of 85 %. This will then define the Allowable Cost for these projects. With this situation, it is a 15 % probability of ending up above Allowable Cost. Cost target for the project manager will be set at Expected Cost, or 50 % probability level when the probability distribution is given as a normal distribution. It is then important to steer both the design and construction to targets (Ballard et al. 2015). TVD is not widely used in the Norwegian public sector.

In TVD, the costumer should set Allowable Cost. Allowable Cost should be set based on the value of the facility for the customer, and what the customer is willing to pay, based on what the customer gets in return (Ballard and Pennanen 2013). The aim is to define the value of the facility, and financial constraints. The customer must decide what he is able and willing to pay to get this value (Zimina et al. 2012). Statsbygg applies this thinking in projects where they are responsible for construction and maintenance, and where they own the facility. Then the users pay yearly tenancy to use the facility. Stochastic estimates could be applied to estimate and set the value. The value could be considered as an uncertain number, and could by stochastic approach be represented by a probability distribution, see Figure 2.

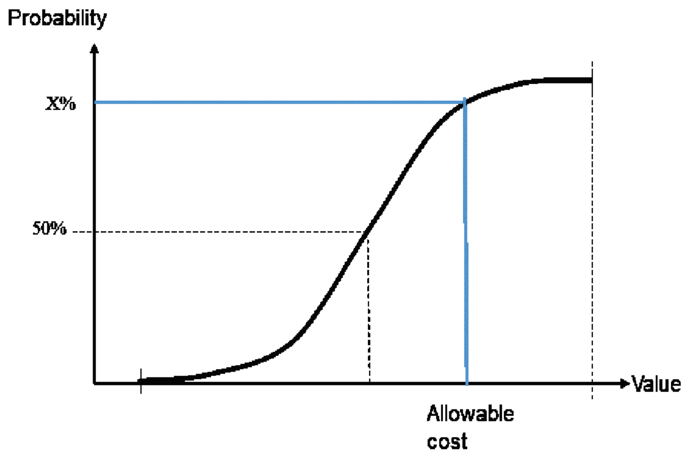


Figure 2. Probability distribution of the value, used to set Allowable cost.

Setting Allowable Cost from the estimates of value of the facility, you would be interested in knowing how likely it is that you manage to create the intended value within the Allowable Cost. Choosing X percentage probability on the probability distribution curve for value will tell you that it is X percentage probability that the value will end up below Allowable Cost. If you choose to set Allowable Cost at 25 % probability, it will be 75 % probability that the value is higher than Allowable Cost. The higher probability you want for achieving the value, the lower probability you should set for Allowable Cost. This also gives a higher contingency.

Both NPRA and Statsbygg use steering targets for the project, and for the project management, set at a lower level than the cost limit (Allowable Cost). Target cost for the project manager is set at Expected Cost for Statsbygg and at P45 for NPRA. Target cost should be set at Allowable Cost or below (Zimina et al. 2012). When it comes to this aspect, the thinking in NPRA and Statsbygg is in line with the thinking in TVD. When the Allowable Cost is set, the design could start. For each design alternative, the Market Cost will be estimated and compared to Allowable Cost and the cost target.

Stochastic estimates could be applied to calculate Market Cost during the design stage in TVD. When Market Cost are estimated for a design solution, stochastic cost estimates could be applied. With the results of the estimate of Market Cost presented as a probability distribution, you are able to analyse the probability of Market Cost ending up below Allowable Cost, see Figure 3. When finishing the design phase, the probability of Market Cost ending up below Allowable Cost should be high, and the level of uncertainty, the standard deviation, should be low. When Allowable Cost is the absolute maximum amount of money available, the probability of ending up below Allowable Cost should be close to 100 %. Then the contingency also would be very high. If you choose to use Expected Market Cost when comparing to Allowable Cost, you have 50 % probability of ending up below this number. Target Cost could be set at a lower level, for example at P45, like NPRA practice. This will give stretch target in order to drive innovation beyond current best practice (Pennanen and Ballard 2008). It is still important to steer to targets during construction.

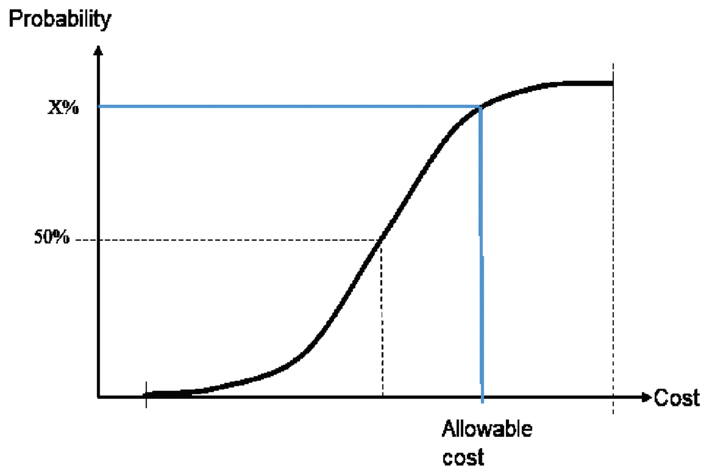


Figure 3. Market Most estimate represented by a probability distribution. Then probability of ending up below Allowable Cost could be found.

A refined framework for setting the targets based on stochastic estimates is proposed in table 1, based on the 9 steps of Pennanen and Ballard (2008). Table 1 include a description of how stochastic estimates could be applied in this framework.

Table 1. Step by step process for setting targets based on stochastic estimates, based on the steps of Pennanen and Ballard (2008).

ID	Step	Implication of Stochastic Estimates
1	Assess the business case.	Business case could include stochastic estimate of Value
2	Determine stakeholder values and define specifications of the project	Stakeholder values could be numbered by stochastic estimates
3	Determine the allowable cost	Allowable Cost could be determined based on a probability distribution of the total value of the asset
4	Determine the expected cost	Expected cost will be output of the stochastic estimate of Market Cost. Expected Cost will be the 50 % quantile, given a normal distribution of the stochastic estimate
5	If expected cost is bigger than the allowable cost then modify the specifications	When using probability distribution to represent Market Cost, Expected Cost would be the 50 % quantile. When comparing with Allowable Cost, you could consider a higher quantile, like 85 % quantile
6	Go to Step 3	
7	When expected cost is equal to or less than the allowable cost, start project delivery by setting target cost equal to or below expected cost	Target Cost below Expected Cost will give less probability than 50 % to reach target, but will at the same time drive innovation beyond current best practice
8	Launch design phase	When estimating Market Cost for design solutions, stochastic estimates could be applied
9	Decompose product level target cost to component level target cost	The component level target cost should be defined on the chosen probability level

CONCLUSION

The purpose of this paper has been to discuss how stochastic estimates could be applied in TVD. A literature review on TVD together with a case study research on practice on stochastic cost estimates has been carried out.

Publications on Target Costing, Target Value Design and Target Value Design were studied to look into how cost targets are set in TVD. In TVD, Allowable Cost is set, based on the value the facility will provide the customer, or what the costumer is willing or able to pay. From the case studies, it is found that stochastic cost estimation methods are used both to estimate costs and to set cost targets. Both the cost limit and the steering goal are set by choosing probability level from a probability distribution of the total project cost.

From the analysis, it is found that stochastic estimates could be applied both to set Allowable Cost based on a probability distribution of the value, and to estimate the Market Cost in TVD based on a probability distribution of the Market Cost. When used to set Allowable Cost, either probability distribution of project costs prior to design or probability distribution of project value could be developed and used. It is a matter of choosing how high probability you want for getting higher value than Allowable Cost. Used to estimate the Market Cost, the probability distribution could be applied to analyse the probability of Market Cost ending up below Allowable Cost for the specific design alternative identified. It is important to remember that if choosing Expected Market Cost, you have 50 % probability of ending up below Allowable Cost. To succeed with the project, it is essential not only to set realistic targets but also to steer the design and the construction to the targets.

Further research should be done to test the suggested approaches for applying stochastic cost estimation methods in TVD.

REFERENCES

Ballard G. 2006. "Rethinking Project Definition in terms of Target Costing", *Proceedings IGLC-14, July 2006*, Santiago, Chile.

Ballard G. 2007. "Target Costing in the Construction Industry". *Presentaion in the P2SL 2007 Conference, Feb 2007.* Berkeley, California.

Ballard G. 2008. "The Lean Project Delivery System: An Update". *Lean Construction Journal*, 2008.

Ballard, G., 2011. Target Value Design: Current Benchmark. *Lean Construction Journal*, pp. 79-84.

Ballard G. and Pennanen A., 2013. "Conceptual Estimation and Target Costing". *Proceedings IGLC-21, July 2013,* Fortaleza, Brazil.

Ballard, G. and Reiser P. 2002. ―The St. Olaf College Fieldhouse Project: A Case Study in Designing to Target Cost‖. *Proceedings of the 12th annual conference of the International Group for Lean Construction*. Elsinor, Denmark.

Bowen, Glenn A. 2009. "Document analysis as a qualitative research method." *Qualitative research journal 9.2* (2009): 27-40.

Cooper R. and Slagmulder R. 1997. "T*arget Costing and Value Engineering*". Portland OR: Productivity Press.

Do, D., Ballard, G. and Tommelein I.D. 2015. "An Analysis of Potential Misalignment of Commercial Incentives in Integrated Project Delivery and Target Value Design.". In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 277-286, available at www.iglc.net.

Do. D., Chen C., Ballard G. and Tommelein I.D. 2014. "Target Value Delivery as a method for controlling project cost overruns". *Proceedings International Group for Lean Construction*. Oslo Norway.

Feil P., Yook K.H. and Kim I.W. 2004. "Japanese Target Costing: A Historical Perspective". *International Journal of Strategic Cost Management*, 11.2.

Fellows, Richard F., and Anita MM Liu. 2015. *Research methods for construction.* John Wiley & Sons, 2015

Flyvbjerg, B., Skamris Holm, M.S. og Buhl, S.L., 2002.Underestimation of Costs in Public Works Projects: Error or Lie? Journal of the American Planning Association, 68 (3), 279-295.

Klakegg, O.J. and Lichtenberg, S. 2016. "Successive Cost Estimation – Successful Budgeting of Major Projects". *Procedia - Social and Behavioral Sciences. vol. 226.*

Lichtenberg, S. 2000. "*Proactive Management of Uncertainty—Using the Successive Principle*". Lichtenberg & Partners. Vedbæk, Denmark.

Lichtenberg S., 2016. " Successful control of Major Project Budgets". *Administrative Sciences. vol. 6 (4).*

Love P.E.D, Smith J., Simpson I, Regan M and Olatunji, O. 2015. "Understanding the landscape of overruns in Transport Infrastructure Projects". *Environment and planning B: Planning and Design 2014*, volume 41.

Morris, P.W.G. og Hough, G.H., 1987. "*The Anatomy of Major Projects: A Study of the Reality of Project Management*". New York: John Wiley and Sons.

Nguyen H.V., Tommelein I.D and Ballard G., 2008. "Process-based cost modelling to support Lean Project Delivery", *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*. Manchester, United Kingdom.

Norwegian Ministry of Finance, 2008. "*Cost Estimation* (In Norwegian)". Norwegian Ministry of Finance, Oslo, Norway.

NPRA 2015. "H*åndbok R764 Anslagsmetoden*". Statens Vegvesen 2015, could be downloaded at www.vegvesen.no.

NPRA 2018. "*Håndbok R760 Styring av prosjekter*". Statens Vegvesen 2018, could be downloaded at www.vegvesen.no

NMF 2008, "*Kostnadsestimering*", Norwegian Ministry of Finance, Oslo, Norway.

KMD 2017. "S*tyring av store statlige byggeprosjekter i tidligfase*", Guidelines, Norwegian Ministry of Local Government and Modernisation, Oslo, Norway.

Pennanen A., Ballard G. and Haahtela Y. 2010. "Design to targets in a target costing process". *Proceedings IGLC-18, July 2010.* Technion, Haifa, Israel.

Pennanen A., 2013. "Conceptual Estimation and Target Costing". *Proceedings IGLC-21, July 2013.* Fortaleza, Brazil

Pennanen A. and Ballard G. 2008. " Determining expected costs in the Target Costin Process". *Proceedings for the 16th Annual Conference of the International Group for Lean Construction*, Manchester, United Kingdom.

PMI 2011. "*Practice Standard for Project Estimating*". Project Management Institute. Newtown Square, USA.

Tanaka, M. (1989) "Cost planning and control systems in the design phase of a new product". Japanese management accounting, A world class approach to profit management. Productivity press, Massachusetts, USA, p 49-71

Tillmann P. A., Do Doanh; Ballard, G. (2017). "A case study on the success factors of Target Value Design." *In LC3 2017 Volume II - Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC), Walsh, K., Sacks,* *R., Brilakis, I (eds)*. Heraklion, Greece, pp. 563 - 570. DOI: https://doi.org/10.24928/2017/0324

Torp, O. and Klakegg, O.J. (2016) Challenges in Cost Estimation under Uncertainty - A Case Study of the Decommissioning of Barsebäck Nuclear Power Plant. *Administrative Sciences. vol. 6 (4).*

Welde M. (2017). "Cost Control in large public investments under the regime of external quality assurance", Concept research program, Norwegian University of Science and Technology, Trondheim, Norway.

Yin, Robert K. 2014. "*Case study research: design and methods* 5th ed." Thousand Oaks.

Zimina D., Ballard G. and Pasquire C. 2012. "Target value design: using collaboration and a lean approach to reduce construction cost". *Construction Management and Economics, 30:5, 383-398*. DOI: 10.1080/01446193.2012.676658

Ko, C.H. and Kuo, J.D. (2019). "Lean Design Process for Formwork Engineering." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 607 –618. DOI: https://doi.org/10.24928/2019/0138. Available at: <www.iglc.net>.

LEAN DESIGN PROCESS FOR FORMWORK ENGINEERING

Chien-Ho Ko[1] and Jiun-De Kuo[2]

ABSTRACT

Formwork engineering is one of major cost factors in reinforced concrete construction, which is not only critical for the successful completion of construction projects, but also critical for profitability. Traditional formwork design process includes waste, resulting non-value-adding manpower and operational time. The purpose of this research is to utilize lean thinking in formwork design so as to enhance design correctness and eliminate waste. A lean design process for formwork enginering is established to achieve this goal. In the design process, design correctness is established to review and correct design errors. An organizational learning environment is thus built. The proposed lean design process is conceptualized using stock-flow diagrams. This research validates the applicability of the proposed approach using a real case. Application results show that the proposed method can reduce wasteful manpower and operational time in formwork engineering.

KEYWORDS

Formwork design, pull, design correctness, system dynamics.

INTRODUCTION

According to Peng (1991), in Taiwan, the reinforced concrete houses account for 87% total floor area of all houses. In addition, formwork material and labor costs occupy approximately 15% total costs of ordinary buildings and one-third of the total cost of reinforced concrete (RC) structures (Peng 1992). Thus, formwork engineering is one key construction affecting the success of a project (Santilli et al. 2011).

The design quality of formwork engineering affects construction quality. In Taiwan, 40% change order in the construction phase could be attributable to design problems (Chang et al. 2007); in other countries and areas, 26% project deficiencies are related to poor designs (Josephson and Hammarlund 1999); and 50% house defects are due to design flaws (NEDO 1988). Therefore, formwork engineering may affect the progress of the whole project (Ko et al. 2011).

Traditional formwork design is solely completed by the general contractor. Waste can be found in the design process. The formwork design, however, relates to diverse

1 Professor, Department of Civil Engineering, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan, +886 8 770-3202, fpecount@yahoo.com.tw; President, Lean Construction Institute-Taiwan; Research Director, Lean Construction Institute-Asia.

2 MS, Department of Civil Engineering, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan.

professional fields of subcontractors (e.g. formwork assembly, scaffold, rebar, electromechanical equipment, concrete work, etc.), as a result, is difficult to be planned by the general contractor without mistakes (Rosowsky et al. 1997; Chen and Shirole 2006). Poor constructability caused by poor coordination, or design change occurring in the construction phase, extends the construction period and increase the cost (Lee et al. 2009).

Although previous studies have deeply discussed mechanics, economy, and minimum usage of formwork engineering, a complete formwork design that relies on a series of design activities has not been fully discovered yet. Previous research lacks a managerial process to integrate individual procedures.

To eliminate waste in formwork engineering, a formwork design process is developed. This paper first introduces background information of the study. Formwork design requirements and system dynamics are explained, followed by the explanation of current formwork design practice. Then, the development of a lean design process for formwork engineering is discussed. To validate applicability of the developed method, a real project is analyzed. Conclusions and future research direction are finally documented.

BACKGROUND INFORMATION

FORMWORK DESIGN CONCEPT

To ensure the formwork quality and reduce construction accidents, codes for formwork design were formulated (TCCP 2000; WHSQ 2006). For example, the "Standard for Construction of Safety and Health Facilities" formulated by the Labor, Safety and Health Committee, Executive Yuan of Taiwan, of which the articles 131 and 146 stated in the 9th chapter indicate that formwork support and disassembly shall have the design made by a dedicated person. Formwork shall be constructed based on the shop drawing. Concrete shall be poured according to the plan. Operations shall be carried out according to the shop drawing. In addition, loading upon the mold shall not exceed the permitted specification before and after removing formwork support. The load borne by the newly poured floor shall also be fully considered (ILOSH 2019). Based on above guidelines, formwork operation shall be designed as a whole; the type of mold shall be selected according to the site conditions; and the formwork type, support type, soil state, fixing method, and conjunction method shall be comprehensively considered to avoid collapse and deformation.

SYSTEM DYNAMICS

This study uses System Dynamics (SD) to understand the behaviour of the propsed design method. SD, created by Professor Jay W. Forrester of the Massachusetts Institute of Technology (MIT), is an approach used to understand behavior of complex systems (Forrester 1961). SD stresses on the consideration of the entire system, understands constitutions within the system and the interaction of constitutions through a systematic thinking. SD can be used to display how the structure, policy, and delay of the system affect its development and stability with the aid of computer simulation (De Marco et al. 2012). It focuses on neither forecast nor single development of trend, but think over causes behind complex changes, i.e. the fundamental mechanism of the entire dynamic operation (Senge

1994). In recent years, SD applications can be found in diverse fields, such as building industry, development poly of water resource, development of automobile industry, cash flow analysis, global warming, and water supply system (Alvanchi et al. 2011; Pastorino et al. 2011; Hassanzadeh et al. 2012).

System Dynamics model mainly consists of four basic elements, i.e. stocks, flows, arrows, and auxiliary variables. These elements are explained using Vensim notations as follows (Eberlein and Peterson 1992):

Stocks

Stocks refer to the status of a system variable at a specific time. Stock values are the result produced by accumulating the net balance of inflows and outflows. In other words, they are the accumulation result in the system in the past.

Flows

Also known as rates, Flows indicate the change in a stock variable and represent the behavior at a moment. Their values are mostly decided by the interaction between stock variables and auxiliary variables, and hence can be viewed as the control variables of the system. Flows are directional, so flows are called “Inflow” when they flow into a stock. In the contrary, “outflows” flow out of a stock.

Auxiliary Variables

Auxiliary variables, also known as converters, indicate an input value, or directly convert an input into an output.

Arrows

Arrows, also called connectors, represent the transmission of relevant information between stocks, flows, and auxiliary variables.

Stocks and flows are used for deducing system status, i.e. presentation of element flows. Arrows and auxiliary variables can be used for deducing causal feedback loop, i.e. representation of variable information flow. Using population as an example, in Figure 1, population is stocks, births and deaths are flows, of which births are inflows and deaths are outflows. Birth rate and death rate are auxiliary variables. With the aid of System Dynamics, the dynamic relation between birth rate, population, and death rate can be analyzed.

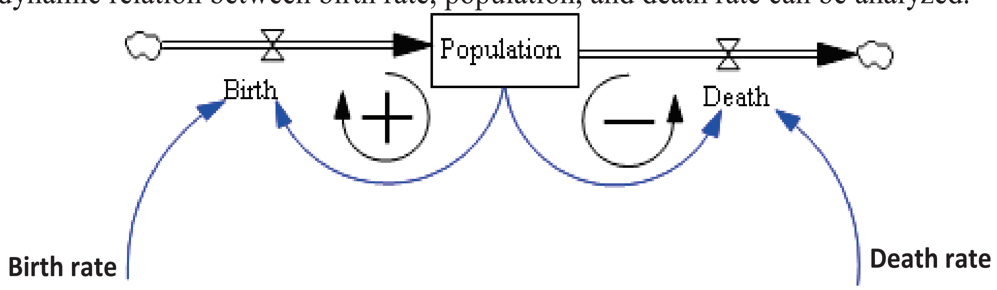


Figure 1: Population Stock-Flow Diagram

CURRENT-STATE VALUE STREAM MAPPING

Current formwork design is composed of preliminary design and detailed design processes, which are usually finished by the general contractor (GC). In preliminary design phase, the site manager draws the building system model according to the design drawing supplied by the architect. In the detailed design phase, the structural engineer establishes the detailed structure according to the preliminary formwork model. While assembling the molds, site manager is responsible for coordinating with the subcontractors such as rebar, formwork, water and electricity about the assembly schedule. If design errors are found or molds cannot be assembled as designed, GC (i.e. site manager and structural engineer) is responsible for changing the design. The formwork subcontractor shall revise the corresponding assembly plan and shop drawing in accordance with the revised design. The scenario is represented using the current-state value stream map demonstrated in Figure 2. According to the figure, problems for the current practice are explained as follows:

1. Before the site manager delivers formwork design for mechanical analysis, the structural engineers do not have an opportunity to express their comments on the design. The chance to obtain a better design is missing.

2. The formwork assembly plan is made by the formwork subcontractor. However, mold assembly may involve other subcontractor activities (e.g. scaffold, rebar, wires, and pipes). A perfect plan is difficult to be conducted by solely formwork subcontractor. As a result, poor constructability and design errors may influence construction delivery and therefore increases cost and deteriorate quality.

3. Current formwork design drawings are mostly the 2D graphs. However, formwork, wiring, piping, and rebar operations overlap. It is hard to find out the conflictions by the 2D graph, and thus the possibility of change order increases.

FUTURE-STATE VALUE STREAM MAPPING

PULL DESIGN

This research adopts the Last Planner and Work Structuring raised by Ballard (2000) to pull the design process so as to make the design flow stable. In traditional formwork design process, the formwork planning is carried out immediately after the general contractor determines the project target. Working items are confirmed before making the assembly schedule. The scheduled working items are completed based on the available resources. Uncompleted works are awaited and can only be finished when resources are sufficient. Traditional planning system, however, often cannot complete the formwork design according to the predetermined design schedule. In order that the scheduled items can be carried out successfully, the Last Planner is added to the formwork design to control the design progress. When making the formwork design schedule, the Last Planner evaluates the current design status, and “pull” the qualified work items (i.e. ready for work) into the design schedule. If the scheduled design items fail to be conducted because of the insufficient preconditions, other operations (backlog) or the future items can be implemented in advance in order to maintain the smooth design progress. This method can avoid rushing through the job caused by the postponement of the work items. When executing the design plan, the resources necessary for the work items, which should be carried out in the future, should be prepared ahead. In case that work items cannot be finished within the specified time, root causes should be discussed.

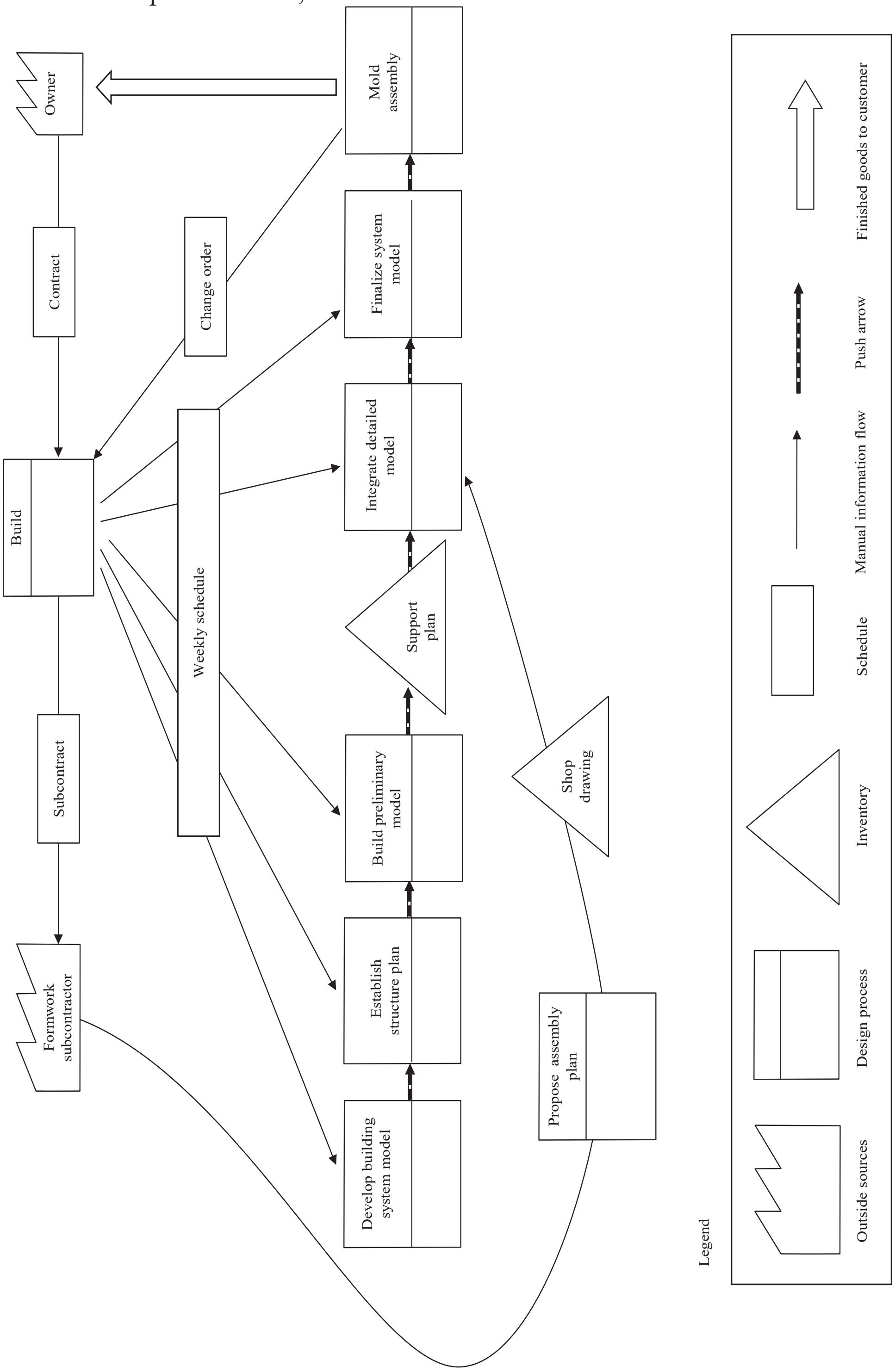


Figure 2: Current-State Value Stream Mapping for Formwork Design

PURSUING PERFECTION

To design the formwork system meeting owner requirements, pull manufacturing and the concurrent design are used for pulling the work items within the system. Designers and owners are take part in design together. The improved process is drawn into the future-state map.

Since formwork design and planning differs from manufacturing process, i.e. the processed work pieces cannot be sent to the next work station through the belt, the supermarket pull system is used for pull the upstream supplier and downstream customer. Production card is a signal to start production, and withdrawal card is a purchase order for receiving items. The mark of the supermarket is left-opened, which corresponds to the supplier. When the preliminary design correctness is reviewed, incomplete and unclear items must be returned to the responsible designer for modification. The withdrawal card also can be used for pulling design to enable the upstream supplier to make a thoroughly improvement in the information sent from the downstream. Finally, the general contractor integrates the formwork detailed model to pull the preliminary design correctness to complete the formwork design.

The value of the completed formwork system model is to satisfy general contractor's requirements. Design mistakes and conflictions can be reduced through the improvement of design correctness, so as to improve the design reliability. The general contractor uses the electronic information flow transfers BIM, and uses the formwork system model to pull the detailed design correctness. As a result, design operations can be pulled in this phase.

The future-state map of the lean design process for formwork enginering is integrated and displayed in Figure 3. Owner contracts the project with the general contractor. General contractor outsources the formwork engineering to the formwork subcontractor. The formwork subcontractor then designs the formwork plan, entrusts the structural engineers to analyze the formwork mechanical behavior. The lean design process for formwork enginering is raised for allowing the general contractor, formwork subcontractor, structural engineers, Architectural/Engineering, and related third parties to jointly participate in the design. With the aid of the feedbacks and modifications in each design phase, the occurrence of design error and the risk of change order during construction phase can be reduced. Furthermore, the pull process is introduced into the design progress so that the design process is smoothed.

VERIFICATION

In order to validate applicability of the proposed method, a real case is used. The studied case, located in Taiwan, is a building project with one basement and four stories. The total floor area is 2185 square meters. In order to analyze the waste made by poor design, formwork operations are analyzed. In this study, formwork assembly and processing are divided into nine operations, i.e. "measure," "walk," "find," "pull," "cut," "pass," "wait," nail," and "mend." The value-adding activities in formwork assembly and processing include "measure," "pull," "cut," "pass," "nail," and "mend." The proportion of value-adding activities accounts for 56.8% operational time. By multiplying design weights, the design weight of formwork assembly and processing can be obtained. These weights represent the proportion of design category results in formwork assembly and processing activity. This case study designs the formwork system using traditional method that has no design correctness examination and organizational learning mechanism. However, in building projects, the rework cost due to design error is up to 35% (Hammarlund and Josephson 1991; Choo 2008). The use of the lean design process suggested in this paper can eliminate unnecessary waste in formwork assemble and processing.

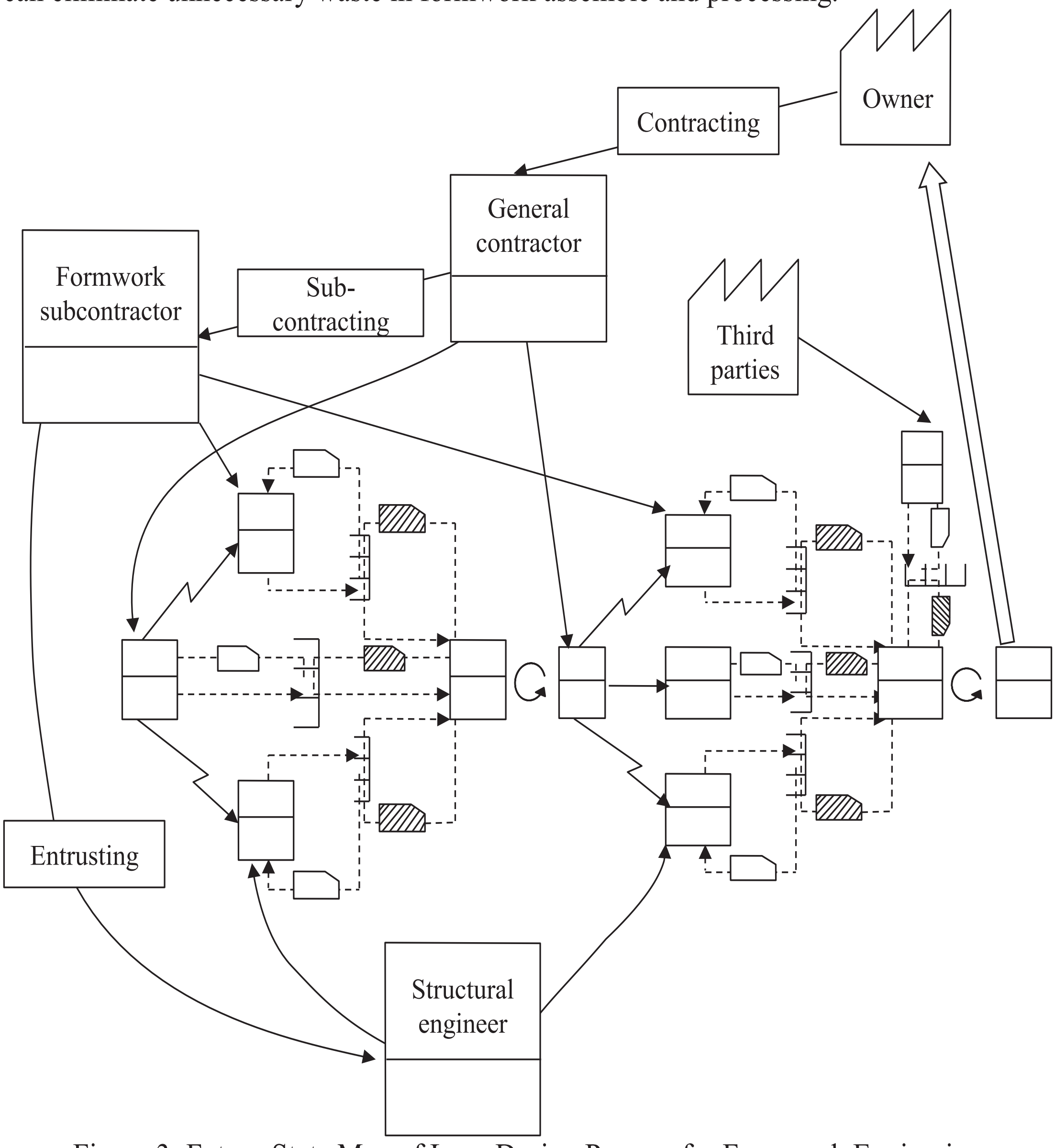


Figure 3: Future-State Map of Lean Design Process for Formwork Enginering

CONCLUSIONS

To reduce waste caused in formwork design, formwork turnkey contract is used to enhance the collaboration between formwork design and assembly members. Furthermore, to establish the organizational learning environment, design correctness ratio is developed to gradually improve design correctness and constructability through co-review and modification. Finally, feasibility of the lean design process for formwork enginering is validated using a real building project using System Dynamics.

In the current practice, formwork design and assembly are carried out respectively by the general contractor and formwork subcontractor. This practice makes formwork design become a mere formality. In this research, the design correctness and constructability are considered while designing the formwork. In addition, through the concurrent design, the design team members can jointly collaborate to help stakeholders identify problems as early as possible and therefore enhance design correctness. The proposed lean design process feedbacks problems to the responsible designer through evaluating design correctness. The design and construction teams are invited to jointly participate in design phase making design drawings more complete and accurate.

REFERENCES

Alvanchi, A., Lee, S., and AbouRizk, S. (2011). "Modeling Framework and Architecture of Hybrid System Dynamics and Discrete Event Simulation for Construction." *Computer-Aided Civil and Infrastructure Engineering*, 26(2), 77-91.

Ballard, G. (2000). *The Last Planner System of Production Control*. PhD Thesis, University of Birmingham, UK.

Chang, S.D., Shi, G S., and Chou, Y.S. (2007). *Courses for Change Order and Remedy Methods in the Construction Phase*. Grant number 96642, China Engineering Consultants, Inc. (in Chinese).

Chen, S.S., and Shirole, A.M. (2006). "Integration of Information and Automation Technologies in Bridge Engineering and Management: Extending the State of the Art." *Journal of the Transportation Research Board*, 1976, 3-12.

Choo, Y. S. (2008). *Reasons and Cost for Design Change during Construction and Correspondence Process Analysis.* MS Thesis, National Cheng Kung University, Tainan, Taiwan.

De Marco, A., Cagliano, A.C., Nervo, M.L., and Rafele, C. (2012). "Using System Dynamics to Assess the Impact of RFID Technology on Retail Operations." *International Journal of Production Economics,* 135(1), 333-344.

Eberlein, R. and Peterson, D. (1992). "Understanding Models with Vensim." *European Journal of Operational Research,* 59(1), 216-219.

Forrester, J. W. (1961). *Industrial Dynamics.* Pegasus Communications, NY.

Hammarlund, Y. and Josephson, P.E. (1991). "Sources of Quality Failures in Building." *Proceedings of the European Symposium on Management, Quality and Economics in Housing and Other Building Sectors*, 671-679.

Hassanzadeh, E., Zarghami, M., and Hassanzadeh, Y. (2012). "Determining the Main Factors in Declining the Urmia Lake Level by Using System Dynamics Modeling." *Water Resources Management*, 26(1), 129-145.

Institute of Labor, Occupational Safety and Health (ILOSH). (2019). Construction Health and Facilities Hygiene Standard, http://www.ilosh.gov.tw/Law/LawPublish.aspx?LID=19, Retrieved on February 16, 2019.

Josephson, P.E. and Hammarlund, Y. (1999). “The Causes and Costs of Defects in Construction: A Study of Seven Building Projects.” *Automation in Construction*, 8(6), 681-687.

Ko, C.H. and Kuo, J.D. (2019). “Making Formwork Design Lean.” *Journal of Engineering, Project, and Production Management*, 9(1), 29-47.

Ko, C.H., Wang, W.C., and Kuo, J.D. (2011). “Improving Formwork Engineering Using the Toyota Way.” *Journal of Engineering, Project, and Production Management*, 1(1), 13-27.

Lee, M.J., Ryoo, B.Y., Sullivan, K.T., and Hanna, A.S. (2009). “RETRACTED: Development of automated change order impact detection and quantification system.” *Automation in Construction*, 18(5), 525-535.

National Economic Development Office (NEDO). (1998). *Faster building for commerce*, HMSO, London.

Pastorino, R., Naya, M. A., Pérez, J. A., and Cuadrado, J. (2011). “Geared PM Coreless Motor Modelling for Driver's Force Feedback in Steer-By-Wire Systems.” *Mechatronics*, 21(6), 1043-1054.

Peng, Y.H. (1991). *Investigation and Analysis of Taiwan Construction Energy*, Research Report, Architecture and Building Research Institute, Ministry of the Interior, Taipei, Taiwan (in Chinese).

Peng, Y.H. (1992). *Investigation and Analysis of Taiwan Construction Energy II*, Research Report, Architecture and Building Research Institute, Ministry of the Interior, Taipei, Taiwan (in Chinese).

Rosowsky, D.V., Philbrick, T.W., and Huston, D.R. (1997). “Observations from Shore Load Measurements during Concrete Construction.” *Journal of Performance of Constructed Facilities*, 11(1), 18-24.

Santilli, A., Puente, I., and Tanco, M.A. (2011). “Factorial Design Study to Determine the Significant Parameters of Fresh Concrete Lateral Pressure and Initial Rate of Pressure Decay.” *Construction and Building Materials*, 25(4), 1946-1955.

Senge, P.M. (1990). *The Fifth Discipline- The Art and practice of the Learning Organization,* Bantam Dell Pub Group.

Technical Committee on Construction Practice (TCCP). (2000). *Code of Practice for Formwork*, SPRING Singapore, Singapore.

Workplace Health and Safety Queensland (WHSQ). (2006). *Formwork Code of Practice*. Department of Justice and Attorney-General, Queensland Government, 2006.

PLENARY PAPERS (3)

Khalife, S., Hamzeh, F. (2019). "A Framework for Understanding the Dynamic Nature of Value in Design and Construction" In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 617–628. DOI: https://doi.org/10.24928/2019/0254. Available at: <www.iglc.net>.

A FRAMEWORK FOR UNDERSTANDING THE DYNAMIC NATURE OF VALUE IN DESIGN AND CONSTRUCTION

Salam Khalife[1] and Farook Hamzeh[2]

ABSTRACT

Since the introduction of the Transformation, Flow, and Value (TFV) theory, the lean construction community has widely invested in research to understand and analyse effectively the concept of value in design and construction. Researchers looked into different contexts, mainly into manufacturing, marketing and business, where the concept of perceived value and value creation has been comprehensively studied. The main driver is that delivering value is regarded as an economic advantage and a pivotal aspect in those industries. Accordingly, researchers used these concepts to reflect on their applicability and compatibility within the construction industry. However, scrutinizing the body of knowledge addressing value in construction, one can notice the wide-ranging and scattered concepts concerning value. This paper thus aims at exploring and assembling the different attributes influencing value in construction. A review and analysis of literature is conducted, mainly in the proceedings of the IGLC conference. An integration framework structuring the multi attributes is then presented focusing on the dynamic nature of value. The overall objective is to identify the research trends concerned with value in construction and specify the probable gaps in knowledge as well as suggesting areas that need further investigation. The research presented in this paper is a first step towards understanding the different dimensions of value and building a unified platform for future research endeavours.

KEYWORDS

Value, collaboration, value generation, stakeholders, value management.

INTRODUCTION

Delivering value in projects has been a major concern in the construction industry. The global competition in the economy and the market imposed a need to find new ways to gain competitive advantage, one of which is achieving a superior customer value delivery (Woodruff 1997). The building industry had always focused on achieving value for the ultimate customer, representing the paying customer or the client (Womack and Jones 1996). In fact, the value concept was predominantly related to attaining customer's

[1] PhD student, Department of Civil and Environmental Engineering, American University of Beirut, P.O. Box 11-0236, Riad El-Solh, Beirut, Lebanon 1107 2020; email: sgk19@mail.aub.edu

[2] Associate Professor, Civil and Environmental Engineering Dept., University of Alberta, Canada, hamzeh@ualberta.ca

requirements. However, researchers and practitioners realized the need to involve the end customer or the user in construction projects. Soon after, a shift towards involving other stakeholders in the supply chain was established, and researchers emphasized the importance of having a multidisciplinary stakeholders approach to maximize value delivery (Emmitt et al. 2005). In the lean approach, similar emphasis is expressed regarding the idea of maximizing value to different customers, the purchasers, users, and producers, representing the entities who deliver the system (Ballard et al. 2001). With recent trends towards sustainability, the customer notion was even more extended to include the society as a whole, and thus social aspects became important considerations in value delivery (Salvatierra-Garrido and Pasquire 2011).

Despite the necessity of recognizing the needs of different involved stakeholders, a number of hurdles stand in the way of achieving maximum project value along with aligning the different needs. Stakeholders come with different values and backgrounds which dramatically complicate the process of construction and lead to conflicts on projects (Fenn et al. 1997). Additionally, the major struggle in the construction industry is understanding project value and its generation throughout the project phases. Koskela (1996) admitted that it is theoretically and conceptually hard to understand value generation during projects. Value is seen as an ambiguous term and it is still not well communicated (Salvatierra-Garrido et al. 2012). Moreover, value conflicts are found to be high in construction organizations leading to low commitment from internal stakeholders (Panahi et al. 2017).

Having acknowledged the fact that value generation and enhancement is problematic on construction projects, researchers invested a great effort in understanding the theoretical concept of value including: what is value? (Emmitt et al. 2005), what are the characteristics of value? (Drevland et al. 2018), is value for all stakeholders of equal importance? (Drevland and Tillmann 2018), etc.

The literature is found to be diverse in connection with value concepts and complications. This paper is at the level of diagnosis to understand the dynamic nature of value. It does not intend to provide an extensive review of literature on the specific concepts of value neither to provide the solutions for value enhancement discussed elsewhere. Instead, the framework presented in this paper aims at paving the road for a better perception of the different factors that affect value in design and construction. Additionally, the authors aim to comprehend the different attributes and the different models presented in the body of knowledge. The research presented in this paper is a primary step towards a more in depth analysis of value through linking the ideas in one coherent framework.

The research aims at answering the following two questions:

- What are the main research streams discussing value in construction projects?
- How can the identified factors be envisioned together and in relation to one another?

METHODOLOGY AND RESEARCH SCOPE

The research presented in this paper is based on a literature review study to generate a unified framework mapping the existing literature. The following steps were pursued: (1) collecting references from the IGLC conference papers and other google scholar papers from the fields of construction as well as fields of marketing and business discussing customers value and concepts related to value generation and enhancement, (2) exploring and scrutinizing the papers and identifying the diverse topics included, (3) categorizing the references according to the topics and keywords identified, (4) developing the framework based on the identified subjects, and (5) making sense of the mapped topics and the framework by adding the different related dimensions in a logical manner based on the overall readings and on the experience of the authors in the construction industry.

The research scope is limited to establishing the framework for future research encounters on topics about value and the factors influencing value enhancement on projects. The authors believe there are many studies tackling the subject at hand, yet the authors couldn't have cited all of these studies. Nevertheless, the authors argue that the framework is all inclusive of those factors and topics related to value. Yet, they are open to the fact that the research does not stop at a certain point in time, and that probable future dimensions shall be explored; otherwise, there is no point of having this frame work as a first step to future research endeavours.

LITERATURE REVIEW

VALUE THEORY

The greatest concern regarding value in any industry is understanding its nature and its characteristics. However, the discussion of value creation is rather old, where it has been debated for 2000 years in different domains and through different interpretations (Ng and Smith 2012).

Value, within the construction project's setting, is often defined as the understanding and achievement of the client's needs or the client's objectives (Bertelsen and Emmitt 2005). Project success is thus evaluated based on these objectives, which were traditionally connected to three main factors: cost, time and quality (Ward et al. 1991). The term 'value' should be distinguished from 'values'. On the one hand, values represent the beliefs, morals, standards and rules that are reflected in the attitude and behavior of individuals; additionally, values influence the individual's assessment of products and services (Thomson et al. 2003). On the other hand, value is the result of an 'evaluative judgement' where values represent the basis for such judgement (Sánchez-Fernández and Iniesta-Bonillo 2007). Therefore, values frame the assessment of value.

In a project's context, the design and construction involve multiple stakeholders and parties: clients, designers, builders, end-users, operators, etc. Researchers studied an extended list of stakeholders on projects. These were categorized into three entities: responsible stakeholder, impacted stakeholder, and interested stakeholder (Zhang and El-Gohary 2016). Each involved party conveys different interests and needs. Although the focus in construction projects is primarily on achieving the owner's and user's objectives, as it is the case in most studies, the fact that every involved stakeholder has his/her own interests and needs, thus formulating a different value perception, cannot be overlooked (Haddadi et al. 2016). In fact, the discussion and agreement of value parameters is "fundamental to the achievement of improved productivity and client/user satisfaction" (Emmitt et al. 2005).

Accordingly, project value is the result of negotiated and shared guiding principles to which all stakeholders shall subscribe (Thomson et al. 2003). Irrespective of the parties' own perception of value at the onset of the project, it is important that stakeholders have a common ground and mutual understanding to what the Project Value is; this shall be established through effective communication and collaboration. "*When individuals collaborate to realize a common goal, projects are formed. A value system can emerge if values are expressed and shared between them*" (Thomson et al. 2003).

Having to agree on a common perspective of what the project value constitutes is explicitly faced with hurdles concerning: communication, the willingness to compromise, and the position or authority of different stakeholders. Yet, another characteristic that brings more complications to the projects is that value is dynamic and evolutionary in nature as it tends to change over time (Emmitt et al. 2004; Sánchez-Fernández and Iniesta-Bonillo 2007). Clients, in general, do not know their full desires and needs at the onset of the project. It is the duty of the designers to guide and collaborate with clients to reveal the full requirements through creative workshops and innovative techniques. Previously, Ballard and Howell (1998) stressed on the role of the designer to clarify the effects of customer's desires (means), which could make an influence on their goals.

Throughout the conceptual and design development phases of projects, designers themselves evolve in their thinking based on the proliferation of more information from across disciplines. As such, the project value perceived would not remain constant. Value co-creation is the term used for expressing the interactive process between the service provider and the customer in order to create value collaboratively (Rozenes and Cohen 2017). Accordingly, several authors suggested having periodic workshops that encompass the developing value perceptions, with an aim to grasp and detect any potential changes needed based on these evolved perceptions (Emmitt et al. 2004).

STAKEHOLDERS THEORY

In an attempt to recognize and understand the stakeholders' influence on value perceptions and project success, researchers investigated in theories within marketing and management related to stakeholders. Donaldson and Preston (1995) elaborated on the stakeholders theory stressing on its core concept which is acknowledging the fact that each stakeholder has 'diverse interests', thus, it is a moral obligation to have a "mutually supportive framework".

Stakeholders are said to have hidden 'reservoirs of power' that they exercise during their interactions within the social network (Bourne and Walker 2005). Accordingly, identifying and managing stakeholders relationships while visualizing their influence through helpful tools, such as the "stakeholder circle" presented by Bourne and Walker (2005), would provide effective ways to enhance project success. Stakeholders' engagement on projects is crucial, and managing their relation and engagement is even more vital that researchers have suggested several methods to address this engagement through project management approaches (Cleland and Ireland 2002). Olander (2007) introduced the 'stakeholders impact index' for studying stakeholders' influence for better project management practices. Additionally, multiple critical success factors (CSF) for stakeholders management were introduced and tested on projects; on top of these listed

CSFs comes "managing stakeholders with social responsibilities" and "assessing stakeholders' needs and constraints" (Yang et al. 2009). Those social responsibilities include economic, legal, ethical and environmental considerations that are said to be preconditions for stakeholders management (Yang et al. 2009).

VALUE GENERATION AND ENHANCEMENT MODELS

"Value is generated through a process of negotiation between customer ends and means" according to Ballard and Howell (1998). Several studies proposed frameworks and models for implementation in an attempt to enhance value on projects during design and construction (Haddadi et al. 2016; Haddadi et al. 2017; Thyssen et al. 2010). Mainly, those models are in connection with approaches such as value engineering (Kelly and Male 2003), value management (Musa et al. 2016), and value-based management (Wandahl and Bejder 2003). Lean principles are at the heart of several models which elaborated on approaches such as target value design, lean project delivery system LPDS, and set-based design (Miron et al. 2015; Tillmann et al. 2013). Other researchers looked into the power of Building Information modelling (BIM) and collaborative approaches in enhancing value on projects (Park et al. 2017). Additionally, conceptual models are developed to augment value co-creation such as the one suggested by Heredia Rojas et al. (2018).

Stakeholder Value Network (SVN) is a method developed to analyse value delivery through computing stakeholders' influence within a network. SVN is used in different domains mainly in engineering systems (Cameron 2007). Feng (2013) used SVN to explore the links between stakeholders in large engineering projects. Zheng et al. (2019) employed the SVN technique to study value flows in BIM based projects.

While the presence of plentiful models and proposed frameworks helped in better understanding stakeholder's value, the aim of maximizing value generation in a project's setting is still an open and debatable topic that needs further investigations. A starting point is understanding the different attributes collectively by mapping them together under one framework.

A MULTI-ATTRIBUTE INTEGRATION FRAMEWORK

The current study explored the literature for concepts related to value and factors within projects that have a direct and indirect influence on value perceptions. The collected information resulted in a set of categories that interrelate with each other and constitute what the authors called a multi-attribute integration framework. The framework is presented in Figure 1. A conceptual framework is "an interconnected set of ideas (theories) about how a particular phenomenon functions or is related to its parts. The framework serves as the basis for understanding the causal or correlational patterns of interconnections across events, ideas, observations, concepts, knowledge, interpretations and other components of experience" (Svinicki 2010), p.5. The framework, developed as per the previously mentioned principles, is considered a visual mapping for the broad topics interfering with value perceptions, generation, and enhancement. In what follows, a thorough explanation of the broad keywords and topics covered in the framework is presented.

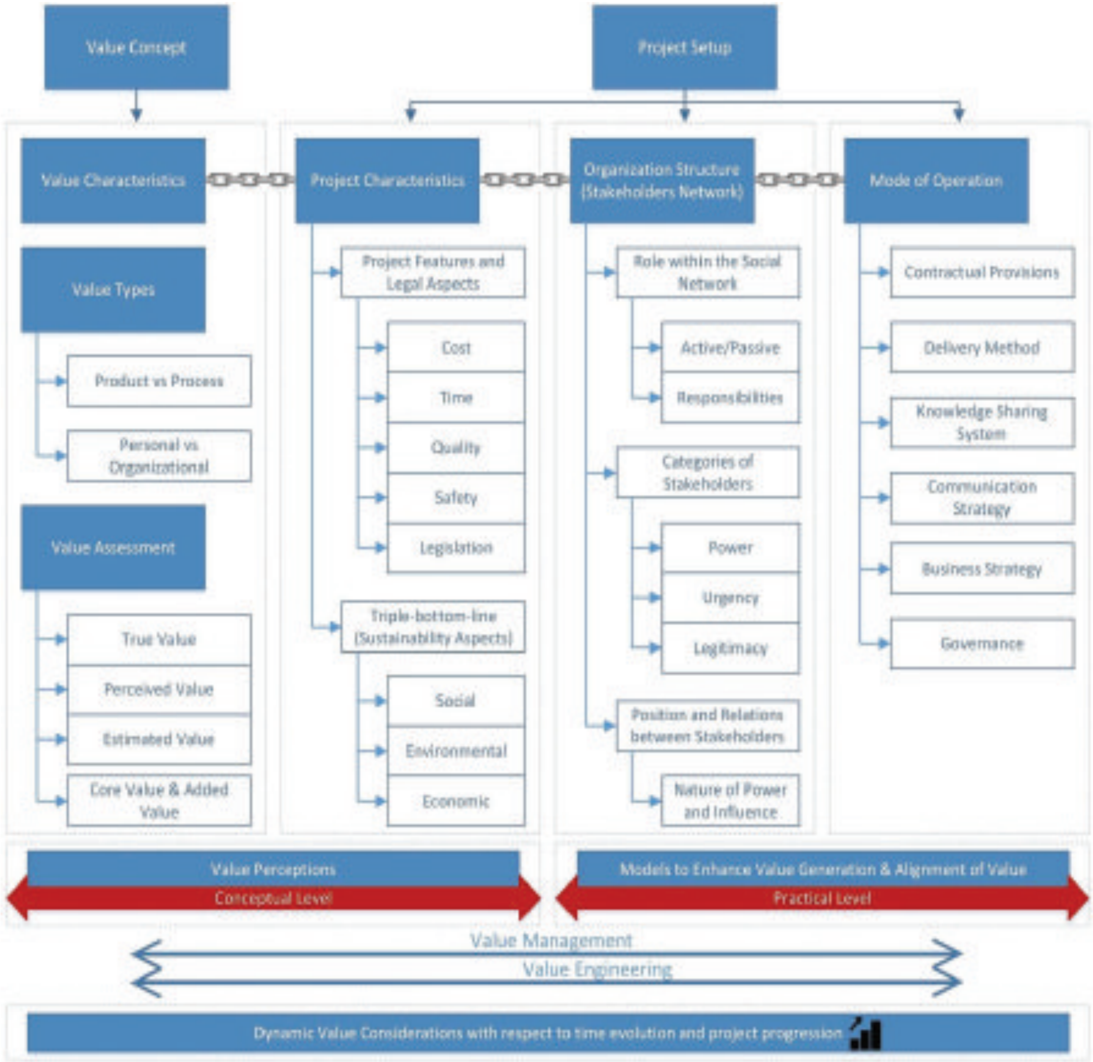


Figure 67. Multi-attribute integration framework

The synthesis of the encountered topics on value resulted in identifying two major headings in the integration framework: the *Value Concept* and the *Project Setup*. Basically, the two headlines are inseparable, where value concepts are usually observed in the corresponding project setup; however, the purpose here is to reflect on the research streams where some studies have discussed concepts related to value irrespective of the project setting or specifications. Yet, more often than not, researchers were eager to further understand the correlations of different attributes stemming from these major areas. The multi-tier attributes under each main heading are explained hereafter.

A. THE VALUE CONCEPT

Understanding the value concept is an essential step towards controlling and managing its impact on the project outcome. The outcome of design as well as the outcome of construction, or the product itself, is contingent upon the perceived value between the different players involved in those phases and the encompassed processes (Kelly et al. 1993).

Based on the literature, the value concept is discussed from three perspectives: characteristics, types, and assessment. First, the research delves into recording *Value Characteristics* which is observed to be a hot topic and a path to understand the 'ambiguous' concept (Barima 2010). Thyssen et al. (2010) identified several characteristics describing value within the construction industry based on their literature exploration. Value is argued to be (1) a subjective judgement due to the interference of human personal interest, (2) an objective measurement when considering and comparing alternatives as to which is more valuable, (3) a context-dependent matter, (4) a dynamic issue as it changes over time, (5) information-dependent, and (6) instrumental for projects (Thyssen et al. 2010). Drevland et al. (2018) built on previous interpretations of value characteristics and defined nine tenets to decompose this complex term. They stressed on the fact that value is a result of an evaluative judgement with its factors being evaluated simultaneously. Thus, consequences are not summative, and value is not linear. Value consequences are expressed in the gained or lost experience of the different stakeholders.

Second, researchers examined *Value Types* in construction projects, and the most common terminology found is differentiating between product value and process value. Emmitt et al. (2005) elaborated on the difference between the two terms. Process value represents both soft values (e.g. resolving conflicts, better communication) and hard values (e.g. adhering to budget and time requirements) that are associated with clients' experience during the delivery of the project by the team. Product value represents the built facility or the project with respect to firmness, commodity, and delight, or the Vitruvian values (Emmitt et al. 2005). These are related to *Project Characteristics* explained under the project setup. Other types of value include personal vs. organizational value, where perceived value shall be considered both at the personal level and at the organizational commitment level (Panahi et al. 2017).

The third aspect deduced from different studies regarding the value concept is *Value Assessment*. Value on projects need to be evaluated so that management practices could take place effectively. Drevland et al. (2018) differentiated between true value, perceived value, and estimated value. Perceived value is dependent on the perceiver's knowledge and values, while true value is achieved when the perceiver has perfect knowledge. The estimated value is recorded by someone else, the estimator, to suspect about the value perception of others based on the knowledge at hand and within its context. Additionally, researchers designated two other types of value on projects: the core value and the added value (Salem Khalifa 2004). Understanding these different assessments would help multi-disciplinary teams and involved stakeholders to establish a common ground to assess the overall project value. Nevertheless, these are only labels for value and actions need to be taken based on factors within the project setting.

B. THE PROJECT SETUP

In addition to value concepts, value is debated in the literature within the project setup. To understand the project setup or the environment and the different players, three main categories need to be assessed: *Project Characteristics*, *Organization Structure*, and the *Mode of Operation*.

Project Characteristics are associated with the project features that are normally set at the beginning of every project. Cost (budget), time (duration), and quality (specifications), designated as the iron triangle in literature, are the basic features in every project. Other characteristics, such safety and legal issues shall be included as they normally affect project value. Further considerations featuring value in projects are the sustainability measures comprising the social, economic, and environmental aspects (Novak 2012). With the current global environmental problems, sustainability measures are instrumental to project value.

Organization Structure is a fundamental category that reflects on the stakeholders' important role in value creation and enhancement. Not all stakeholders take an active role in the project to maximize value and some are passive recipients of value, whether it is positive or negative (Drevland et al. 2017). The type of responsibilities carried by each involved party in the project setting is an additional attribute affecting the overall project value. Earlier, Mitchell et al. (1997) categorized stakeholders based on three attributes: Power, Urgency, and Legitimacy. Haddadi et al. (2016) focused on the major facet which is power. The position and relation between stakeholders is attributed to the nature of power they hold and thus the influence on other stakeholders.

The *Mode of Operation* is the third core aspect that has a direct effect on enhancing value generation on projects. The delivery method, the contractual provisions, and the knowledge sharing system are basic drivers when it comes to value delivery. Matthews and Howell (2005) explain the difficulties in maximizing value on projects that are restricted with a type of contract that impedes coordination and instead rewards individuals on optimizing their performance at the expense of others. Therefore, the call for integration in project delivery and implementing relational contracting have shown positive trends towards aligning stakeholders interests (Forbes and Ahmed 2010). Likewise, strategies describing the mode of operation on projects, such as communication strategies, business strategies, and governance are interesting attributes to be studied in connection with value on construction projects. Some also have suggested integrated governance to augment value generation (Tillmann et al. 2012). Other researchers have tested the use of Building Information Modeling BIM on fostering collaboration to enhance project value as described earlier in the literature section.

The set of models found in the literature tackling issues of generating and maximizing value on projects address the practical level and relate to the *organization structure* and the *mode of operation*. On the contrary, value perceptions work on the conceptual level and thus relate to the *value concept* and the *project characteristics*. Value management and value engineering practices are also associated with the mentioned attributes but do not necessarily include all the needed strategies to enhance project value. Other gaps are found in the process of being able to measure and evaluate project value as a basis for a control mechanism aimed at value enhancement on the practical level.

C. TIME PROGRESSION AND VALUE EVOLUTION

The aforementioned factors and attributes are not constant as any of those listed attributes in the framework might change with time. Therefore, there is a need to emphasize on the dynamic nature of value.

Nonetheless, the authors need to stress on the fact that all categories are interrelated. Hence, the value concept and the three main categories of the project setup are subcategories of one another as represented in Figure 2. This also emphasizes on the dynamic nature that project value entails. Therefore, any potential change in any of the categories would affect other factors in other categories, such as changing the knowledge sharing system or coordination strategies would have a direct effect on stakeholders' relations and, subsequently, value perceptions.

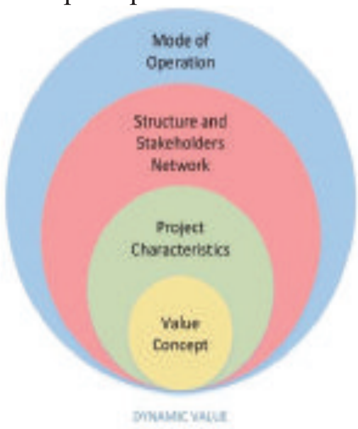


Figure 68. The integration between value related aspects rendering value as dynamic

The fact that construction projects are complex in their nature is well established within the management literature. A further dimension is added which is qualifying construction processes as emergent and highly dynamic systems in an emergent setting with a complex-emergent customer organization (Bertelsen and Emmitt 2005). This further explains the dynamic nature of production systems with a direct influence on value perceptions. Accordingly, with time progression, value perceptions might be revisited where any of the core project values could change to result in an added value for the project. These changes are mainly observed during design, where iterations are a common feature in the conceptual design and design development phases; trade-offs are thus made to satisfy the collective project value based on different stakeholders' input.

CONCLUSION

The value concept has been gaining momentum in construction specifically in the lean construction industry. A synthesis of the encountered topics within the literature resulted in a conceptual framework for understanding the diverse categories and attributes in regards to value generation, communication and enhancement. The framework helps in establishing a shared understanding about the concepts, factors, and aspects addressing value in design and construction. Certain gaps were observed on the practical level mainly regarding enhancing project value based on the collective attributes. Therefore, project management practices need to cater for the different factors within the organization structure and the mode of operation. The paper elaborated on the dynamic nature of value based on the emergent nature of the projects and their setting, and based on the interconnectedness of project attributes. Future research endeavours shall consider the proposed framework as basis for imminent proposed solutions for value measurement.

REFERENCES

Ballard, G., and Howell, G. "What kind of production is construction." *Proc., Proc. 6 th Annual Conf. Int'l. Group for Lean Construction*, 13-15.

Ballard, G., Koskela, L., Howell, G., and Zabelle, T. "Production system design in construction." *Proc., Proceedings of the 9th annual conference of the International Group for Lean Construction*.

Barima, O. J. I. J. o. P. M. (2010). "Examination of the best, analogous, competing terms to describe value in construction projects." 28(3), 195-200.

Bertelsen, S., and Emmitt, S. "The client as a complex system." *Proc., 13th International Group for Lean Construction Conference: Proceedings*, International Group on Lean Construction, 73.

Bourne, L., and Walker, D. H. (2005). "Visualising and mapping stakeholder influence." *Management decision*, 43(5), 649-660.

Cameron, B. G. (2007). "Value network modeling: a quantitative method for comparing benefit across exploration architectures." Massachusetts Institute of Technology.

Cleland, D. I., and Ireland, L. R. (2002). *Project management: strategic design and implementation*, McGraw-Hill.

Donaldson, T., and Preston, L. E. (1995). "The stakeholder theory of the corporation: Concepts, evidence, and implications." *Academy of management Review*, 20(1), 65-91.

Drevland, F., Lohne, J., and Klakegg, O. J. "Ethical Dilemmas in Value Delivery: Theoretical Conditions." *Proc., 25th Annual Conference of the International Group for Lean Construction*, 145-152.

Drevland, F., Lohne, J., and Klakegg, O. J. (2018). "Defining An Ill-defined Concept–Nine Tenets On The Nature Of Value."

Drevland, F., and Tillmann, P. A. "Value for Whom?" *Proc., 26th Annual Conference of the International Group for Lean Construction*Chennai, India, 261-270.

Emmitt, S., Sander, D., and Christoffersen, A. K. "Implementing value through lean design management." *Proc., Proceedings of the 12th Int. Conference*, 361-374.

Emmitt, S., Sander, D., and Christoffersen, A. K. "The value universe: defining a value based approach to lean construction." *Proc., 13th International Group for Lean Construction Conference: Proceedings*, Int. Group on Lean Construction, 57.

Feng, W. (2013). "Strategic management for large engineering projects: the stakeholder value network approach." Massachusetts Institute of Technology.

Fenn, P., Lowe, D., and Speck, C. (1997). "Conflict and dispute in construction." *Construction Management & Economics*, 15(6), 513-518.

Forbes, L. H., and Ahmed, S. M. (2010). *Modern construction: lean project delivery and integrated practices*, CRC press.

Haddadi, A., Johansen, A., and Andersen, B. (2016). "A Conceptual Framework to Enhance Value Creation in Construction Projects." *Procedia Computer Science*, 100, 565-573.

Haddadi, A., Johansen, A., and Bjørberg, S. (2017). "Best Value Approach (BVA): Enhancing Value Creation in Construction Projects." *Business systems research journal: international journal of the Society for Advancing Business & Information Technology (BIT)*, 8(2), 84-100.

Haddadi, A., Temeljotov-Salaj, A., Foss, M., and Klakegg, O. J. (2016). "The Concept of Value for Owners and Users of Buildings – A Literature Study of Value in Different Contexts." *Procedia - Social and Behavioral Sciences*, 226, 381-389.

Haddadi, A., Torp, O., Lohne, J., and Lædre, O. (2016). "The link between stakeholder power and value creation in construction projects." *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*Boston, MA, USA.

Heredia Rojas, B., Liu, L., and Lu, D. (2018). "Moderated effect of value co-creation on project performance." *International Journal of Managing Projects in Business*, 11(4), 854-872.

Kelly, J., and Male, S. (2003). *Value management in design and construction*, Routledge.

Kelly, J., Male, S., and MacPherson, S. (1993). *Value management: A proposed practice manual for the briefing process*, Royal Institution of Chartered Surveyors London.

Koskela, L. "Towards the theory of (lean) construction." *Proc., Proceedings of the Fourth Annual Conference of the Int. Group for Lean Construction*, 26-27.

Matthews, O., and Howell, G. A. J. L. c. j. (2005). "Integrated project delivery an example of relational contracting." 2(1), 46-61.

Miron, L. I. G., Kaushik, A., and Koskela, L. "Target value design: the challenge of value generation." *Proc., 23rd Annual Conference of the international group for lean construction*, 29-31.

Mitchell, R. K., Agle, B. R., and Wood, D. J. J. A. o. m. r. (1997). "Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts." 22(4), 853-886.

Musa, M. M., Pasquire, C., and Hurst, A. (2016). "Where lean construction and value management meet."

Ng, I. C., and Smith, L. A. (2012). "An integrative framework of value." *Special issue–Toward a better understanding of the role of value in markets and marketing*, Emerald Group Publishing Limited, 207-243.

Novak, V. M. "Value paradigm: revealing synergy between lean and sustainability." *Proc., Proceedings of the 20th Conference of the International Group for Lean Construction*, 51-60.

Olander, S. (2007). "Stakeholder impact analysis in construction project management." *Construction management and economics*, 25(3), 277-287.

Panahi, B., Moezzi, E., Preece, C. N., and Wan Zakaria, W. N. (2017). "Value conflicts and organizational commitment of internal construction stakeholders." *Engineering, Construction and Architectural Management*, 24(4), 554-574.

Park, C.-S., Kim, H.-J., Park, H.-T., Goh, J.-H., and Pedro, A. (2017). "BIM-based idea bank for managing value engineering ideas." *International Journal of Project Management*, 35(4), 699-713.

Rozenes, S., and Cohen, Y. (2017). *Handbook of Research on Strategic Alliances and Value Co-Creation in the Service Industry*, IGI Global.

Salem Khalifa, A. (2004). "Customer value: a review of recent literature and an integrative configuration." *Management decision*, 42(5), 645-666.

Salvatierra-Garrido, J., Pasquire, C., and Miron, L. "Exploring value concept through the iglc community: Nineteen years of experience." *Proc., Proceedings for the 20th Annual Conference of the Int. Group for Lean Construction, San Diego, CA*.

Salvatierra-Garrido, J., and Pasquire, C. (2011). "Value theory in lean construction." *Journal of Financial Management of Property and Construction*, 16(1), 8-18.

Sánchez-Fernández, R., and Iniesta-Bonillo, M. Á. (2007). "The concept of perceived value: a systematic review of the research." *Marketing Theory*, 7(4), 427-451.

Svinicki, M. D. (2010). "A guidebook on conceptual frameworks for research in engineering education." *Rigorous Research in Engineering Education*, 1-53.

Thomson, D. S., Austin, S. A., Devine-Wright, H., and Mills, G. R. (2003). "Managing value and quality in design." *Building Research & Information*, 31(5), 334-345.

Thyssen, M. H., Emmitt, S., Bonke, S., and Kirk-Christoffersen, A. (2010). "Facilitating client value creation in the conceptual design phase of construction projects: a workshop approach." *Architectural Eng. and Design Management*, 6(1), 18-30.

Tillmann, P., Ballard, G., Tzortzopoulos, P., and Formoso, C. (2012). "How integrated governance contributes to value generation: insights from an IPD case study."

Tillmann, P., Tzortzopoulos, P., Formoso, C. T., and Ballard, G. "Contributions of existing practices to pursuing value in construction projects." *Proc., Proc. IGLC-21: 21st Annual Conference of the Int. Group for Lean Construction*, 359-368.

Wandahl, S., and Bejder, E. "Value-based management in the supply chain of construction projects." *Proc., The 11th annual conference on Lean Construction, Blacksburg. Edt.: Martinez and Formoso*.

Ward, S. C., Curtis, B., and Chapman, C. B. (1991). "Objectives and performance in construction projects." *Construction Management and Economics*, 9(4), 343-353.

Womack, J. P., and Jones, D. T. (1996). *Lean Thinking: Banish waste and Create wealth in your corporation*, Free Press, New York.

Woodruff, R. B. (1997). "Customer value: The next source for competitive advantage." *Journal of the Academy of Marketing Science*, 25(2), 139.

Yang, J., Shen, G. Q., Ho, M., Drew, D. S., and Chan, A. P. (2009). "Exploring critical success factors for stakeholder management in construction projects." *Journal of civil engineering and management*, 15(4), 337-348.

Zhang, L., and El-Gohary, N. M. (2016). "Discovering Stakeholder Values for Axiology-Based Value Analysis of Building Projects." *Journal of Construction Engineering and Management*, 142(4), 04015095.

Zheng, X., Lu, Y., Li, Y., Le, Y., and Xiao, J. (2019). "Quantifying and visualizing value exchanges in building information modeling (BIM) projects." *Automation in Construction*, 99, 91-108

Barth, K.B., Formoso, C.T., Sterzi, M.P., (2019). “Performance Measurement in Lean Production Systems: an Exploration on Requirements and Taxonomies” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 629–640. DOI: https://doi.org/10.24928/2019/0266. Available at: <www.iglc.net>.

PERFORMANCE MEASUREMENT IN LEAN PRODUCTION SYSTEMS: AN EXPLORATION ON REQUIREMENTS AND TAXONOMIES

Karina B. Barth[1], Carlos T. Formoso[2] and Marcus P. Sterzi[3]

ABSTRACT

Performance measurement plays an important role in project and business management, as it focuses on the most important aspects of the business, provides real data and guides actions for improvement. It also provides support for the implementation of some Lean Production principles, such as reducing the share of non-value-adding activities (waste), increasing process transparency, building continuous improvement into the process, and benchmarking. Despite its importance, very little has been reported on the development of PM systems that are effective for assessing the impact of lean implementation. In addition, there is a lack of studies on how Lean companies (or projects) use indicators and to what extent these reflect the result of actions that have been undertaken. Therefore, this paper presents preliminary results of a research study that aims to propose a set of requirements for Performance Measurement (PM) Systems from a lean production perspective, and a taxonomy of metrics for lean production systems. It discusses the scope of the performance metrics adopted by five companies from South America involved in the implementation of Lean Production Systems. The scope of this investigation is limited to construction projects as production systems, rather than PM at the level of construction organizations.

KEYWORDS

Performance measurement, lean construction, production management, continuous improvement, kaizen.

INTRODUCTION

Performance measurement (PM) is a theme that has received much attention in the literature since the Nineties, both in the field of Operations Management (Neely et al. 1997) and in Construction Management. Regarding the construction industry, several contributions can be found in the literature, including conceptual approaches (Kagioglou et al. 2001), guidelines for assessing PM systems (Costa and Formoso 2004); implementation models (Love and Holt 2000); comparisons between metrics adopted by different companies (Costa

[1] PhD Candidate, Building Innovation Research Unit - NORIE, Federal University of Rio Grande do Sul, Brazil, kbertotto@gmail.com

[2] Professor, Building Innovation Research Unit - NORIE, Federal University of Rio Grande do Sul, Brazil, formoso@ufrgs.br

[3] MSc, Building Innovation Research Unit - NORIE, Federal University of Rio Grande do Sul, Brazil. Consultant and Managing Partner at LD Consulting, marcus@ldconsulting.com.br

et al. 2006); and PM in specific sectors or processes (Robinson et al. 2005). Moreover, there has been several initiatives promoted by industrial organizations that have proposed key-performance indicators or benchmarking clubs (Costa et al. 2006). The design of a PM system involves more than the selection and definition of appropriate measures for assessing the efficiency or effectiveness of processes and organizations (Costa and Formoso 2004). It should contain several key elements: (a) procedures for collecting and processing data; (b) timetables and protocols for distributing information about performance to users within and outside the organization; (c) a learning approach to identify what actions can be taken to further improve performance; and (d) a review process which ensures that the PM system is regularly updated (Neely et al. 1997). PM systems play a key role in business management, as it provides the necessary information for process control, enables the establishment of challenging and feasible goals, and facilitates communication between different managerial levels (Hall et al. 1991) Moreover, it helps to align efforts and resources to the most important aspects of the business (Lantelme and Formoso 2000) and produce data that can be used as a reference for process improvement (Pavlov and Bourne 2011).

Despite its importance, many problems concerned with measuring performance in construction projects have been pointed out in the literature, such as: (i) most companies use traditional lagging indicators that are focused on results making them ineffective to support timely decision making (Sarhan and Fox 2013); (ii) some PM systems contain too many measures, most of them linked to supporting rather than critical processes (Costa and Formoso 2004); (iii) the implementation of PM systems is limited to the selection of isolated measures, neglecting the necessary changes in decision-making (Beatham et al. 2004); and (iv) PM systems are not properly integrated to improvement initiatives (Kennerley and Neely 2003).

PM has an important role in the implementation of some Lean Production principles, such as reducing the share of non-value-adding activities (waste), increasing process transparency, building continuous improvement into the process, and benchmarking (Koskela 2000). However, the literature on PM for Lean Production Systems in the Construction Industry is relatively scarce. Very often, the implementation of Lean concepts and principles in production management is simply monitored by Last Planner related indicators (España et al. 2012; Sacks et al. 2017). There seem to be opportunities for extending PM systems in companies that have adopted the Lean Production Philosophy, especially by using some leading indicators related to core Lean and principles, such as pull production, WIP control, and continuous flow, for instance. In fact, despite the large number of Lean implementations reported in the literature, very little has been reported on the development of PM systems that are effective for assessing the impact of lean implementation (Sanchez and Pérez 2004). Besides, there is a lack of studies on how Lean companies (or projects) use indicators and to what extent these reflect the result of actions that have been undertaken (Bellisario and Pavlov 2018). By contrast, PM cannot be considered as an end in itself: it must be regarded as a support activity, not adding value directly to the product (Koskela 1992).

This paper presents preliminary results of a research study that aims to propose a set of requirements for PMS from a lean production perspective, and a taxonomy of metrics for lean production systems. It discusses the scope of the performance metrics adopted by five companies from South America involved in the implementation of Lean Production

Systems. The scope of this investigation is limited to construction projects as production systems, rather than PM at the level of construction organizations.

ROLE OF PM IN LEAN PRODUCTION SYSTEMS

REQUIREMENTS FOR PM SYSTEMS

PM plays a different role in lean production systems when compared to traditional managerial systems (Maskell 1991). Traditional measures compare task completion, cost results, and quality data to the plan or budget (España et al. 2012). This is based on the thermostat model: controlling means returning to standard by correcting deviation, but not much effort is made in the identification and elimination of the root causes of those deviations (Koskela and Howell 2002).

Koskela (1992) makes some recommendations for the development of PM systems so that it supports the application of lean production concepts: investigate the causes of the problems, measure waste by assessing the share of non-value-adding activities, monitor variability, cycle time and defects, and promote continuous improvement (or learning). In summary, PM systems should be capable of evaluating the production system performance in relation to flow and value, in addition to transformation (traditionally monitored), in order to support decision making (España et al. 2012). Therefore, the definition of performance metrics in Lean Production Systems should address a set of requirements (adapted from MASKELL, 1991):

(i) Have a direct relation with the manufacturing strategy: there are two reasons to keep PM aligned with the company's manufacturing (or production) strategy. The first one is the need to assess whether the strategic goals are being achieved, and their achievement is directly linked to the actions taken (and measured) in production. The second reason refers to the translation of strategy through operational measures that prioritize what is most important to the company. In addition, (Bhasin 2008) points out the importance of establishing an effective system which translate the information gathered from PM to an effective strategy for action.

(ii) Use primarily nonfinancial measures: PM must be close to actions at the shop floor level by using metrics that shows what is most relevant. This provide reliable information about operational reality (Bellisario and Pavlov 2018). By contrast, financial measures are important for accounting controls and external reporting, but not for guiding the daily actions of production.

(iii) Create local control systems: indicators should be revised in order to meet the requirements of each situation (Koskela 1992). Lean manufacturing organizations continuously adapt their performance measures to suit their context, consequently stimulating debate and creating opportunities for learning (Bellisario and Pavlov 2018). Therefore, it is beneficial to provide some degree of freedom for the manager of each plant (or project) to adopt some indicators that meets their local needs. They will differ from one plant (or project) to another, being used for local control. The role of these indicators is to stimulate the involvement of operational teams in continuous improvement initiatives.

(iv) Be flexible and change by time as needed: as continuous improvement play an important role in Lean implementation, a PM system must be able to keep pace with changes in the production system (Maskell 1991). External changes to the company may also require updating the indicator system (Kennerley and Neely 2003)

(v) Be simple and provide quick feedback to users: stakeholders should be able to understand the meaning and importance of the information provided. Metrics should be objective and simple. Moreover, PM systems must provide relevant, reliable and timely information (Neely et al. 1997). As information is clear and simple, deviation detection becomes faster, allowing decision-making and. actions to be performed in a short amount of time (Maskell 1991). This results in a form of feedback which better fits the needs of shop-floor employees and managers (Fullerton and Wempe 2009).

(vi) Promote improvement and learning by increasing process transparency: the results of PM must be made available to decision makers on-time and at the point of use. Besides supporting the early detection of problems, process transparency facilitate collaboration among team members (Ewenstein and Whyte 2007), mitigate problems related to the management of complex production systems (Viana 2015), and increase workforce motivation (Galsworth 1997). The choice of the metrics and the form of displaying them depend of the specific needs of each user (e.g. managers, workers, subcontractors, etc.). Bhasin (2008) also points out the importance of adopting information and communication technology to automate data collection and analysis and the production of reports, when possible.

TAXONOMY FOR PM IN LEAN PRODUCTION SYSTEMS

The use of two categories, result (or output) and process indicators, has already been widely discussed in the literature, and represents one of the key requirements for PM systems in general (Beatham et al. 2004). It means that PM must go beyond just indicating a result. It should have a more important role, aligned with lean principles; collaborative teams with a culture of responsibility; structured critical analysis and decision making; use of historical data; continuous learning and improvement; and effective communication (España et al. 2012). According to Karlsson and Åhlstrom (1996), the performance of Lean Production Systems can be analyzed by considering a set of factors (named groups of indicators): elimination of waste, continuous improvement, zero defects, just-in-time, and multifunctional teams. For each factor (or manufacturing objective), Karlsson and Åhlstrom (1996) identified the determinants that could reflect the changes in a company in the process to become lean, based on the concepts proposed by Womack, Jones, and Ross (1990).These determinants can be actions, principles or changes implemented in a company with the aim of improving performance. Sanchez and Pérez (2004) applied the model proposed by Karlsson and Åhlstrom (1996), by adapting to the context of services. Based on Karlsson and Åhlstrom (1996) and Sanchez and Pérez (2004), Rivera and Manotas (2014) adopted five factors (named dimensions) for PM, which are related to continuous improvement. Table *29* presents the factors adopted in those three research studies.

Rivera and Manotas (2014) proposes a set of 21 performance indicators for monitoring the implementation of lean practices, and points out that they must be integrated to continuous improvement initiatives. These authors proposed a taxonomy for metrics in terms of Focus and Scope. Focus is related to the way decision makers use them and can be divided in **process** focus and **result** focus. Scope is concerned with the way indicators are be monitored, collected and used, and can be divided in organizational and frequency scope.

Karlsson and Åhlström (1996)	Sánchez and Pérez (2004) and Rivera and Manotas (2014)
Elimination of waste	Elimination of waste
Continuous improvement	Continuous improvement
Zero defects	-
Just In Time (JIT)	Continuous flow and Pull-driven systems
Pull instead of push (related to JIT)	
Multifunctional teams (MT)	Multifunctional teams
Decentralized responsibility (related to multifunctional teams)	-
Integrated functions (related to MT)	-
Vertical Information Systems (related to MT)	Information systems

Table 29: Factors adopted for measuring performance of Lean Production Systems

RESEARCH METHOD

The research work described in this paper has a descriptive character, and corresponds to one of the early stages of the research project that aims to propose a set of requirements for PM in Lean Production Systems in the construction industry. The performance metrics of five construction companies from Latin America adopted for assessing the performance of production systems have been analyzed. Table 30**Error! Reference source not found.** presents the profile of the group of companies. These were selected for the following reasons: have a well-structured PM systems; have successfully implemented a number of lean production practices; provided access to information. The main sources of evidence adopted were: analysis of documents and visual devices, participant observation, and unstructured interviews with managers.

	Company A	Company B	Company C	Company D	Company E
Company size	Large	Large	Small-sized	Large	Large
Main activities	Construction and real estate development for middle and upper-middle-class residential markets	Services and integrated solutions in construction for Industrial and offshore works	Construction and real estate development for middle and upper-middle-class residential markets	Construction and real estate development for low, middle and upper-middle-class residential markets	Development and construction buildings for private clients (mostly industrial projects)
Main characte-ristics	Considered as a benchmark in Lean Construction, started lean implementation in the 90's	Multinational Company that have implemented lean in complex projects (e.g. offshore)	Family owned company, started a Lean Journey less than 3 years ago	Started a Lean journey Company less than 3 years ago	Works mostly as a contractor, in a wide range of different projects. Started its Lean journey less than 5 years ago
Main lean practices adopted	- Last Planner - Kanban - 5S - Prototyping - Visual management - Standardized work	- Last Planner - Kanban - Multi-function teams - Visual management - Standardized work - Value Stream Mapping	- Last Planner - Visual management - Task completion control - Takt-time planning	- Last Planner - Visual Management - 5S - Task completion Takt-time planning	- Last Planner - Visual Management - Takt-time planning

Table 30: Description of the five companies

All five companies have kept a historical database of indicators, which is sometimes used for comparisons and decision-making. They have to some extend undertaken internal and external benchmarking exercises.

Performance Measures Used by the Companies

This section describes the performance metrics related to the lean implementation that have been used by the group of five companies. All of them had other metrics, not reported in this paper, which are often linked to the traditional way of measuring performance, such as cost deviation, project delays, and project progress. Table 31 provides an overview of the metrics adopted by the five the companies.

Indicators	Company A	Company B	Company C	Company D	Company E
Last Planner Metrics	x	x	x	x	x
Effectiveness of LPS Implementation	x		x	x	
Daily OTP (On Time Performance)		x			
Gemba Walk Wastes		x	x		
Number of Kaizen Ideas		x			
Terminality and Anticipation			x	x	
HeatMap				x	
Batch Adherence Control				x	x
Cycle Time				x	x
Rhythm Deviation	x		x	x	x

Table 31: Indicators supporting lean practices identified in the companies studied.

Last Planner Metrics

All companies had implemented Last Planner System (LPS), and adopted the metrics that are often used at the look-ahead and weekly planning level: overall PPC (Percentage of Plan Completed), PPC for different crews or subcontractors; Causes for the non-completion of work packages; Overall number of constraints identified (NCI); Percentage of Constraints Removed (PCR); and Relative number of constraint for each category.

Effectiveness of LPS Implementation

Three of the companies used a metric that assess the degree of implementation of planning and control practices. It is based on a checklist of 15 practices, that was originally proposed by Bernardes and Formoso[4]. This checklist covers the tree planning horizons and allows the evaluation of the degree of maturity of planning systems. None of the companies used maturity models for doing a broad assessment of Lean implementation beyond LPS.

Daily OTP (On Time Performance).

Daily OTP indicator monitors the percentage of the daily tasks that is completed, in relation to the number of tasks planned through the cards in the PPM Board[5] for each project or supervisor. This metric is similar to the PPC indicator (calculated daily) but is extracted from the visual management panel of each project (PPM Board). Deviations between planned and executed activities are calculated and presented in a visual device. The Weekly OTP indicator is an

[4] Bernardes, Maurício, and Formoso, Carlos. 2002. "Contributions To the Evaluation of Production Planning and Control Systems in Building Companies." IProc. of the Ann. Conf. of Int'l Group for Lean Construction, 10., 2002, Gramado: 1–11.

[5] Daily planning panel, similar to a Heijunka Box. Visual tool for a daily scheduling of execution and pre-fabrication; based on Takt time on a daily basis and commitment plan (Last Planner System).

overview of the performance over a four week period, and provides some details from the current week (e.g. progress of work by team, supervisor and area). Data comes from Daily Performance Sheets (Daily OTP). Correction and prevention actions are proposed in response to deviations pointed out by this indicator. These are defined and recorded in A3 reports. This indicator can also be used for monitoring deviations in relation to the Takt Time on a daily basis, process efficiency and utilization of capacity, especially regarding bottleneck resources.

Gemba Walk Waste

The aim of the Gemba Walk is to identify waste (non-value-adding activities) in different processes in the construction site. This measure is carried out on a regular basis to ensure the continuous identification and removal of waste, based on previous Gemba walk. It typically undertaken every two weeks, and involves both top managers and site managers. During the Gemba walk, it is essential to observe how the process is carried out in the work area, as well as to speak to workers who are performing the job, so as to ensure the process is fully understood. While conducting the Gemba walk, one should identify the different types of waste at different work stations, follow the material and information flows and look out for possible wastes. Some waste categories can be used, such as the Seven Wastes by Ohno (1988)[6], underutilization of labor, and energy waste.

Number of Kaizen Ideas

This indicator is based on the improvement initiatives coming from that were put into practice. Each idea is evaluated by a lean team, that authorizes or not its application in other projects. The metric is calculated in a monthly basis (number of kaizens applied per month). This indicator can be used for giving awards to individual employees or groups of employees whose idea results in the best improvement (e.g. reduction in the number of man-hours or non value adding time). Sometimes the proportion of top-down and bottom-up kaizen ideas is also calculated, i.e. the ratio between the number of kaizens ideas originated in the shop floor and the number of kaizens ideas coming from top managers, senior managers and directors.

Terminality and Anticipation

According to Koskela (2004), the beginning of an activity should consider the concept of "complete kit" (Ronen 1992). When this not occurs, there is a reduction of performance in terms of efficiency and quality, named making-do, which may cause other types of waste, such as: increase in the share of non-value-adding activities; increase in work in progress (WIP); increase in cycle time; rework; lack of safety; and unfinished work. De Vargas (2018) [7] proposed metrics related to those wastes: percentage of completed packages with terminality and percentage of anticipated tasks. These indicators are generated from a matrix that relates activities (columns) to production units (rows). Each cell presents information of task status, whether it is in progress; stopped; or not released (not started). In the case of stoppage, a cause must be reported. The indicator Percentage of Anticipated Tasks is the ratio between anticipated and non-anticipated tasks. The terminality indicator is calculated by the percentage of tasks that started, but were not

[6] Ohno, Taiichi. The Toyota Production System: Beyond Large-Scale Production. Portland, Oregon: Productivity Press, 1988.

[7] De Vargas, F. B. (2018). "Método para Planejamento e Controle da Produção baseado em Zonas de Trabalho e BIM." Dissertação (Mestrado em Engenharia Civil) – PPGCI, Porto Alegre.

completed. The third indicators is concerned with the causes that prevented task from accomplishment. Besides, the matrix itself provides a visual map of project status and information for monitoring cycle time. Figure 69 shows an example of the matrix.

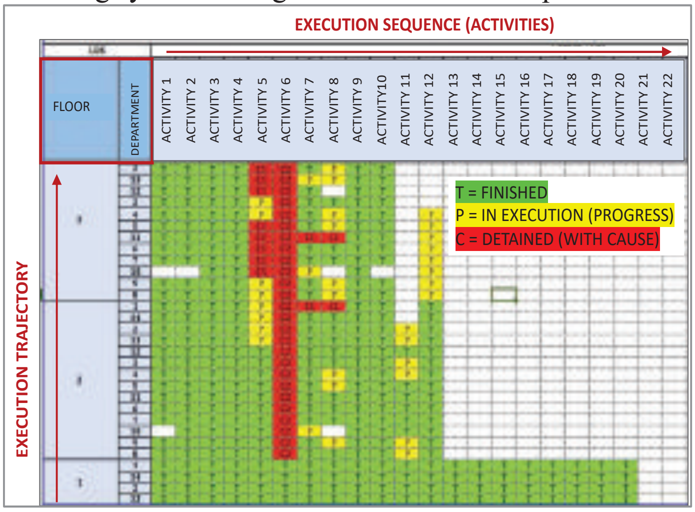


Figure 69: Examples of the chart for anticipation and terminality control.

Heatmap

Heatmaps are visual representations of colors that show how the workers are distributed along production units shows an example. It helps to control the number of people working in each floor, apartment or batch. When combined with the terminality indicator it provides a better overview of project progress for decision making. When workers are scattered in a construction site, a larger team is needed to keep track of the execution of the tasks. In this scenario, the occurrence of low quality, re-work, WIP, and informal work is usual.

Batch Adherence Control

The Batch adherence indicator shows the adherence of the tasks executed or planned at the lookahead level, considering a Location Based System. It is the ratio between the number of batches (or sub-stages) performed by the number of batches (sub-stages) planned for the period. Viana (2015) pointed out that the use of metrics concerned with batch adherence can contribute to the reduction of work-in-progress. Figure 71

shows an example of this type of control. It shows the trend of starting new work packages (new batches) without the completion of the previous ones, increasing generating WIP.

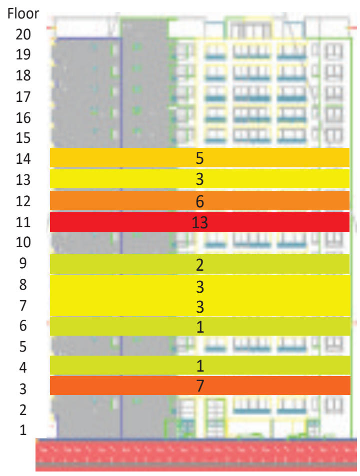


Figure 70: Example of Heatmap.

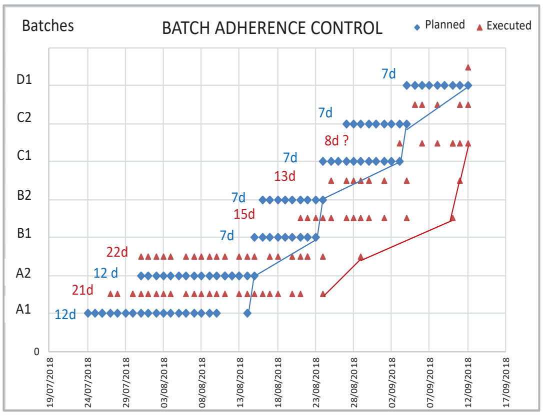


Figure 71: Example of a chart to monitor batch adherence.

Cycle Time

According to Rother and Shook (1998) cycle time refers to how often a part or product is completed by a process, including processing time, storage, inspection and rework. In a project with repetition in the production base units (or production batches) it is important to monitor the cycle time for the execution of each batch. The goal is to extract cycle time information from each batch/activity for monitoring its variance and promoting optimization. It generates alerts for the planning process on a pull system. Monitoring cycle time variance may leads to increased productivity and faster delivery to the customer (Ballard 2001); waste elimination, faster cycles of deviation detection and correction (Koskela 1992).

Deviation of Rhythm

Rhythm control represents a form of critical process control that incorporates lean concepts, whereas only fully accomplished tasks (batches) are considered. Each team must complete their work in a specified batch in a certain amount of time, also called takt time (Frandson et al. 2015). The indicator encourages the entire team, including subcontractors, to focus their work on completing the lot (with terminality). Figure 72 shows the impact that critical tasks have on other activities. Since most of this activities are critical for production, a change in one line (or activity) needs to be monitored and the others should to be evaluated for any interference.

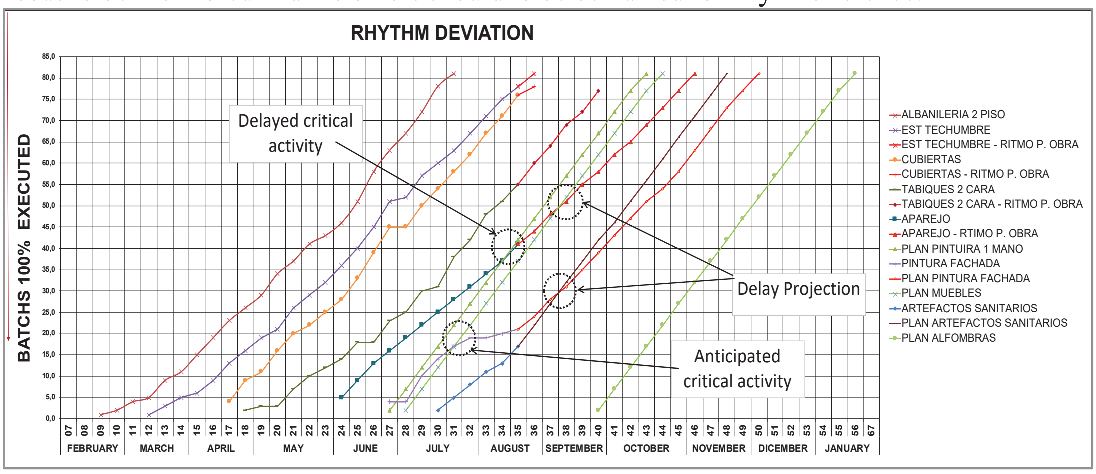


Figure 72: Example of a chart to monitor the rhythm of different processes.

DISCUSSION

A preliminary assessment of the degree of adoption of the requirements for performance metrics identified in the literature was made for the five companies. Three different grades have been used in this assessment, based on the perception of the research team: totally adopted (T), partially adopted (P), and not adopted (N). Figure 73 presents this results for each of those companies. Companies A and B can be considered as the most advanced ones in terms of PM. Moreover, most companies were effective in terms of implementing quick feedback to users and process transparency. The least considered requirement was create local control systems and none of the companies have fully adopted that requirement.

Requirements	Company A	Company B	Company C	Company D	Company E
Have a direct relation with manufacturing strategy	P	T	P	P	P
Use primarily nonfinancial measures	T	T	P	T	P
Create local control systems	P	P	N	N	P
Be flexible and change by time as needed	T	P	P	N	N
Be simple and provide quick feedback to users	T	T	T	T	T
Promote improvement and learning by increasing process transparency	T	T	P	T	P

Figure 73: Adoption of requirements for the design of PM systems

Table 32ERROR! REFERENCE SOURCE NOT FOUND. presents the classification of the metrics adopted by the group of companies according to a set of lean principles. This is an initial analysis based on the taxonomies proposed in the literature. Further work is necessary to refine this taxonomy, considering the context of the construction industry. It is worth mentioning that none of the companies emphasize in their control systems metrics related to zero defects and multifunctional teams.

Lean Principles	Indicators aligned to lean principles
Elimination of waste	Gemba Walk Wastes
Continuous improvement	Number of Kaizen Ideas Top-down and Bottom-up Kaizen Ideas Proportion
Just In Time (JIT)	HeatMap
Pull instead of push	Last Planner Measures Effectiveness LPS Implementation Daily OTP
Continuous flow	Terminality and Anticipation Batch Adherence Control Cycle Time
Takt time planning	Rhythm Deviation

Table 32: Indicators and corresponding Lean Principle

FINAL COMMENTS

This paper has presented some preliminary results of an investigation on the requirements and taxonomies for PM systems for lean production systems. The main lean metrics adopted by five companies from South America have been briefly presented and assessed, considering the requirements and taxonomies that have been proposed in the literature. In the future, additional metrics could be suggested for monitoring other aspects of lean implementation, such as waste reduction (e.g. work sampling technique, inventory level), pull production, and supply chain integration. Also further work is necessary to refine the set of requirements, considering PM systems as a whole, rather that only the design of the metrics. Moreover, none of the taxonomies proposed in the literature for performance metrics are directly applicable to the construction industry, and future work concerned with taxonomies applicable to lean production systems in the construction industry is needed.

REFERENCES

Ballard, G. (2001). "Cycle time reduction in home building." *9th annual conference of the International Group for Lean Construction*, 1–10.

Bassioni, H. A., Hassan, T. M., and Price, A. D. F. (2008). "Evaluation and analysis of criteria and sub-criteria of a construction excellence model." *Engineering, Construction and Architectural Management*, 15(1), 21–41.

Beatham, S., Anumba, C., Thorpe, T., and Hedges, I. (2004). "KPIs: A critical appraisal of their use in construction." *Benchmarking: An International Journal*, 11(1), 93–117.

Bellisario, A., and Pavlov, A. (2018). "Performance management practices in lean manufacturing organizations: a systematic review of research evidence." *Production Planning & Control*, Taylor & Francis, 29(5), 367–385.

Bhasin, S. (2008). "Lean and performance measurement." *Journal of Manufacturing Technology Management*, 19(5), 670–684.

Costa, D. B., and Formoso, C. T. (2004). "A set of evaluation criteria for performance measurement systems in the construction industry." *Journal of Financial Management of Property and Construction*, 9(2), 91–101.

Costa, D. B., Formoso, C. T., Kagioglou, M., and Alarcon, L. F. (2006). "Benchmarking Initiatives in the Construction Industry: Lessons Learned and Improvement Opportunities." *Journal of Management in Engineering*, 22(4).

España, F., Tsao, C. C. Y., and Houser, M. (2012). "Driving Continuous Improvement By Developing and Leveraging Lean Key Performance Indicators." *20th Conference of the International Group for Lean Construction*.

Ewenstein, B., and Whyte, J. K. (2007). "Visual representations as 'artefacts of knowing.'" *Building Research & Information*, 35(1), 81–89.

Frandson, A. G., Seppänen, O., and Tommelein, I. D. (2015). "Comparison Between Location Based Management and Takt Time Planning." *In: Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*, 28-31 July, Perth, Australia, 3–12.

Fullerton, R. R., and Wempe, W. F. (2009). "Lean manufacturing, non-financial performance measures, and financial performance." *International Journal of Operations and Production Management*, 29(3), 214–240.

Galsworth, G. (1997). *Visual systems: harnessing the power of the visual workplace*. American Management Association, New York.

Hall, R. W., Johnson, H. T., and Turney, P. B. B. (1991). *Measuring up : charting pathways to manufacturing excellence*. Business One Irwin, Homewood, Illinois, USA.

Kagioglou, M., Cooper, R., and Aouad, G. (2001). "Performance Management in Construction: a Conceptual Framework." *Construction Management and Economics*, 19(1), 85–95.

Karlsson, C., and Åhlstrom, P. (1996). "Assessing changes towards lean production." *International Journal of Operations & Production Management*, 16(2), 24–41.

Kennerley,M., and Neely,A.(2003). "Measuring performance in a changing business environment." *International Journal of Operations and Production Management*, 23(2), 213-229.

Koskela, L. (1992). "Application of the new production philosophy to construction." *Standford Univeristy, Center for Integrated Facility Engineering, Technical Report*, 1–81.

Koskela, L. (2000). "An exploration towards a production theory and its application to construction." *VTT Publications*, Technical Research Centre of Finland.

Koskela, L. (2004). “Making Do - The Eight Category of Waste.” *Proc. of the 12th Ann. Conf. of Int’l Group for Lean Construction, Denmark*.

Koskela, L., and Howell, G. (2002). “The underlying theory of project management is obsolate.” *Proceedings of the PMI Research Conference*, 293-302.

Lantelme, E., and Formoso, C. T. (2000). “Improving Performance Through Measurement: The Application of Lean Production and Organisational Learning Principles.” *International Conference of the International Group for Lean Construction*.

Love, P. E. D., and Holt, G. D. (2000). “Construction business performance measurement: the SPM alternative.” *Business Process Management Journal*, 6(5), 408–416.

Maskell, B. H. (1991). *Performance measurement for world class manufacturing:* Productivity Press, Portland, OR.

Neely, A., Richards, H., Mills, J., Platts, K., and Bourne, M. (1997). “Designing performance measures: a structured approach.” *International Journal of Operations & Production Management*, 17(11), 1131–1152.

Pavlov, A., and Bourne, M. (2011). “Explaining the effects of performance measurement on performance: An organizational routines perspective.” *International Journal of Operations and Production Management*, 31(1), 101–122.

Rivera, L., and Manotas, D. F. (2014). “Performance Measurement in Lean Manufacturing Environments.” *Lean Manufacturing in the Developing World*, 445–460.

Robinson, H. S., Anumba, C. J., Carrillo, P. M., and Al-Ghassani, A. . (2005). “Business performance measurement practices in construction engineering organisations.” *Measuring Business Excellence*, 9(1), 13–22.

Ronen, B. (1992). “The complete kit concept.” *International Journal of Production Research*, 30(10), 2457–2466.

Rother, M., and Shook, J. (1998). *Learning to See: Value stream mapping to create value and eliminate muda*.

Sacks, R., Seppänen, O., Priven, V., and Savosnick, J. (2017). “Construction flow index: a metric of production flow quality in construction.” *Construction Management and Economics*, Routledge, 35(1–2), 45–63.

Sanchez, A. M., and Pérez, M. P. (2004). “The use of lean indicators for operations management in services.” *International Journal of Services Technology and Management*, 5(5/6), 465.

Sarhan, S., and Fox, A. (2013). “Performance measurement in the UK construction industry and its role in supporting the application of lean construction concepts.” *Australasian Journal of Construction Economics and Building*, 13(1), 23–35.

Viana, D. D. (2015). “Integrated production planning and control model for engineer-to-order prefabricated building systems.” Ph. D. Federal University of Rio Grande do Sul, Porto Alegre.

Waggoner, D. B., Neely, A., and Kennerley, M. (1999). “The forces that shape organisational performance measurement systems:” *International Journal of Production Economics*, 60–61, 53–60.

Womack, J. P., Jones, D. T., and Ross, D. (1990). *The Machine that Changed the World*. Rawson Associates, New York, NY.

Yu, I., Kim, K., Asce, A. M., Jung, Y., Asce, A. M., Chin, S., and Asce, M. (2007). “Cost contingency management (2007).” *Journal of Management in Engineering*, 23(3), 131–139

Dakhli, Z., Lagier, S., Ducoulombier, L., and Lafhaj, Z. (2017). "Economics of Using a Distribution Centre for a Renovation Housing Project." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 641–650. DOI: https://doi.org/10.24928/2019/0212. Available at: <www.iglc.net>.

ECONOMICS OF USING A DISTRIBUTION CENTER FOR A RENOVATION HOUSING PROJECT

Zakaria Dakhli[1], Steven Lagier[2], Laure Ducoulombier[3] and Zoubeir Lafhaj[4]

ABSTRACT

The use of a distribution centre is a common practice in industry and an emerging practice in construction. The main reason is that logistics is not considered to be the primary concern and interest of construction. On the other hand, current research shows that construction can be considered as a kind of production. The logistics side in construction is underrrated, especially since the cost of materials constitutes a large proportion of the cost of construction. While the research conducted on the use of distribution centers shows some benefits, a comparative cost between this type of logistics and the traditional method of supply has not yet been carried out in detail. The lack of figures and extensive studies makes it difficult for professionals to adopt it. The case study in this paper highlights the economics of using a distribution center for a housing renovation project. the paper also suggests a practical framework that assess the economics of using a distribution center in for housing.

KEYWORDS

Construction site, supply chain, distribution center, third party logistics, logistics, cost, benefits, lean construction

INTRODUCTION

Increasing the margin for construction companies goes hand in hand with the exploration of continuous improvement techniques such as those provided by Lean Construction (Howell and Ballard 1998; Arbulu and Ballard 2004). Another type of change concern the application of industrialized building systems (Warszawski 2003). Gains are also reported thanks to the use of BIM and technology enabled improvements and robotics as well (Eadie et al. 2013; Lin et al. 2014; Bock 2015).

Construction logistics are, on the other hand, an inherent component of the construction practice (Jasti and Kodali 2014; Dotoli et al. 2015). Moving in and out materials is the obvious form of construction logistics. There are also financial and information flows which are more difficult to assess and to track meticulously in a construction project

[1] Professor, Civil and Envir. Engrg. Dept., Director of the Project Production Systems Lab., Univ. of California, Berkeley, CA 94720-1712, USA, +1 510 643-8678, tommelein@berkeley.edu

[2] Managing Director, The Change Business Ltd., Stroud, United Kingdom, +44 7968 485 627, alanmossman@mac.com

because of the large number of transactions in a project lifetime (sometimes even in a single day).

In this context, logistics could be a performance leverage for the construction industry (Ghanem et al. 2018). A great number of construction managers doesn't see logistics as a critical point in construction (Caldas et al. 2014) but thinks of it as a by-product when managing construction projects. (Vidalakis et al. 2011) agree on the importance of intermediary organizations in best managing construction logistics. An array of research presents case studies on the use of third party logistics in construction (Ekeskär 2016; Sundquist et al. 2017), network design models for construction logistics (Motaghedi-Larijani et al. 2012), and models / simulations (Ng et al. 2008; Vidalakis et al. 2011). However, few research focus on the economics underlying such logistics systems in construction.

Distribution centers in construction are mainly used to rationalize the distrubiton by packaging the components and delivering them together to site. In other words, distribution centers are used as a buffer and a method of supply for clustering elements intended to be assembled together. For construction, it means delivering a package composed of construction products intended to be utilized on the site. A consequent number of research is conducted to explore this practice in construction. (Court et al. 2006) implemented this for a large mechanical and electrical project. They divided the components into 3 categories: A, B, C. « A » category comprises modular product and they are shipped directly onsite. Category "B" is for "components from suppliers" and "C" "Consumables from suppliers". Those two categories are subjected to Kitting via a fast Kitting supply channel to the site. In a variety of case studies, distribution center logistics are outsourced to a third party logistics (Vaha et al. 2004). Distribution centers are well adopted in the UK where the Kitting practice is supported by the government (EC Harris 2013). This is due to a difficult access to cities, the aim being to reduce transportation flows (in & out).

This research article is an attempt to measure the economics of using a distribution center to manage construction logistics. For that, we formulated indicators to assess the impact of the logistics approach and analyse them to help the scientific community derive general.

CASE STUDY

The case study is a rehabilitation operation in an occupied environment of a former mining city with 184 housing units located in the city of Lens. This operation is a follow up of a previous similar operation (similar types of housing) in Lens (the same district) that rehabilitated 95 houses, and was carried out few years ago by the same general contractor. Both operations are carried out by the same general contractor. The Lens 95 project was carried out following a "classic logistics" approach, which means without the use of a consolidation center, while the Lens 184 operation used a third party logistics provider, combined with some lean tools for project management (details in the following section).

WORK REPARTITION

Part of the work was realized by the general contractor and the rest was subcontracted as described in Table 1. For the plastering work, half of the housing units are realized by the general contractor and the rest by the subcontractor.

Table 33: Work repartition

Contracted work	Sub-contracted work
Border tiles. electric switchboards.	building curage (structural cleaning)
Floors	Roofing and house covering
Sanitation	Asbestos disposal
External woodworks, windows	Coatings, painting
Plastering work (50%)	Plastering work (50%)
Plumbing	Floor coverings
	Electricity, gas

PLANNING AND LABOUR MANAGEMENT

Average number of employees: 22 workers for the general contractor and 80 in total.
Typical work cycle:

- 20 simultaneous houses.
- Delivery of 3 units (houses) per week.

Example of the planning for one house:

- The tenant moves on Monday.
- The work is realized in a 8 to 10 weeks timeframe.
- During the last week:
  Wednesday: Pre-reception meeting with the tenant.
  Thursday: final quality checks with tenant.
  Friday: tenant moves to his renovated house.

THE LOGISTICS APPROACH

The operation's site has a limited space available for the storage purposes, which in fact implies more frequent deliveries from suppliers. Therefore, It appears that the use of a buffer stock outside the renovation site is more advantageous in terms of delivery and order management. It should be noted, however, that all subcontractors have maintained a traditional procurement approach. Only the general contractor was involved in the logistics developed with the distribution center. The characteristics of the distribution center's supply chain are as follow:

- Buffer stock (consolidation centre) 10 minutes from the site.
- Delivery frequency : Monday-Wednesday-Thursday.
- Delivery on D-1 on site (just-in-time).
- Order preparation time: 3 hours.

Figure 74: Storage at the distribution center

Lean Construction elements were used to support the logistics approach. More specifically, the following:

- Adaptation of the LPS (Last Planner System): planning, work preparation, and first run studies.
- Visual management (tables and screens to visual data site).
- Follow-up of the work for each house with coloured tablets.
- Organisation of teams to standardise the work (rail teams, dubbing and placo...).
- Creation of tools to promote productivity and ergonomics (tool trailers).
- The use of the digital model and a tablet interface for the various housing information.
- Autonomous teams: those teams are onsite, multidisciplinary, and follow the work sequence thanks to LPS.

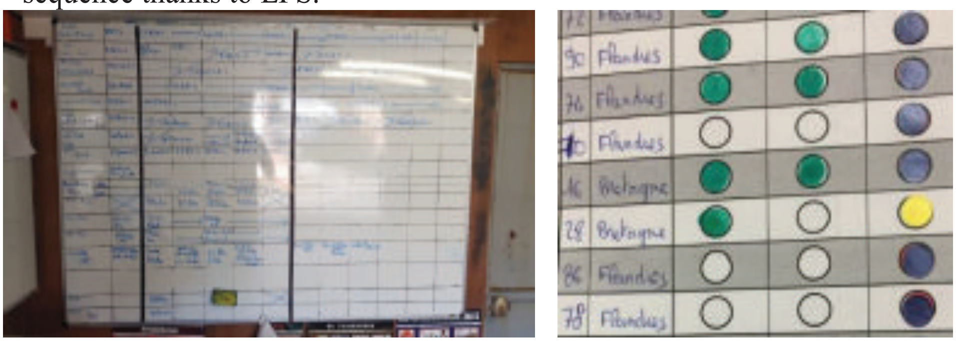


Figure 75: Lean Construction elements used to support the logistics approach

SCOPE OF THE STUDY

Every month, the construction manager analyses the site budget. The figures make it possible to compare the estimated budget of the operation and the progress made as a function of the actual expenditure, mainly in terms of materials purchased and man-hours consumed. These different expenses are subdivided into tasks and work trades.

Since the logistics approach implemented is only deployed for the general contractor, this research study do not investigate the use of the distribution center by subcontractors.

BUDGET FORMULATION

An important aspect of the budget management and monitoring is the concept of budget and expenditure converted in man-hours. The method used is similar to the Earned Value Methode (EVM). Since the main resource is the "time" of work, it is often more relevant to quantify expenses at first glance in terms of hours rather than in euros. This approach is also found within the engineering offices that prepare before the actual excution of work. Indeed, this department is required to carry out an objective planning of the operation with a manpower curve and a budget in man.hours. This document serves as a guide for the construction manager.

Every month, the construction manager provides information on the actual progress in terms of the number of houses renovated. For this case study, this is the most telling progress indicator. In fact, we have a clearer idea of the progress of the project with a measure such as: "90 houses completed out of 184" rather than the measure "1100 plates of plasterboard installed out of 2000".

As explained above, project expenses are analysed in terms of man.hours and therefore can easily be converted into euros if necessary using an average hourly rate.

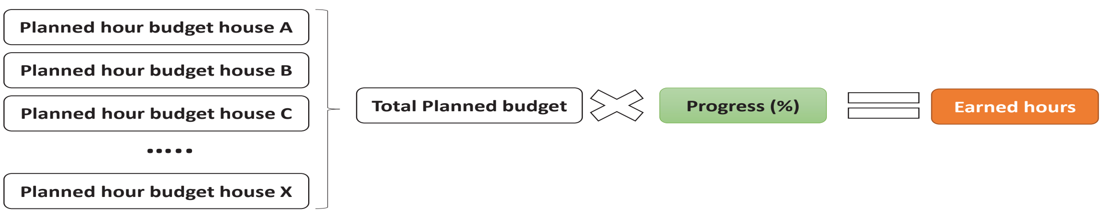


Figure 76: How the budget is controled

Figure *76* shows the indicator used by the construction manager to analyse the labour expenditure of the operation. A planned budget per house was previously established during the design phase, which corresponds to the estimated number of man.hours. This gives a total estimated budget of man.hours for all 184 units. From there, the construction manager informs the number of housing units built for each trade, resulting in a percentage of progress as a function of the total number of houses. Therefore, for each trade, we can know the number of estimated hours allocated as a function of the actual progress. This indicator is called: the number of "earned" hours. In other words, it is the budget expressed as the estimated hours in view of the actual progress of the project ("to achieve what has been done so far, so many hours had been planned").

This indicator is directly compared with the actual number of hours spent, which corresponds for each task and trade to the sum of the companions' daily scores. This is therefore the real expenditure of man.hours. We therefore obtain a difference in expenditure (in hours) between the forecast and the actual as shown in Figure 77.

Figure 77: Calculation of the expenditure gap

The budget is also composed of materials and various ancillary costs. However, we will not study these cases because they are not affected by the lean and/or logistics approach. As an example, if we take the example of a plasterboard partition, the quantities of materials to be used to make it are independent of the organization of the renovation site.

THE PLANNED BUDGET

Thanks to the experience gained on the previous similar renovation project on Lens 95, the general contractor established the estimated hour budget of Lens 184 project based on the actual hour budget of Lens 95. Nevertheless, it was necessary to take into account the supposed gains of the logistics service implemented on Lens 184, which directly translates into a time saving in terms of handling the various elements. Handling times were therefore estimated for each concerned task and trade. This amount of hours was therefore deducted from the actual budget of Lens 95 based on the allocation of materials for each trade. As a consequence, it is possible to establish a budget in hours (subsequently converted into euros) to be allocated to the logistics service as shown in Figure *78*.

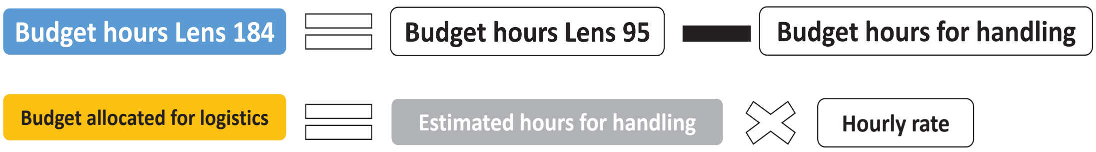


Figure 78: Forumulation of the provisional budget

FORMULATION OF THE COST INDICATOR

For this type of operation, the cost indicator “number of hours per house” is representative of the yield and makes it possible to correlate the quantity of resources (hours) with the planning and deadlines, as shown in Figure *79*. Indeed, the duration of the operation, through the planning, is a commitment of the general contractor towards the owner. So, we can consider that the excecution time for a typical house fixed. However, this is rarely the case with regard to the quantity of resources (mainly labor) to be implemented. As a result, the general contractor adjusts many variables orders to meet the deadlines. Thus, for a given implementation period, the least resources (hours) are consumed, the smallest the ratio "number of hours per house" is. Moreover, if the general contractor wishes to allocate more resources to make up for a delay, the ratio of "number of hours per house" will deteriorate. We therefore have an indicator that reflects economic profitability by directly integrating completion times.

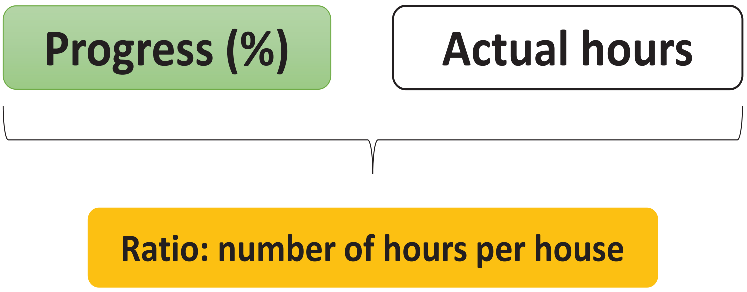


Figure 79: Formulation of the indicator "number of hours per house"

HOW THE INDICATOR WAS USED?

The allocated budget for Lens 95 and the planned budget of Lens 184, built on the basis of that of Lens 95 by means of the logistics budget (estimated handling hours), will serve as a basis for comparisons as shown in Figure 80. The same reasoning as for the actual ratio can be applied.

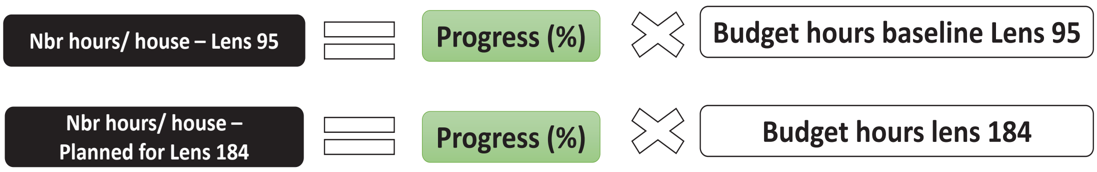


Figure 80: Formulation of ratios "number of hours per house"

RESULTS AND DISUCSSION

A first analysis consists in taking into account all the trades realized by the general contractor and determining the "number of hours per house" ratio as presented in Figure *81*.

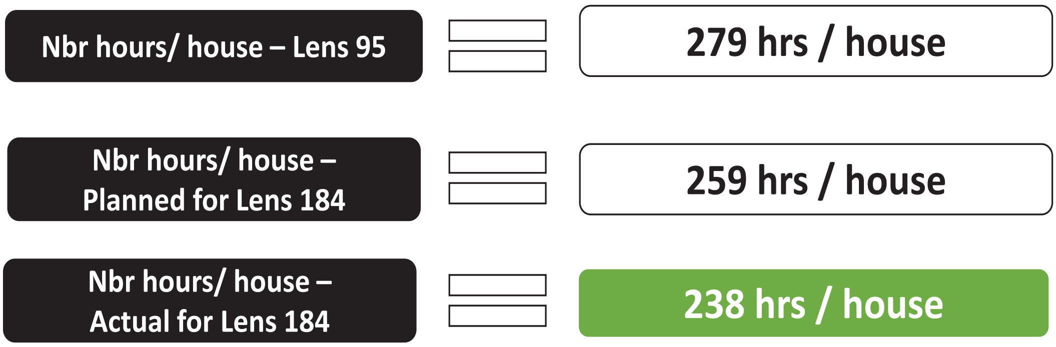


Figure 81: Results of the different ratios number of hours per dwelling

We observe a real gain compared to what was achieved on the previous operation Lens 95 and even compared to what was estimated for the Lens 184 site including the logistician service. However, this overall ratio hides the potential disparities between the different trades. In other words, the ratio does not provide information on what trade is actually impacted by the distribution centre service and where lies the cost benefits for each trade.

Table *34* presents the breakdown of the various "number of hours per dwelling" ratios according to the tasks and batches of the operation. There is therefore a disparity of gains between the different batches, so it is natural to ask the question of which batches allow an overall gain and what are their weights compared to the other batches. Indeed, the more hours allocated to a lot is important in relation to the total, the more this lot will influence the number of hours per dwelling. The supervision task in question comes from the budget in hours allocated to the assistant site manager. Even if this was used to constitute the logistics budget, this data corresponds more to a financial charge due to the change in status of the assistant site manager than to a physical reality. This will therefore not be analysed in detail later on.

Table 34: Breakdown of the different ratios number of hours per house

	Ratios		
	Lens 95	Planned Lens 184	Actual Lens 184
Tasks	Ratio Lens 95	Planned ratio Lens 184	Actual ratio Lens 184
Supervision	17,12	8,63	14,17
Sanitation	15,50	15,50	11,37
Houris floors	12,31	12,31	7,12
Restructuring	4,10	4,10	0,00
Masonry	3,37	3,37	2,33
Listels	15,54	15,14	18,44
Windows installation	23,36	19,48	24,97
Plumbing	45,10	43,56	48,26
Interior joinery	57,54	57,14	40,63
Plasterwork	77,34	72,26	61,32
Serrurerie	6,01	6,01	0,00
Finitions	6,08	6,08	9,30

(blue)	Tasks charged to the logistics budget
(yellow)	Tasks not taken into account in view of the progress of the project
(green)	Ratio lower than expected for Lens 184
(orange)	Ratio between the one of Lens 95 and the planned one of Len 184
(red)	Ratio higher than the one of Len 95

To measure the "weight" of each trade, three ABC analyses (pareto diagram) has been carried out, including a criterion on the number of actual hours spent, coupled with the provisional budget and the progress of Lens 184, to check that there are no inconsistencies (Table *35*). Indeed, a task with a large allocated budget that in reality requires a relatively small number of hours or that does not have a progress report in the same orders of magnitude would reflect poor management or forecasting or, more probably, an inconsistency in the data.

The construction of an ABC ranking has been done in the following way: the elements were classified in descending order according to the criterion considered (here the different trades classified according to the number of forecasted hours, the number of actual hours spent and the progress). Then the values were cumulated in descending order and expressed as a percentage of the total of the criterion considered. To classify, we considered the first three trades of class A, the next three of class B and the others of class C.

Table 35: ABC classification of tasks

Tasks	Type	Total hours spent (%)	Expense class
Plasterwork	Plasterwork	31	A
Plumbing	Plumbing	50	A
Interior joinery	Interior carpentry	64	A
Windows installation	Exterior carpentry	74	B
Listels	Structural work	82	B
Sanitations	Structural work	88	B
Supervision	Structural work	93	C
Finitions	Finitions	96	C
Floors	Structural work	99	C
Masonry	Structural work	100	C
Restructuring	Structural work	100	C
Locksmithing	Locksmithing	100	C

On one hand, this ABC ranking suggests that there are no inconsistencies between the progress, the estimated budget and the hours spent, because even if the order is not necessarily strictly respected for each criterion, there are no differences in categories. In other words, a trade that has a significant weight in terms of hours spent is also important in terms of the expected budget and progress. On the other hand, this classification gives a first insight into the tasks that may take a great part in construction logistics costs.

CONCLUSION

The objective of this research paper is to quantify the economic impact of using a distribution center for a housing renovation project. While the use of distribution centers is common in industry, its introduction in construction is relatively new and the application bases are not yet in place as well as the economic model associated with this practice. Also, the economics of construction supply chains are not well documented in literature. The case study of this paper is a renovation housing project where the distribution center was used only by the general contractor and not the subcontractors. The logistics approach and the budget formulation were presented. The budget was developed thanks to the experience gained on a similar project and in the same district. The results reveal the cost and the gains associated with the use of a distribution center . The benefits depends largely on the trades associated. This paper also suggests a practical framework that assess the economics of using a distribution center in for housing. Future studies should investigate other variables that may impact the cost equation such as subcontracting practices and the type of construction (new instead of renovation).

REFERENCES

Arbulu R, Ballard G (2004) Lean Supply Systems in Construction. In: IGLC (ed) 12th Annual Conference of the International Group for Lean Construction. Helsingør, Denmark, p 13

Bock T (2015) The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. Autom Constr 59:113–121. doi: 10.1016/j.autcon.2015.07.022

Caldas CH, Menches CL, Reyes PM, et al (2014) Materials Management Practices in the Construction Industry. Pract Period Struct Des Constr 20:

Court P, Pasquire C, Gibb A, Bower D (2006) Design of a Lean and Agile Construction System for a Large and Complex Mechanical and Electrical Project. In: IGLC (ed) 14th Annual Conference of the International Group for Lean Construction. Santiago, Chile

Dotoli M, Epicoco N, Falagario M, et al (2015) An integrated approach for warehouse analysis and optimization: A case study. Comput Ind 70:56–69. doi: 10.1016/j.compind.2014.12.004

Eadie R, Browne M, Odeyinka H, et al (2013) BIM implementation throughout the UK construction project lifecycle: An analysis. Autom Constr 36:145–151. doi: 10.1016/j.autcon.2013.09.001

EC Harris (2013) Supply Chain Analysis into the Construction Industry. A Report for the Construction Industrial Strategy. UK

Ekeskär A (2016) Exploring Third-Party Logistics and Partnering in Construction. Linkoping University

Ghanem M, Hamzeh F, Seppänen O, Zankoul E (2018) A New Perspective of Construction Logistics and Production Control: An Exploratory Study. pp 992–1001

Howell G, Ballard G (1998) Implementing Lean Construction. In: IGLC (ed) 6th Annual Conference of the International Group for Lean Construction. Guarujá, Brazil, pp 13–15

Jasti NVK, Kodali R (2014) Lean production: literature review and trends. Int J Prod Res 53:867–885. doi: 10.1080/00207543.2014.937508

Lin Y-C, Cheung W-F, Siao F-C (2014) Developing mobile 2D barcode/RFID-based maintenance management system. Autom Constr 37:110–121. doi: 10.1016/j.autcon.2013.10.004

Motaghedi-Larijani A, Jabalameli M-S, Tavakkoli-Moghaddam R (2012) A network design model considering inventory cost from a third party logistics perspective. Int J Manag Sci Eng Manag 7:29–35. doi: 10.1080/17509653.2012.10671204

Ng ST, Fang Y, Ugwu OO (2008) Modelling construction material logistics system with stochastic Petri nets. Constr Innov 8:46–60. doi: 10.1108/14714170810846512

Sundquist V, Gadde LE, Hulthén K (2017) Reorganizing construction logistics for improved performance. Constr Manag Econ 6193:1–17. doi: 10.1080/01446193.2017.1356931

Vaha P, Heikkila T, Kilpelainen P, et al (2004) Construction logistics. UK

Vidalakis C, Tookey JE, Sommerville J (2011) Logistics simulation modelling across construction supply chains. Constr Innov 11:212–228. doi: 10.1108/14714171111124176

Warszawski A (2003) Industrialized and Automated Building Systems: A Managerial Approach, E&FN Spon. Taylor & Francis Group

STREAM 11: PROJECT PERFORMANCE

Hackett, V., Harte, P., Chendo, J. (2019). "The Development and Use of Last Planner® System (LPS) Guidance." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 651–662. DOI: https://doi.org/10.24928/2019/0101. Available at: <www.iglc.net>.

THE DEVELOPMENT AND USE OF LAST PLANNER® SYSTEM (LPS) GUIDANCE

Vince Hackett[1], Peter Harte[2], and Jorge Chendo[3]

ABSTRACT

This paper addresses the development and use of last planner system (LPS) implementation guidance. Lean construction (LC) as operationalised by tools including the LPS has been deployed over 25 years with documented successful outcomes. Yet, the literature also reveals widespread implementation failures, in part due to a guidance shortfall. To address this issue, guidance principles were developed, informed by longitudinal action research (AR) undertaken over 18 months investigating LPS usage on 7 sequential projects on the ongoing refurbishment of a liquified natural gas (LNG) plant in North West Australia.

AR, the main research method used, combined continuous experimentation with analysis using a variety of data and evidence sources. By examining the process and outcomes of the action, explanations and further ideas are forthcoming, setting the platform for new action. The paper describes further longitudinal LPS implementation aided by the developed guidance on a £1.5 billion UK infrastructure project.

The research contributes to knowledge with ongoing LPS guidance development, through testing and refinement with AR cycles. Further guidance into the use and melding of off-site manufacture and lean construction practice is also being developed and deployed. The limitations are that only LNG refurbishment and infrastructure projects have been researched to date.

KEYWORDS

Lean construction (LC), Last planner system (LPS), lean construction guidance, Action Research (AR)

INTRODUCTION

Chronically low workflow reliability with attendant work flow variability in construction projects, was identified in 1992, as a main factor causing construction underperformance by Glenn Ballard and Greg Howell (Kalsaas, et al. 2015) This discovery spurred the development of LC, with a suite of tools including the LPS, developed to reduce workflow variability. Ballard et al. (2016) in describing the history and evolution of the LPS says that its first aim was to improve workflow reliability, achieved by collaborative meetings

[1] Lean Construction Lead A14 IDT. 07702 464460, vince.hackett@ntu.ac.uk
[2] Project Manager Carey Construction, peter.harte@careysplc.ie
[3] Structures Manager A14 IDT, Jorge.chendo@thea14.com

between first line supervisors, producing weekly co-ordinated work plans. These decision makers involved in planning and delivering the work were termed Last Planners (LPs). They must fully understand their own work and have the authority to make decisions, with assistance by those who can provide information required on aspects of safety, quality, logistics and master programming. Planning is undertaken in reverse order, driven by the prerequisites of each activity, with outputs used to develop detailed schedules aligned with master schedule milestones (Ballard et al. 2016). Traditional planners are called First Planners.

The master schedule normally using critical path method (CPM) software, sets cost and schedule targets aligned with project scope, whilst monitoring progress toward those targets. The task of LPS production planning is to steer projects towards CPM derived targets. For efficacy, both must operate in harmony. Huber and Reiser (2003) note that commonality can be achieved between CPM and a collaborative planning system implementation and Olivieri et al. (2016) proposed a model to systematise the integration of LBMS (Location based management system), LPS and CPM. Yet, obtaining the required CPM/LPS synergy is challenging, Issues include ineffectiveness in dealing with multiple constraints such as deadline and resource limits (Hegazy and Menesi 2010), not allowing for the interruption of activities (Shi and Deng 2000), and reported misuse of the software to produce illogical impractical schedules (Korman and Daniels 2003). Furthermore, delinking is used to make the schedules "work", with reporting not reflecting "reality" and complex scheduling produced that management and supervisory staff struggle to interpret (Hackett 2017).

Notwithstanding issues described, LPS implementation itself proves a challenging process, with successful outcome realisation problematic due to several factors. These include a lack of appropriate training, a lack of senior management support, an inability to motivate people, a lack of honesty and trust between participants and a failure to select and train the right people (Cano et al. 2015). Furthermore, research reveals a paucity of implementation guidance. Howell et al. (2002) outlines nine implementation steps, Mossman (2012) provides some general advice on LPS implementation, and there is some discussion on guidance provision (Fernandes et al. 2016, Mejía et al. 2016). Yet, in the main there is little evidence of specific guidance for LPS implementation with a lack of implementation know-how still one of the main barriers to lean construction implementation (Zanotti et al. 2017). The research was undertaken in part to address this issue, whilst addressing the challenge of harmonising LPS and CPM usage.

There is also limited research on establishing a relationship between PPC metrics and performance. Ballard and Howell (1994) demonstrated improved productivity performance of 30% with crews achieving a PPC above 50%. Liu and Ballard (2008) in statistical analysis of a pipe installation project established positive correlation between rising PPC metrics and productivity levels. Here the contractor achieved costs improvements of 24%, aligned with consistently high PPC levels, Yet, research on correlation is limited, a gap addressed in this research.

The paper describes the initial research and its outcomes, including guidance developed. Subsequently, the guidance was used to assist LC implementation on a UK infrastructure project. The implementation is described using several case studies to demonstrate positive outcomes, setbacks and how these setbacks are used to evolve practice particularly in forming synergy between lean construction and lean production practice.

RESEARCH METHOD

Initial research was undertaken on the ongoing refurbishment of an integrated liquefied natural gas (LNG) plant, the 200 ha Karratha Gas Plant (KGP) in the Pilbara region of western Australia. Deterioration over time of the protective cladding, insulation and paint systems has resulted in local external corrosion of pipe-work and vessels, requiring corrective maintenance. The refurbishment work is being implemented over a five to ten-year period, extends the operating life of the plant. Work is carried out on a working plant, with projects undertaken online (on live plant) and offline (on isolated sections of plant). The short and intense nature of the projects enabled investigation of LC implementation with lean tools used including the LPS on 7 projects undertaken sequentially over an 18-month primary research period. LPS implementation included the use of pull planning, weekly work planning (WWP) and daily huddles (DH).

AR, the research method used, integrates "learning by doing" where learning is aided by reflection (Coughlan and Bannick 2012). Learning is used to bring about change, by collaborating with those who do the work and who will eventually embed worthwhile change. AR combines continuous experimentation with analysis using several forms of data and evidence. By examining the process and outcomes of the action, a platform is set for continual improvement (Burns 2007), where organisational issues and the people interacting in these issues are part of the research process (Coghlan and Brannick 2012). The use of this method had the merit of philosophy alignment between AR and lean construction, where lean is characterised as enabling people to learn and learn how to learn. (Hackett 2017).

RESEARCH OUTCOMES

Analysis of 20 semi-structured interviews on CPM usage was undertaken to assist in its melding with the LPS. A further research outcome was the development of the guidance principles listed and described below, with a principle defined as a proposition that is a guide for behaviour or evaluation.

Guidance Principles

1. Obtain real buy in and support from executive management including clients
2. Identify and engage formal leaders especially senior management
3. Identify and engage informal leaders
4. Identify and engage change agents
5. Use early development of a high-level strategy and a robust logical milestone map
6. Use of master schedule milestones to inform the LPS pull planning process
7. Use a disciplined approach
8. Use of boundary objects

9. Use LPS meetings to assist continuous improvement and innovative practice
10. Use pre-existing lean or lean type knowledge and existing initiatives
11. Standardise good practice and continuous improvement.

The principles are described as follows.

1. *Obtain real buy in and support from executive management including clients.* This is referred to as gaining political cover, essential prior to any embedment process. Support may be demonstrated by mandated use of lean construction identified in contract and procurement documentation.
2. *Identify and engage formal leaders especially senior management.* The engagement of formal leaders especially senior management is pivotal to successful implementation. Leaders with prior positive experience and knowledge of a lean approach tend to provide higher levels of continuous support. Continuous support is demonstrated by consistent attendance at the LPS meetings, mainly in a watching brief, but providing guidance as necessary allowing decision makers to take control, whilst offering direction as dictated by the meeting flow.
3. *Identify and engage informal leaders.* Informal leaders exert influence over the team, come from the team and are chosen by the team (Pescosolido 2001), are willing to stand up and act to influence the behaviour of teammates through means other than formal authority (Ross 2014). A shared team vision encourages the emergence of informal leaders who play a key role in developing group efficacy, enabling team mates to achieve at higher levels than normal (Zhang et al. 2012). AR demonstrates that they tend to be supervisors, site engineers and project engineers, identified at forums such as H&S pre-start meetings.
4. *Identify and engage change agents.* Change agents are defined as those who assist in organisation transformation and continuous improvement. Change agents tend to be formal leaders previously involved in successful implementation of LC or LC type approaches on the current or other projects.
5. *Use early development of a high-level strategy and a robust logical milestone map.* Strategy development involves a reasoned short description on work sequence informing the development of a robust master programme, whose milestones direct production planning.

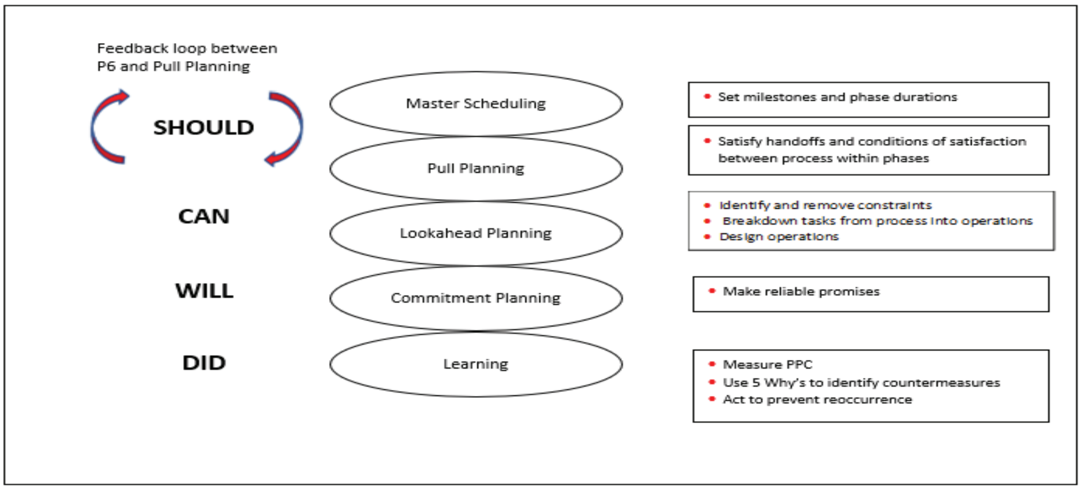


Figure 82: Current process benchmark for the last planner system (amended), (Ballard and Tommelein 2016)

6. *Use of master schedule milestones to inform the LPS pull planning process.* The meetings use the process benchmark (figure 1), which directs the implementation of LPS production planning as informed by master scheduling project milestones,

7. *Use a disciplined approach.* Timings for the DH, WWP and pull planning meetings must be agreed by common consent. All meetings must start at the agreed times, following a set procedure with decision makers fully prepared. Particularly avoid overburdening with an excess of new and inexperienced LPs with coaching and mentoring provided in advance. Commitments can only be made by the LPs.

8. *Use of Boundary Objects.* Boundaries present barriers to knowledge transfer. Boundary objects are defined by their capacity to serve as bridges between intersecting social and cultural worlds. Carlile (2002, 2004) identified three boundaries; syntactic, semantic and pragmatic. Syntactic boundaries are created by differences across groups in terms of the use of different language, grammar and symbols. Semantic boundaries are caused by differences in accepted interpretations and meanings, where knowledge needs to be translated rather than just transferred. Examples include the different interpretation of risk between those from an engineering and legal backgrounds. Pragmatic boundaries occur when groups involved in collaborative practice have differing or conflicting interests, where solution agreement is blocked by self-interest. There are a range of boundary objects, including BIM models, forms, sketches and drawings, mock-ups and narratives. In the current implementation, a primary boundary object is the magnet used in the LPS process.

9. *Use LPS meetings to assist continuous improvement and innovative practice.* The LPS meetings are an opportunity for decision makers to interact and pool experience and knowledge to aid constraint identification and removal as well as innovative practice development and opportunity realisation.

10. *Use pre-existing lean or lean type knowledge and existing initiatives.* Leaders/informal leaders with positive implementation experience or who intuitively use lean approaches can become implementation enablers. People include superintendents/works managers, general foremen, supervisors and managers. People identified are some of the most supportive in the implementation process, leading and mentoring the implementation. One of the first and most important implementation phases is the identification and engagement of such people.
11. *Standardise good practice and continuous improvement including evolution of the tools.*

A further aspect investigated was the correlation between PPC levels and performance.

ONGOING LPS IMPLEMENTATION

OUTCOMES

The LPS is being implemented and further refined using AR principles on a 34-kilometre UK infrastructure project over the last 2 years, where the use of LC is mandated and supported by the client Highways England. Differing outcomes from the ongoing usage are investigated, particularly as it affects performance and continuous improvement. Whilst literature and the ongoing research demonstrated considerable issues with the use and worth CPM, it is now integral in traditional construction and must be engaged with. Therefore, the research has investigated the amalgamation of the CPM and the LPS. To do this, the P6, which sets project direction is constantly refreshed and updated by pull planning meetings, where a bridge is established between the two approaches of traditional and lean construction (figure 1). Further research was undertaken in aligning lean construction and lean production approaches.

Case Study 1:

The earliest LPS usage on the current project was on the construction of an interchange and associated works, aided by the guidance principles. There was evidence of support and engagement by formal and informal leaders, with pre-existing lean knowledge demonstrated by some team members. This knowledge was used in the development of the WWP board (figure 2), reporting on the previous week, planning what WILL be completed in the upcoming week and CAN be completed in the following 4 weeks. A disciplined approach was employed in the implementation of the LPS meetings, with timings and procedure set and adhered to by mutual agreement. There was also evidence of autonomous development of practice. This included the use of the WWP for early identification of procurement requirements (figure 2). Furthermore, the board was used to level resources. Resource levelling i.e. balancing labour and plant availability represents an ongoing challenge in the construction industry. This challenge was addressed in autonomous change introduced by a contractor decision maker where a second pass was instituted after the initial weekly planning, with some re- timing of non-critical activities as required to level resources. This resulted in more effective use of labour and plant resources, smoothing work flow.

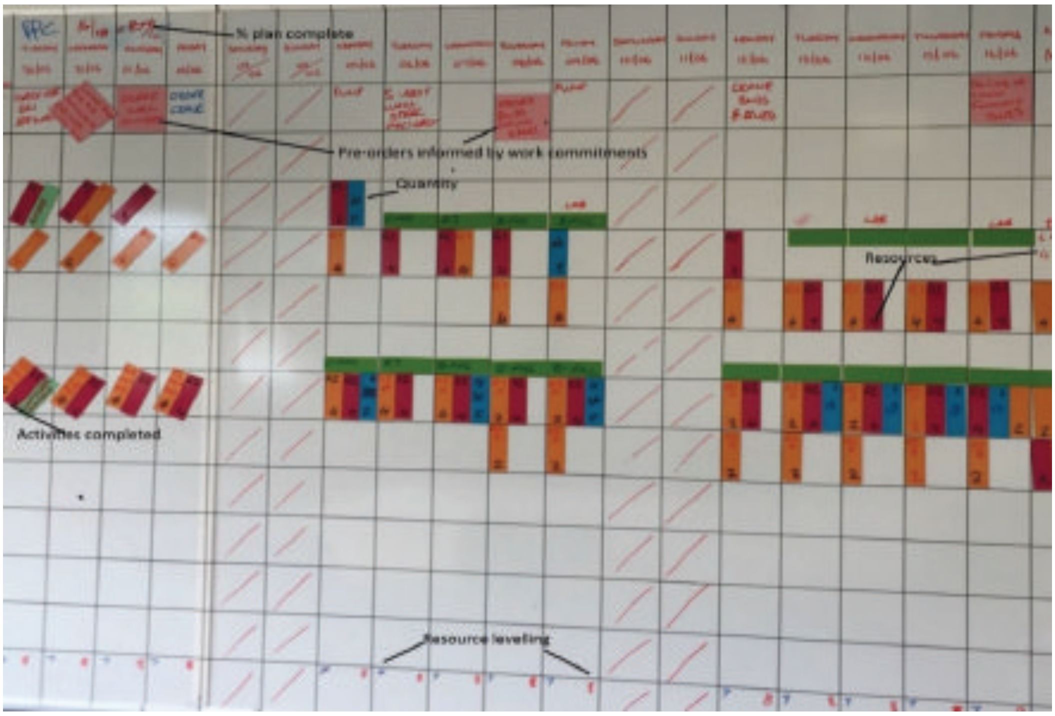


Figure 83: Evolution of practice

Furthermore, the LPs used the WWP to transfer knowledge and information, assisting continuous improvement, immediately deployed in production. Solutions and opportunities implemented included the following: pre-decking a section of the bridge under construction to directly load reinforcing off delivery wagons, use of couplers to improve workflow and productivity. However, whilst constraints were identified there was some resistance to constraint identification and ownership of constraint removal. This is an important element of the LPS philosophy, differentiating it from traditional construction. This was recognised as a failing with more disciplined constraint analysis used on subsequent implementation.

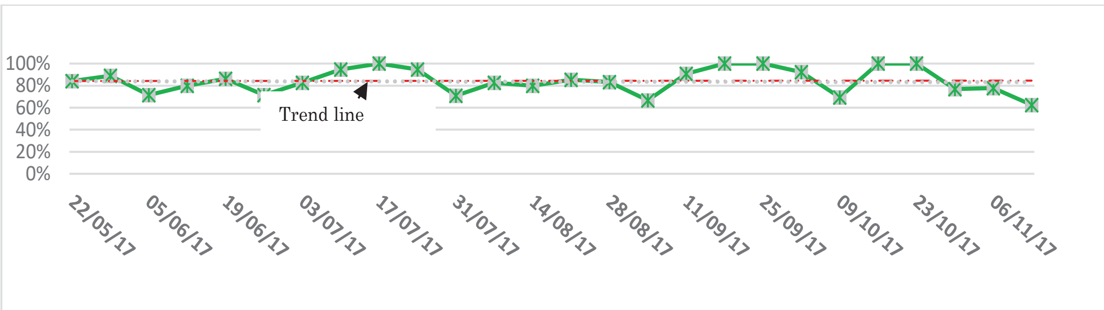


Figure 84: PPC data

Performance improvement identified included the development and use of innovative practice as described. Furthermore, high and steady PPC metrics (figure 3) correlated to a 25%, schedule compression with a 6 weeks compression in 7 months achieved. This aligned with the previous research outcomes (Hackett, 2017). Lessons learned including confirmation of LP ability to develop innovative practice and the recognition of the need for more disciplined constraint analysis. These lessons informed ongoing implementation.

Case Study # 2

In this instance, the LPS was implemented on a section including the construction of extensive bridge and associated works, where issues with the lean production process were revealed. Here the term lean production is used to describe off site manufacturing and prefabrication of components. In the enabling construction phase, including earthworks, piling, abutment and pier construction high PPCs trends were recorded. These aligned with performance improvements including a 20% schedule compression achieved over a 6-month period. Conversely, with the commencement of structural steel erection, PPC metrics were lower and more variable, trending at 55% with a corresponding schedule underperformance. PPC levels and performance outcomes improved after 5 months trending at 75% but dipped again with precast unit installation commencement. These findings run counter to preconceptions that offsite manufacture implementation positively impacts the construction process. Research to determine reasons using informal conversations, lessons learned workshops, observation and trend analysis to collate the following reasons for performance achieved revealed the following:

- A lack of pre-planning and interface with supply chain and sub- contractors.
- A limited use of BIM as a visualisation tool.
- Failure to adhere to pre-planning undertaken – particularly sequencing
- Breakdown in logistics control- deliveries out of synchronisation
- Traditional construction mind-set predominant
- Use of batch and queue rather than just in time (JIT) logistics
- High amounts of defects with dependence on expediting at the end of process.

These lessons learned were applied on other work fronts, one described below.

Case Study #3

This section of critical scope consists of some of the more complex work on the scheme, involving, new motorway interchange and structures construction, reconstruction and demolition on live infrastructure, whilst dealing with numerous complex constraints including major utility diversions, archaeological excavations, interfacing with local business' and residents whilst maintaining traffic flow on a major arterial traffic route.

The LPS had been employed on this section with implementation supported and developed by leadership with previous lean construction experience and informed by current embedment. Again, implementation was directed by the process map (figure 1) but with greater focus on synergy development between the P6 programme and LPS pull planning. Milestones developed were used to populate WWP meetings (figure 4). The embedment was relatively quick, aided by strict adherence to the guidance principles. This was enabled by the formal and informal leadership. Dave et al. 2015 notes a widespread lack of synchronisation and integration between LPS and CPM, with a need for a more comprehensive approach to unification. In response to these and similar criticisms, and after some early setbacks a tight interrelationship was established (figure 1), with high level milestone maps continually updated in fortnightly pull planning meetings. Here the constraints likely to impede workflow are identified for removal with ownership designated. In addition, the P6 master programmes was updated monthly, using an integrated pull planning meeting attended by planners, relevant decision makers, including principle contractor and subcontractor senior management.

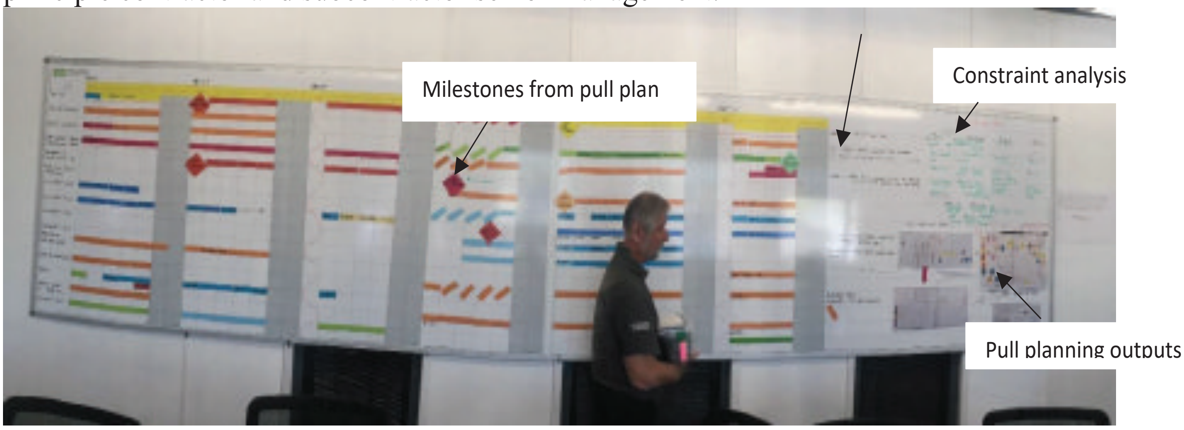


Figure 85: WWP using P6/pull planning milestones.

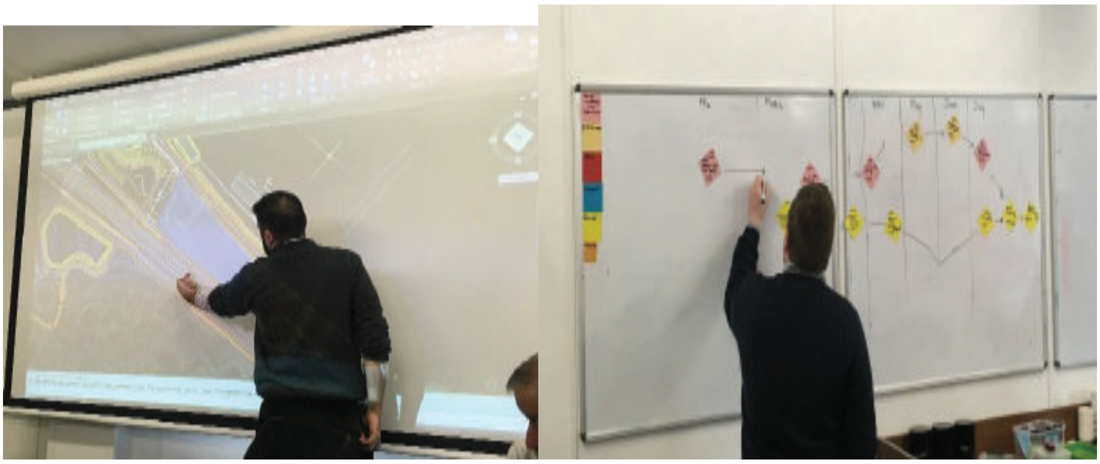


Figure 5: Pull planning meeting

Off-line manufacturing and fabrication were employed, primarily on the construction of 2 bridges with the decks manufactured off line and transported into place using self-propelled mobile transport (SPMT). Here, previous knowledge gained, and learning outcomes above guided the LPS implementation. This process involved the use of the LPS (figure 1), commencing 9 months prior to the proposed lift dates. Ongoing pull planning engaged decision makers including main contractor, sub-contractor and supply chain using BIM as a visualisation tool (figure 5). Furthermore, animation was employed to guide and inform the work flow (https://bit.ly/2QrS9cF). Again, pull planning meetings were integral to continuous collaborative development of tightly interrelated CPM schedules and LPS production planning.

A JIT approach was employed for deliveries of steel and reinforced concrete components. There was conscious shift from a push approach to a lean production one with a focus on maintaining previously developed sequencing with defects free components arriving at work fronts. This approach was assisted by rigorous collaborative quality control aided by designated QA personnel verifying component quality prior to delivery.

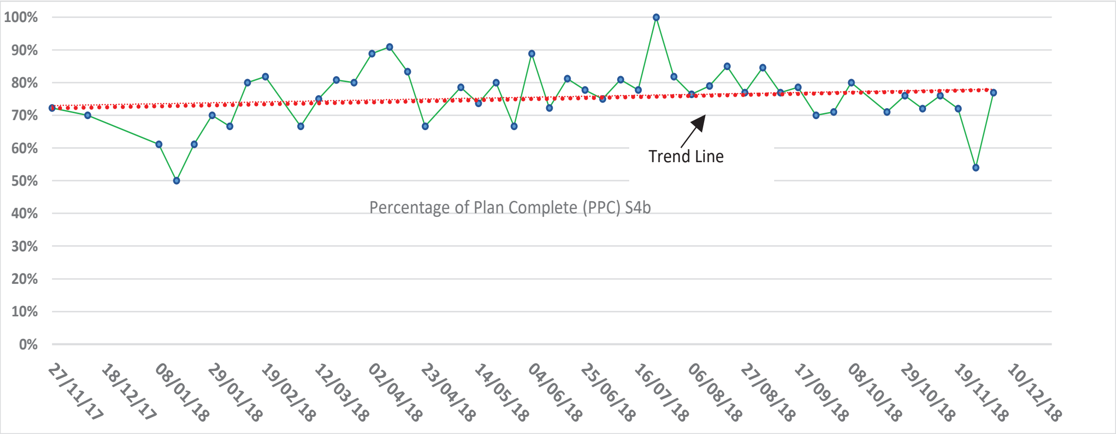


Figure 6: PPC trends

This implementation is one of the more robust, with early consistently high PPC metrics achieved (figure 6), correlating to enhanced schedule performance and continuous improvement. The SPMT lift, a critical path activity achieved schedule compression of 4 weeks, equating to a 25% performance improvement, with a world first of a dual SPMT deck lift over one weekend closure (https://binged.it/2TBDTQM).

CONCLUSIONS AND DISCUSSION:

The paper described ongoing LPS implementation and development using a scientific approach in the form of AR. Here, implementation is cyclical with lessons learned from each cycle informing the implementation of the subsequent cycle. The literature revealed a gap with a shortage of guidance in LPS implementation to steer successful implementation. Early research addressed this gap with the development of 11 guidance principles. Furthermore, a positive relationship was established between consistently high ppc metrics and performance improvement, with steady state PPCs of 70% and above aligning with 20-25% schedule compression as described in case studies 1 and 3, combined with innovative practice development and use. There is limited research demonstrating such a relationship and the research on both projects demonstrated correlation. Furthermore, the issue of the synergetic usage of CPM and the LPS usage was addressed.

The limitations are that further research is required investigating implementation in further sectors.

REFERENCES

Ballard, G. and Tommelein, I.D., 2016. *Current Process Benchmark for the Last Planner System.* Berkeley, CA. USA: p2sl Berkeley.

Burns, D., 2007. *Systemic Action Research: A Strategy for whole system change.* Bristol, UK.: The Policy Press.

Cano, S., et al., 2015. Barriers and success factors in Lean Construction Implementation - Survey in Pilot Context. *In: IGLC 23: Global Problems- Global Solutions, Perth WA, August.* IGLC, pp. 631-640.

Carlile, P.R., 2004. Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries. *Organization Science,* 15 (5), 555-568.

Carlile, P.R., 2002. A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. 13 (4), 442-455.

Coughlan, D. and Bannick, T., 2012. *Doing Action Research in your own organization.* 3rd ed. London UK: Sage Publications.

Dave B. et al. 2015. Intelligent Products: Shifting the Production Control Logic in Construction (With Lean and BIM). *23rd Annual Conference of the International Group for Lean Construction.* Perth, Australia, 29-31 Jul 2015. pp 341-350

Fernandes, N., et al., 2016. 24th Annual Conference of the Int'l. Group for Lean Construction. *In: Proposal for the Structure of a Standardization Manual for Lean Tools and Processes in a Construction Site, Boston, MA, USA,* pp. 103-112.

Hackett, V., 2017. *The Impact of a Collaborative Planning Approach on Engineering Construction Performance.* PhD., Nottingham Trent University, UK.

Hegazy, T. and Menesi, W., 2010. Critical Path Segments Scheduling Techniques. *Journal of Construction Engineering & Management,* (136), 1078-1085.

Howell, G. and Ballard G. 1994. Implementing Lean Construction: Reducing Inflow variation "Proc. Conference on Lean Construction, Santiago, Chile. Sept 1994.

Howell, G.A. and Macomber, H., 2002. *A Guide for New Users of the Last Planner™ System Nine Steps for Success.* Bloomington, USA: Lean Project Consulting, Inc.

Huber, B. & Reiser, P. 2003, 'The Marriage of CPM and Lean Construction' In:, *11th Annual Conference of the International Group for Lean Construction.* Virginia, USA.

Kalsaas, B.T., Skaar, J. and Thorstensen, R., 2015. Pull v Push in Construction Work Informed by the Last Planner. *In: IGLC 23 Global Problems - Global Solutions, Aug.* pp. 103-112.

Korman, R. and Daniels, S., 2003. Critics can't find the logic in many of today's CPM schedules, users want software with flexibility, but is it true CPM? *Engineering News-Rec,* 250 (20), 30-33.

Liu, M. and Ballard G. 2008, Improving labor productivity through production control. In Proceedings for the 16th Annual Conference of the International Group for Lean Construction.

Mejía, C., et al., 2016. A Route Map for Implementing Last Planner® System in Bogotá, Colombia. *In: 4th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA,* IGLC, pp. 83-92.

Mossman, A., 2012. *Last Planner collaborative conversations for predictable design & construction delivery.* Oxford: The Change Company.

Pescosolido, A.T., 2001. Informal Leaders and the Development of Group Efficacy. *Small Group Research,* 32 (1), 74-93.

R Olivieri, H., Seppänen, O. and Granja, A. D. (2016). "Integrating LBMS, LPS and CPM: A Practical Process" In: Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction, Boston, MA, USA, sect.6 pp. 3–12, C.A., 2014.

Shi, J.J. and Deng, Z., 2000. Object- oriented resource - based planning method for construction. *International Journal of Project Management,* 18, 179-188.

Zanotti, N.L., Maranhao, F.I. and Aly, V.L., 2017. Bottom up strategy for lean construction on site implementation. *In: Proceedings for the 25th Annual conference for the international group for lean construction, Heraklion Greece, 2017.* IGLC, pp. 325-335.

Zhang, Z., Waldman, D.A. and Wang, Z., 2012. A multilevel investigation of leader-member exchange, informal leader emergence and individual team performance. *Personnel Psychology,* 65 (1), 49-78.

Ibrahim, MW., and Hanna, AS. (2019). "Comparative Analysis of Project Performance Between Different Project Delivery Systems." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 663– 674. DOI: https://doi.org/10.24928/2019/0183. Available at: <www.iglc.net>.

COMPARATIVE ANALYSIS OF PROJECT PERFORMANCE BETWEEN DIFFERENT PROJECT DELIVERY SYSTEMS

Michael W. Ibrahim[1], and Awad S. Hanna[2]

ABSTRACT

Project Delivery System (PDS) defines the relationship and timing of involvement between different contracting parties. The main PDSs referred to in cited literature are: Design-Bid-Build (DBB), Construction Management at Risk (CMR), Design-Build (DB), and Integrated Project Delivery (IPD). By applying statistical tests such as Analysis of Variance (ANOVA) F-test and Kruskal-Wallis H-test to a dataset of 109 projects, this paper compares the performance of the four PDSs. As a result, statistically significant performance differences among the examined PDSs were identified in five performance areas: cost, schedule, quality, communication, and change management. Furthermore, performing pairwise comparisons using post-hoc statistical tests to each pair of PDSs shows that DBB performs markedly worse than the other examined PDSs, especially IPD. The findings presented in this paper should encourage industry professionals to move away from the DBB model, and towards IPD and other synergic PDSs.

KEYWORDS

Integrated Project Deliver (IPD), Collaboration, Relational, Project Performance, Quantitative Analysis.

INTRODUCTION

Despite being a large contributor to the global economy, the construction industry is fraught with waste and inefficiencies, leading to declining productivity (Teicholz 2013; Ibrahim 2018). An often-cited root cause of the poor productivity of the construction industry is systemic fragmentation which promotes confrontational culture (Yates and Battersby 2003). The result of this fragmentation has been an increase in the use of transactional contracts rather than a 'project-first' attitude (Thomsen et al. 2010). This has led to a trend of stakeholders increasing the pad to their estimates in an effort to protect themselves from a higher level of perceived risk (Iwanski 2013). These padded estimates have caused an increased reliance on the arbitration process. Thus, even more productivity is lost as project stakeholders devote time and resources to both issuing and facing claims, rather than the project.

[1] California State University, Los Angeles, United States of America

[2] University of Wisconsin-Madison, United States of America

One of the primary fronts on which the industry is attempting to combat the systemic fragmentation within itself is in the evolution of the PDSs. The general trend of PDSs chronologically is: DBB to CMR to DB to IPD. This paper studies the performance of the four aforementioned PDSs using metrics in five areas: cost, schedule, quality, communication, and change management. This is done identifying statistically significant performance differences among the four PDSs and investigating how each pair of PDSs performs differently using data collected from 109 projects.

LITERATURE REVIEW

Extensive research has been conducted to evaluate the performance of traditional PDSs. To varying degrees, much of this research concluded that more collaborative delivery systems achieved superior performance as compared to less collaborative ones. Most notably, it was shown that DB outperformed CMR, which in turn outperformed DBB in terms of unit cost, construction speed and delivery speed (Konchar and Sanvido 1998). This trend of performance improvement has suggested that even more collaborative PDS, such as IPD, will further enhance project delivery performance. With the introduction of IPD as a new PDS, many case studies were conducted to assess its performance. Almost all of these case studies showed that IPD projects finished on time, under budget, and with positive relations within the project team (Hanna 2016). By statistically analyzing 35 projects, it was shown that IPD outperformed non-IPD in 12 metrics spanning six performance areas: quality, communication, change management, business, recycling, and schedule (El Asmar et al. 2013). Also, from a subcontractor's perspective, it was shown that IPD outperformed non-IPD in four performance areas: quality, schedule, communication, and change management (Iwanski 2013). More recently, analyzing 32 projects presented statistical evidences for the superior performance of IPD/'IPD-ish' projects as compared to non-IPD projects in two metrics spanning two performance areas: communication and change management.

Although most of the cited studies claim that more collaborative PDSs outperformed less collaborative ones, none of them provided statistical analysis of the performance differences between the four main PDSs. Instead, they either studied the performance differences among the three traditional PDSs or compared the performance of IPD to the three traditional ones collectively. This paper aims to fill this gap by statistically analyzing the performance differences between the four PDSs.

RESEARCH METHODOLOGY

DATA COLLECTION AND DOCUMENTATION

To perform a comprehensive assessment of performance differences between the four main PDSs, an extensive project-based survey was used to collect data (El Asmar et al. 2013; Ibrahim 2016). This survey was designed to evaluate project delivery performance across key performance areas. As a result, this paper studies project delivery performance using eight performance metrics spanning five performance areas. These specific performance areas and metrics were selected to be consistent with cited literature and based on data availability. Following are the five investigated performance along with their corresponding performance metrics and units of measurement:

- Cost performance area: construction cost growth (% of total cost).
- Schedule performance area: schedule growth (% of total duration).
- Quality performance area: enumeration of punch-list items (number/$1M) and overall systems quality (scale of very low to very high).
- Communication performance area: enumeration of Request for Information (RFI) forms (number/$1M) and RFI processing time (weeks).
- Change management performance area: overall project changes (% of total cost) and change order processing time (weeks).

Using this survey, substantial data was collected from 109 projects. This number of projects provides a considerable improvement, in terms of sample size, relative to related studies that collected data from 32 projects (Hanna 2016), 35 projects (El Asmar et al. 2013), and 49 projects (Cho et al. 2010). Also, the representativeness of the collected dataset was validated by making sure that its statistical distribution was consistent with cited literature (Ibrahim 2016).

Data Characteristics

Of the 109 studied projects, 28% were DBB, 32% were CMR, 23% were DB and 17% were IPD. From a geographical perspective, data was solicited with no specific geographic preference, thus the dataset of this study included projects from 31 states across the U.S., as well as projects from Canada, Colombia, and Ireland. Regarding the types of the studied construction projects, the dataset consisted mainly of institutional (39% of the data), industrial (29% of the data), and commercial projects (18% of the data). The rest of the dataset was infrastructure and large multi-story residential projects. The total dollar amount of construction work for the studied projects combined was around $16.2 billion, with an average project cost of each examined PDSs being around $150 million.

The distribution of project type within each PDS was akin to the distribution of all projects in the study. Of the DBB projects, 46% were institutional, 35% were industrial, 14% were commercial, and 4% were infrastructure. Of the CMR projects, 51% were institutional, 23% were industrial, 14% were commercial, 6% were infrastructure, and 6% were residential. Of the DB projects, 28% were institutional, 40% were industrial, and 32% were commercial. Of the IPD projects, 44% were institutional, 28% were industrial, 22% were commercial, and 6% were infrastructure. Statistical tests revealed that the project type was not a statistically significant factor impacting project performance, regardless of PDS.

In addition, distributions of further project factors were statistically examined within each PDS to ensure that the four examined PDSs had similar project characteristics. As a result, reported statistically significant performance differences between the examined PDSs should be directly linked to the type of PDS and not to confounding variables.

Statistical Framework

Using this data, statistical modelling techniques, including ANOVA and the Kruskal-Wallis H Test, were performed to determine if significant differences existed across the performance of the examined PDSs. In this analysis, the independent variable was the PDS type, and the dependent variable was each of the eight-performance metrics. For each dependent variable, the null hypothesis was that the performance across the four PDSs was the same, whereas the alternative hypothesis was that the performance across the four PDSs was dissimilar. Normality and homoscedasticity assumptions were thoroughly examined through applying Shapiro-Wilk test and Levene's test when determining which statistical tests were most suitable for each performance metric.

If it was statistically evident that PDSs performed differently in a given performance metric, corresponding post-hoc statistical tests, including Tukey-Kramer and Conover-Iman with Ŝidák corrections, were applied to the set of pairwise comparisons. This additional analysis was performed to offer more statistical insight into how each pair of PDSs performs differently. The statistically proven findings of this paper should provide project stakeholders with the means to assess the performance of different PDSs, thus making well-informed decisions when choosing a delivery system for their projects.

RESEARCH FINDINGS

OVERALL FINDINGS

Table 1 lists the studied performance metrics, followed by the corresponding p-values of examining the null hypothesis of constant performance across the examined PDSs. The smaller the p-value, the stronger the evidence of statistically significant performance difference across the examined PDSs in the corresponding performance metric. To define statistical significance, this paper employed the common p-value threshold of 0.05, below which the performance differences between PDSs are to be considered significantly different with 95% confidence level.

Table 1: Statistical analysis of performance differences among the examined PDSs

Performance Area	Performance Metric	p-value
Communication	Enumeration of RFIs	0.00
Change management	Change order processing time	0.00
Schedule	Schedule growth	0.00
Communication	RFI processing time	0.00
Cost	Construction cost growth	0.00
Change management	Overall project change	0.00
Quality	Overall systems quality	0.00
Quality	Enumeration of punch-list items	0.02

Figure 1 presents comparative box and whisker plots demonstrating the performance differences between the examined PDSs.

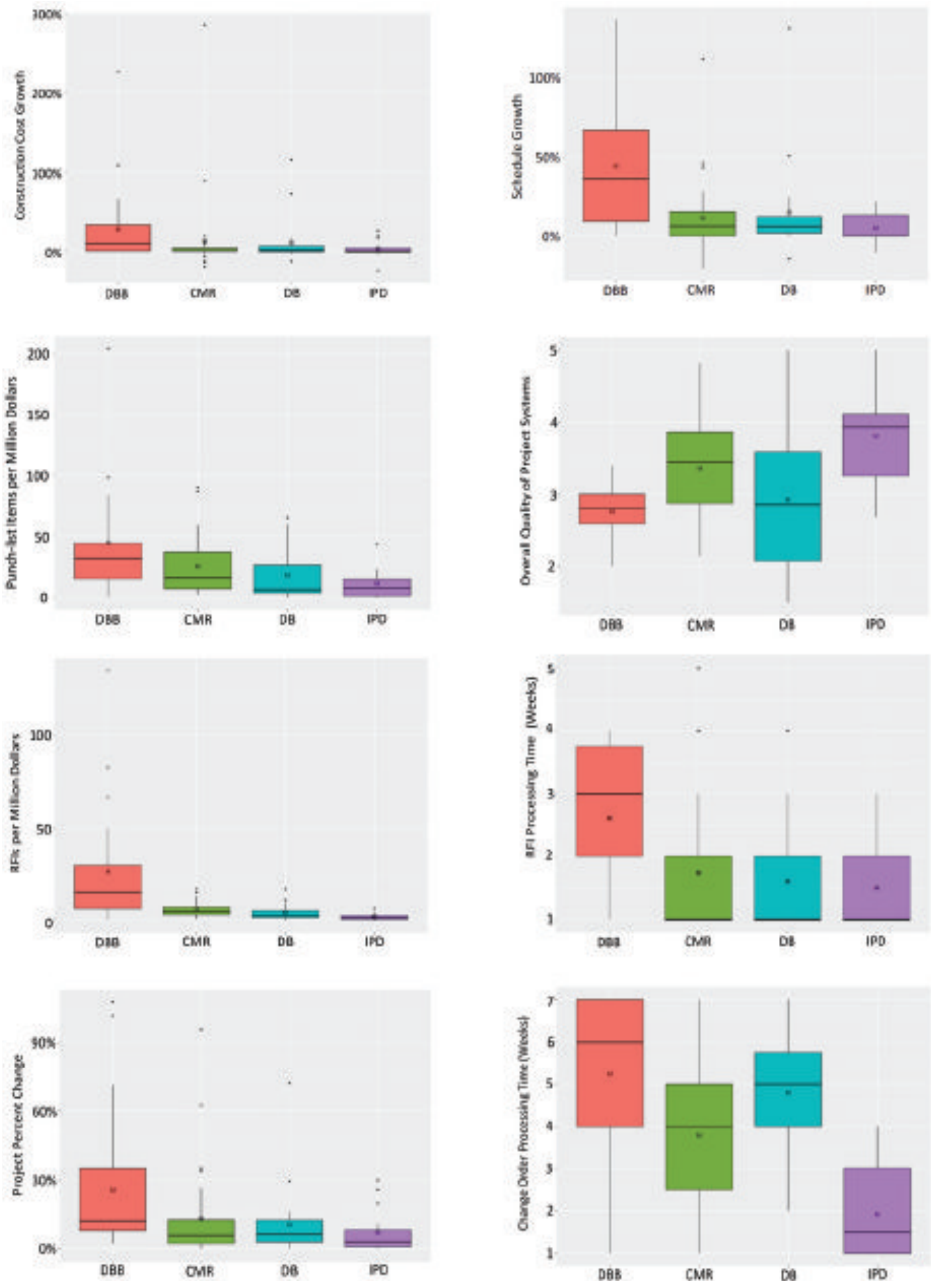

300%
200%
100%
0%
Construction Cost Growth
DBB
CMR
DB
IPD
100%
50%
0%
Schedule Growth
DBB
CMR
DB
IPD
200
150
100
50
0
Punch-list Items per Million Dollars
DBB
CMR
DB
IPD
5
4
3
2
Overall Quality of Project Systems
DBB
CMR
DB
IPD
100
50
0
RFIs per Million Dollars
DBB
CMR
DB
IPD
5
4
3
2
1
RFI Processing Time (Weeks)
DBB
CMR
DB
IPD
90%
60%
30%
0%
Project Percent Change
DBB
CMR
DB
IPD
7
6
5
4
3
2
1
Change Order Processing Time (Weeks)
DBB
CMR
DB
IPD

Figure 1: Comparative box-and-whisker plots for the performance of examined PDSs

Figure 1 demonstrates the performance differences between the examined PDSs. In addition, the p-values presented in Table 1 show that the investigated data provided enough evidence to conclude that the examined PDSs significantly differ, at 95% confidence level, in the eight studied performance metrics. The following five subsections are separated by performance area to provide the detailed findings for these eight metrics.

COST PERFORMANCE AREA

Application of the Kruskal-Wallis H test to the percentage of cost growth returned a p-value of 0.00. This provided sufficient statistical evidence at 5% significance level to reject the null hypothesis, thus concluding that construction cost growth percentage significantly differs across the examined PDSs at a confidence level of 95%. Table 2 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Table 2: Pairwise comparison about construction cost growth

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.004	IPD
IPD and CMR	0.891	Not applicable
IPD and DB	0.621	Not applicable
DB and DBB	0.047	DB
DB and CMR	0.816	Not applicable
CMR and DBB	0.003	CMR

Applying post-hoc Conover-Iman tests provided statistical evidence at 95% confidence level to support the following findings: DBB projects have higher construction cost growth percentage compared to IPD projects; DBB projects have higher construction cost growth percentage compared to DB projects; and DBB projects have higher construction cost growth percentage compared to CMR projects. Combining these three findings shows that DBB has the poorest performance level regarding this metric.

SCHEDULE PERFORMANCE AREA

Application of the Kruskal-Wallis H test to the percentage of schedule growth returned a p-value of 0.00. This provided sufficient statistical evidence at 5% significance level to reject the null hypothesis, thus concluding that schedule growth percentage significantly differs across the examined PDSs at a confidence level of 95%. Table 3 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Applying post-hoc Conover-Iman tests provided statistical evidence at 95% confidence level to support the following findings: DBB projects have higher construction schedule growth percentage compared to IPD projects; DBB projects have higher construction schedule growth percentage compared to DB projects; and DBB projects have higher construction schedule growth percentage compared to CMR projects. Combining these three conclusions, DBB was, again, proven to be the poorest performing PDS with regard to this performance metric.

Table 3: Pairwise comparison about schedule growth

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.000	IPD
IPD and CMR	0.685	Not applicable
IPD and DB	0.582	Not applicable
DB and DBB	0.005	DB
DB and CMR	0.944	Not applicable
CMR and DBB	0.000	CMR

Quality Performance Area

Application of the Kruskal-Wallis H test to the number of punch-list items per million dollars resulted in a p-value of 0.02. Therefore, statistical evidence at 5% significance level was presented to reject the null hypothesis, thus concluding, at 95% confidence level, that the number of punch-list items per million dollars changes when the PDS changes. Table 4 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Table 4: Pairwise comparison about number of punch-list items per million dollars

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.014	IPD
IPD and CMR	0.155	Not applicable
IPD and DB	0.815	Not applicable
DB and DBB	0.041	DB
DB and CMR	0.406	Not applicable
CMR and DBB	0.447	Not applicable

Application of post-hoc Conover-Iman tests provided sufficient statistical evidence to support the following conclusions at 95% confidence level: IPD projects have fewer punch-list items per million dollars than DBB projects; and DB projects have fewer punch-list items per million dollars than DBB projects.

To calculate the second metric (overall quality of project systems), respondents evaluated the quality of each of 11 major project systems as well as the quality of the entire project, using a scale of 1 to 5. The average of these ratings corresponds to the project's overall systems quality. These major project systems are foundation, structure, interior finishes, exterior enclosure, roofing, mechanical systems, electrical systems, site, process equipment, conveying systems, and specifications. Application of ANOVA to this metric returned p-values of less than 0.00. Therefore, sufficient statistical evidence existed to reject the null hypothesis at 5% significance level, thus concluding that the overall quality of project systems differs across the studied PDSs at a confidence level of 95%.

Table 5 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Table 5: Pairwise comparison about overall quality of project systems

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.002	IPD
IPD and CMR	0.221	Not applicable
IPD and DB	0.013	IPD
DB and DBB	0.799	Not applicable
DB and CMR	0.293	Not applicable
CMR and DBB	0.057	Not applicable

Application of post-hoc Tukey-Kramer tests found statistical evidence at 95% confidence level to support the following conclusions: IPD projects have higher overall systems quality than DBB projects; and IPD projects have higher overall systems quality than DB projects.

Communication Performance Area

Application of the Kruskal-Wallis H test to the number of RFIs per million dollars returned a p-value of 0.00. This low p-value provided statistical evidence at a significance level of 5% to reject the null hypothesis, thus concluding that there is a statistical evidence at 95% confidence level that the number of RFIs per million dollars changes when PDS changes. Table 6 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Applying post-hoc Conover-Iman tests showed statistical significance at a confidence level of 95% for the following conclusions: CMR projects have fewer RFIs per million dollars than DBB projects; DB projects have fewer RFIs per million dollars than DBB projects; and IPD projects have fewer RFIs per million dollars than DBB projects. Therefore, DBB was shown to be the PDS that has the poorest performance with regard to this performance metric. Additionally, it was found that, at 95% confidence level, IPD projects have fewer RFIs per million dollars than CMR projects.

When the Kruskal-Wallis H test was applied to RFI processing time (weeks), a p-value of 0.00 was returned. This low p-value provided statistical evidence at a significance level of 5% to reject the null hypothesis, from which it was concluded that there is statistical evidence at 95% confidence level that RFI processing time changes when PDS changes. Table 7 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Table 6: Pairwise comparison about number of RFIs per million dollars

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.000	IPD
IPD and CMR	0.000	IPD
IPD and DB	0.154	Not applicable
DB and DBB	0.000	DB
DB and CMR	0.104	Not applicable
CMR and DBB	0.001	CMR

Table 7: Pairwise comparison about RFI processing time

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.002	IPD
IPD and CMR	0.854	Not applicable
IPD and DB	0.978	Not applicable
DB and DBB	0.000	DB
DB and CMR	0.855	Not applicable
CMR and DBB	0.002	CMR

Results from the application of the post-hoc Conover-Iman tests showed statistical significance at a confidence level of 95% for the following conclusions: IPD projects have shorter RFI processing times than DBB projects; DB projects have shorter RFI processing times than DBB projects; and CMR projects have shorter RFI processing times than DBB projects. These statistically significant findings demonstrate that DBB has the poorest performance with respect to this metric relative to the examined PDSs.

Change Management Performance Area

Application of the Kruskal-Wallis H test to the project percent change returned a p-value of 0.00. This provided statistical evidence at 5% significance level to reject the null hypothesis, thus concluding that project percent change significantly differs across the examined PDSs at a confidence level of 95%. Table 8 demonstrates the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Application of post-hoc Conover-Iman tests found statistical evidence to support the following conclusions at the 95% confidence level: DBB projects have higher project percent change compared to IPD projects; DBB projects have higher project percent change compared to DB projects; and DBB projects have higher construction project percent change compared to CMR project. Combining these three conclusions, DBB was proven to be the PDS that had the poorest performance regarding this metric.

Table 8: Pairwise comparison about overall project percent change

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.001	IPD
IPD and CMR	0.526	Not applicable
IPD and DB	0.625	Not applicable
DB and DBB	0.019	DB
DB and CMR	0.976	Not applicable
CMR and DBB	0.013	CMR

Application of ANOVA to the change order processing time returned a p-value of 0.00, providing statistical evidence to reject the null hypothesis at 5% significance level, thus concluding that this metric significantly differs across the examined PDSs. Table 9 presents the p-values resulting from applying pairwise comparisons between each pair of PDSs.

Table 9: Pairwise comparison about change order processing time

Pair of PDSs	p-value	Significantly Better PDS at 95% Confidence Level
IPD and DBB	0.000	IPD
IPD and CMR	0.010	IPD
IPD and DB	0.000	IPD
DB and DBB	0.859	Not applicable
DB and CMR	0.227	Not applicable
CMR and DBB	0.061	Not applicable

Application of post-hoc Tukey-Kramer tests found statistical evidence at 95% confidence level to support the following conclusions: IPD projects have higher project systems quality than DBB projects; and IPD projects have higher project systems quality than DB projects.

CONCLUSIONS

The comparative statistical analysis presented in this paper shows that there are statistically significant differences across the four examined PDSs, at 95% confidence level, in eight metrics spanning five performance areas: communication, change management, schedule, cost and quality. For these eight metrics, post-hoc statistical tests were applied to investigate the performance differences between each pairing of PDSs. As a result, it was shown that IPD outperformed DBB in the eight metrics, IPD outperformed CMR in two metrics, and IPD outperformed DB in two metrics. Results also demonstrated that DB outperformed DBB in six metrics, and CMR outperformed DBB in five metrics. Overall, DBB was proven to be the lowest performing PDS in five metrics. Based on this paper's findings, industry practitioners should be encouraged to move away from DBB and towards IPD to create an environment that fosters collaboration and optimal project performance.

REFERENCES

Cho, S., Ballard, G., Azari, R., and Kim, Y. (2010). "Structuring Ideal Project Delivery System." Proc., IPPC4, 2010.

El Asmar, M., Hanna, A., and Loh, W. (2013). "Quantifying Performance for the Integrated Project Delivery System as Compared to Established Delivery Systems." J. Constr. Eng. Manage., 10.1061/(ASCE)CO.1943-7862.0000744, 04013012.

Hanna, A. (2016). "Benchmark Performance Metrics for Integrated Project Delivery." J. Constr. Eng. Manage. ,10.1061/(ASCE)CO.1943-7862.0001151 , 04016040.

Ibrahim, M.W. (2016). "Modeling, Benchmarking, and Maximizing Project Delivery Performance." Master's Thesis. University of Wisconsin–Madison.

Ibrahim, M. W. (2018). "Improving Project Performance by Mitigating Out-of-Sequence Work and Assessing Construction Readiness." Ph.D. Dissertation. The University of Wisconsin-Madison.

Iwanski, M. (2013). "Performance of Integrated Project Delivery (IPD) for Mechanical and Electrical Contractors." Master’s Thesis. University of Wisconsin-Madison.

Konchar, M., and Sanvido, V. (1998). "Comparison of U.S. project delivery systems." J. Constr. Eng. Mgmt., 124, 435.

Teicholz, P. (2013). "Labor-Productivity Declines in the Construction Industry: Causes and Remedies" (another look). AECbytes Viewpoint, 67.

Thomsen, C., Darrington, J., Dunne, D., and Lichtig, W. (2010). "Managing Integrated Project Delivery." Construction Management Association of America, Mclean, VA.

Yates, J. K., and Battersby, L. C. (2003). "Master builder project delivery system and designer construction knowledge." Journal of Construction Engineering and Management, 129(6), 635-644.

Ibrahim, MW., and Hanna, AS. (2019). “Comparative Analysis of Project Performance Between Different Project Delivery Systems.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 663– 674. DOI: https://doi.org/10.24928/2019/0183. Available at: <www.iglc.net>.

Farzad, M.R., and Cameron, V.A. (2019). “Implementing Lean Visual Tools on The Closeout Phase of A Global-Scale Industrial Project.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 675 – 686. DOI: https://doi.org/10.24928/2019/0184. Available at: <www.iglc.net>

IMPLEMENTING LEAN VISUAL TOOLS ON THE CLOSEOUT PHASE OF A GLOBAL-SCALE INDUSTRIAL PROJECT

Mohammad Reza Farzad[1], Vhybirt A. Cameron[2]

ABSTRACT

The construction industry has long been struggling with issues such as safety, efficiency, and quality. Many tools and methods have been introduced to alleviate the current problems of this industry. Lean practices have been promising in recent years in the matter of improving project safety, communications and efficiency. However, these tools have mainly been implemented at the peak of a construction project's activities, where resources are at their highest levels, but seemed to be neglected at the ending phase of closeout. To study the effectiveness of lean practices in this phase, this paper has evaluated the utilization of visual management methods as a case study on a large-scale multi-phase, multi-cultural industrial project in Mexico. Hence, a visual matrix was developed after thorough analysis and continues improvement. Moreover, procedures were developed to use this tool to communicate, track and coordinate the closeout process. After the completion of the project, five milestone dates were extracted, and the information was compared against previous phase data. The result of the study shows that using this tool can decrease the duration of the closeout process, improve the communication between different stakeholders and aid to overcome challenges derived from differences in culture, methods, and expectations.

KEYWORDS

Lean construction, closeout, visual management, international, multi-culture.

INTRODUCTION

A construction project does not simply start and finish at the operation phase of the project. One of the important milestones which is usually defined in the construction contract is substantial completion. The American Institute of Architects (2007) has defined this document as “The stage in the progress of the Work when the Work or designated portion thereof is sufficiently complete in accordance with the Contract Documents so that the Owner can occupy or utilize the Work for its intended use”. The process after this stage is labelled as the start of the closeout process. This closeout phase which can be referred as

[1] VDC Engineer, Gilbane Building Company, 13750 San Pedro Ave., Ste. 550, San Antonio, TX 78232, USA, +1 571 216-6016, mfarzad@gilbaneco.com

[2] Project Manager, Gilbane Building Company, 13750 San Pedro Ave., Ste. 550, San Antonio, TX 78232, USA, +1 210 714-3641, vcameron@gilbaneco.com

the final one percent of the project, is a complicated process that usually involves corrections and deliverable handovers to the client. This process is usually neglected in the primary planning of the project (Carson et al. 2009). Studies show that the mismanagement of project closeout not only can have direct financial impacts on the contractor due to contractual obligations but also can impact their relationship with the client for future business (Arditi et al. 2008). The result of the surveys conducted by Rogers (2012) demonstrate that most of the stakeholders believe other parties are to blame for the delay in the closeout process. In addition, studies also show that a lack of communication and motivation are important factors that create delays in the closeout process (Kaul 2014). Furthermore, studies show that communication is one of the key problems in the construction industry, especially in projects with employing minorities and diverse background groups. (Loosemore and Lee 2002).

Moreover, there are many studies that have been conducted on improving the communication by using different tools and methods. Among these, visual management as a lean tool is proven to improve the communication and decision making in managing processes (Koskela et al. 2018). This is especially evident on projects that have language barriers, as visual management has shown to facilitate the communication on jobsites to improve the health and safety of the workers (Bust et al. 2008). Although there are numerous studies utilizing visual management tools in different stages of construction, there are few evidences of using this tool in the closeout process of projects where communication is a challenge.

This study aims to evaluate the effectiveness of lean visual management tools in resolving the issues raised in the closeout stage of a construction project.

LITERATURE REVIEW

LEAN VISUAL TOOLS IN CONSTRUCTION

Although visual management tools have been used in construction industry for a while as signs, color coding, and hazard elements, there is a large potential for implementation in managerial levels and site logistic improvement (Tezel et al. 2013). Tezel et al. (2015) have investigated the advantages of visual management as a "managerial strategy" which can benefit a project in aspects such as transparency, ease of information flow and minimizing complication in communication. The study has suggested a pathway for effective implementation of this process. Furthermore, other studies have been conducted on the benefits of using visual tools to improve construction safety, sustainability and information transparency. (Bae and Kim 2008; Valente and Costa 2014; Bust et al. 2008).

Some researchers have integrated Building Information Modeling (BIM) tools with visual management to improve the efficiency and communication in construction projects. Sacks el al. (2009) study shows using visual tools in daily construction work integrated with 3D representation of the jobsite has improved communication, organization, accessibility and facilitates the distribution of information to project members at different levels of management. In addition, Laine et al. (2014) has developed a 3D model-based system to improve information management in a construction project in Finland. The result of the study has suggested a reduction in the duration and waste of several activities.

Furthermore, BIM based visual management tools have reduced communication and decision-making time in a healthcare project in Chile which had minimized delays that are typical for this type of project (Matta et al. 2018).

Lean visual tools have been utilized in large scale international projects to overcome their complex issues. Studies such as Barbosa et al. (2013) have evaluated the implementation of lean visual tools in a large-scale construction company in Brazil which has proven improvement in safety, teamwork and communication. Furthermore, Tezel and Aziz (2017) have suggested that integration of information technology and visual management can be beneficial for the construction and post construction phases of a large-scale project.

Recently, more companies around the world are taking advantage of lean practices and specifically, visual management at different levels and departments in the construction industry (Brandalise et al. 2018; Tezel et al. 2011; Tezel et al. 2015). Despite this, none of these studies have shown the use of visual management tools in the closeout phase of the construction project. Most of the studies have mainly focused on the execution of the work, which is the peak of the bell curve for a construction project's lifecycle, where project activities and manpower are typically at their highest. The final stage which is crucial for the future of different stakeholders involved in a large-scale project is most times neglected. (Carson et al. 2009).

RESEARCH METHOD

CASE STUDY

The study was conducted on an international industrial construction project in Mexico. This project was established in multi-phases; each phase with similar scope and characteristics. The significance of this project was the presence of stakeholders with multiple nationalities and backgrounds. Hence, this case study could investigate using lean visual tools in a project with cultural differences which has not been thoroughly evaluated by other researchers (Valente et al. 2016).

The goal of this study was to develop a visual management tool throughout the project by analysing the root causes of existing issues and continuous improvement to reach a level which the tool could be fully utilized. Furthermore, to investigate the effectiveness of using lean visual tool in the closeout process, a comparison was conducted between two distinct phases that were constructed by multiple contractors in this project. The first phase (phase 1) was constructed during years 2014-2016. During this phase, the visual tool was under development and only implemented for selected contractors for further development. Consequently, the tool was employed project-wide for phase two and it was shared with contractors and the client. Phase 2 was started on 2016 and completed on 2018.

DEVELOPMENT OF THE VISUAL MANAGEMENT MATRIX

To determine the suitable tools and methods for this project an evaluation was conducted. Analysing the causes of the various issues was determined by using the 5 why analysis (Figure 1).

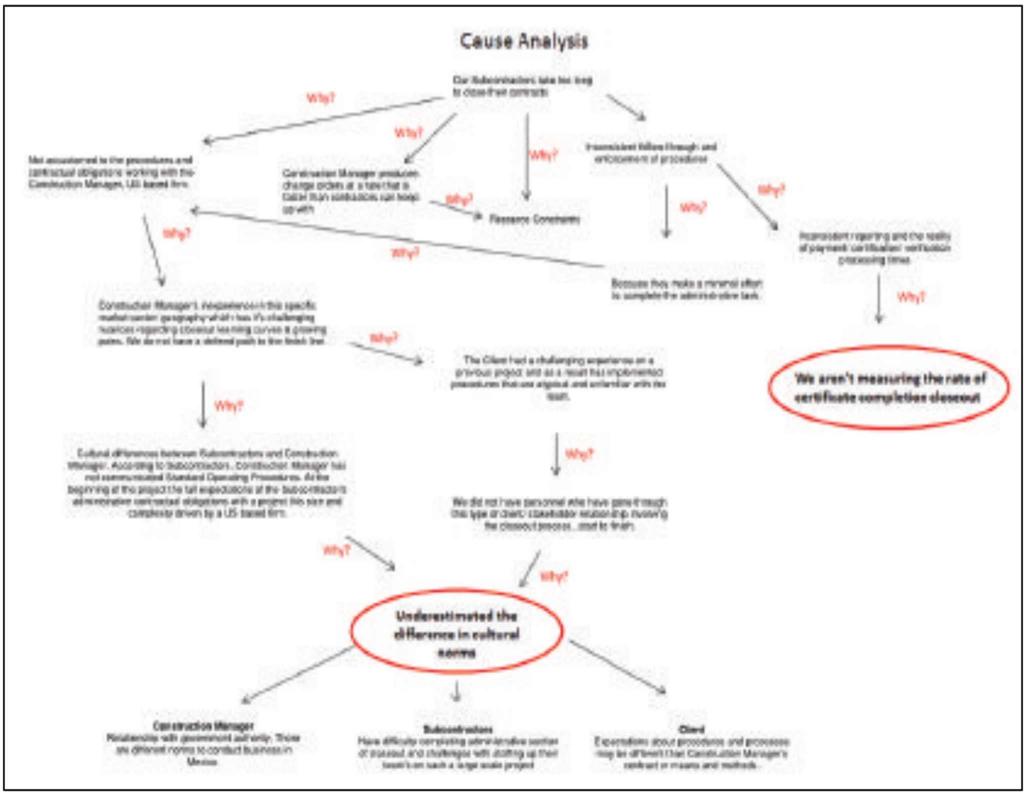
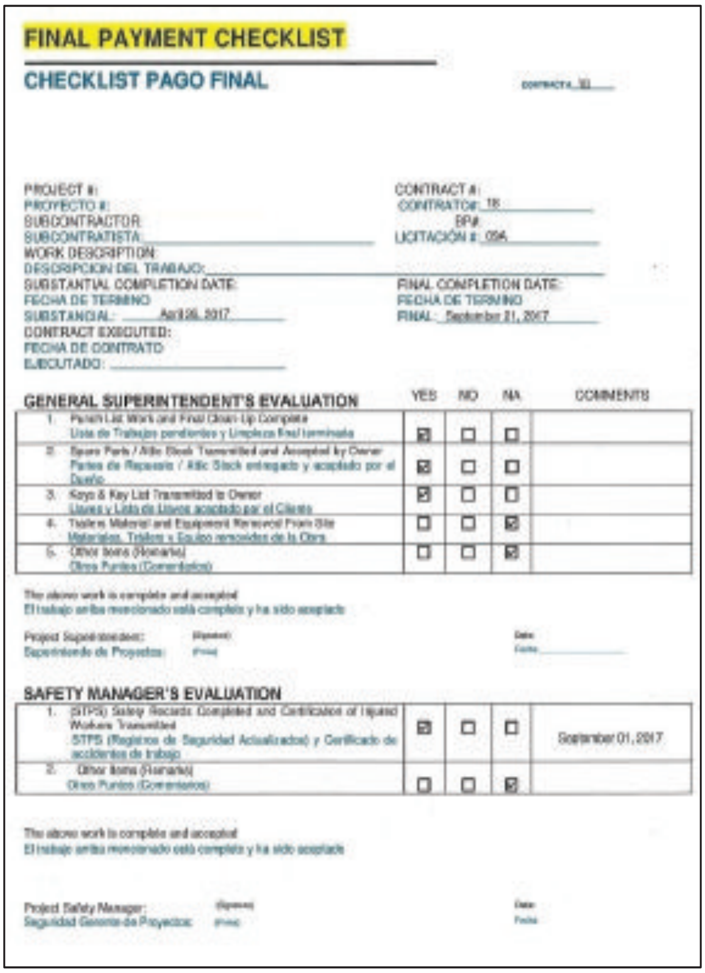


Figure 1: 5 Whys Analysis Conducted to Evaluate the Root Causes

The results showed that the difference in cultural norms and procedures were underestimated and there were inefficient standard procedures to track progress. Therefore, cultural differences caused difficulties in communication between different parties. To address this issue a visual tool (matrix) should have been designed to communicate to all project stakeholders, about the status of any given bid package and subcontractor throughout the construction phase which at the same time could track progress.

The initial efforts included extracting all the contractual deliverables and creating a sequence to clearly show how each phase and milestone flowed from beginning to end. The challenges faced by the project team were unique since a project of this size and scope had not been completed by anyone on the initial team before. Furthermore, other challenges included special Mexican federal requirements, team members with different procedural norms and the multi-cultural diversity of the stakeholders. The team utilized the company's typical final payment checklist which had general contractual items that would be verified before a subcontractor received their final payment, closing their contract (Figure 2).



FINAL PAYMENT CHECKLIST

CHECKLIST PAGO FINAL

PROJECT #:
PROYECTO #:
SUBCONTRACTOR:
SUBCONTRATISTA:
WORK DESCRIPTION:
DESCRIPCION DEL TRABAJO:
SUBSTANTIAL COMPLETION DATE:
FECHA DE TERMINO
SUBSTANCIAL: April 26, 2017
CONTRACT EXECUTED:
FECHA DE CONTRATO
EJECUTADO:

CONTRACT #:
CONTRATO#: 18
BP#:
LICITACIÓN #: 094
FINAL COMPLETION DATE:
FECHA DE TERMINO
FINAL: September 21, 2017

GENERAL SUPERINTENDENT'S EVALUATION

	YES	NO	NA	COMMENTS
1. Punch List Work and Final Clean-Up Complete / Lista de Trabajos pendientes y Limpieza final terminada	☒	☐	☐	
2. Spare Parts / Attic Stock Transmitted and Accepted by Owner / Partes de Repuesto / Attic Stock entregado y aceptado por el Dueño	☒	☐	☐	
3. Keys & Key List Transmitted to Owner / Llaves y Lista de Llaves aceptado por el Cliente	☒	☐	☐	
4. Trailers Material and Equipment Removed From Site / Materiales, Trailers y Equipo removidos de la Obra	☐	☐	☒	
5. Other Items (Remarks) / Otros Puntos (Comentarios)	☐	☐	☒	

The above work is complete and accepted
El trabajo arriba mencionado está completo y ha sido aceptado

Project Superintendent: (Signature)
Superintendente de Proyectos: (Print)
Date:
Fecha:

SAFETY MANAGER'S EVALUATION

	YES	NO	NA	COMMENTS
1. (STPS) Safety Records Completed and Certification of Injured Workers Transmitted / STPS (Registros de Seguridad Actualizados) y Certificado de accidentes de trabajo	☒	☐	☐	September 01, 2017
2. Other Items (Remarks) / Otros Puntos (Comentarios)	☐	☐	☒	

The above work is complete and accepted
El trabajo arriba mencionado está completo y ha sido aceptado

Project Safety Manager: (Signature)
Seguridad Gerente de Proyectos: (Print)
Date:
Fecha:

Figure 2: Standard Closeout Checklist Used in The Project to Document the Process

The checklist became the basis for the matrix items including the specific deliverables unique to this multi-phased project. The matrix deconstructed the final payment checklists and displayed them in a format whereby the phase of a project could easily be seen in its entirety.

The format of the matrix evolved throughout the life of the project based on continuous improvements and feedback from internal team members and the client. Colour was used as a visual tool to guide viewers to important aspects of the project and their status. Red was used to alert team members of items that required attention while contrasting circles highlighted changes from the last updated matrix. The matrix was updated on a weekly basis and reports were distributed among different stakeholders. In addition, the issue was tackled right away by making the topic of closeout a weekly agenda item with subcontractor staff meetings and reinforcing outstanding deliverables with a matrix printed on 48 inches by 60 inches and pasted on our wall (Figure 3).

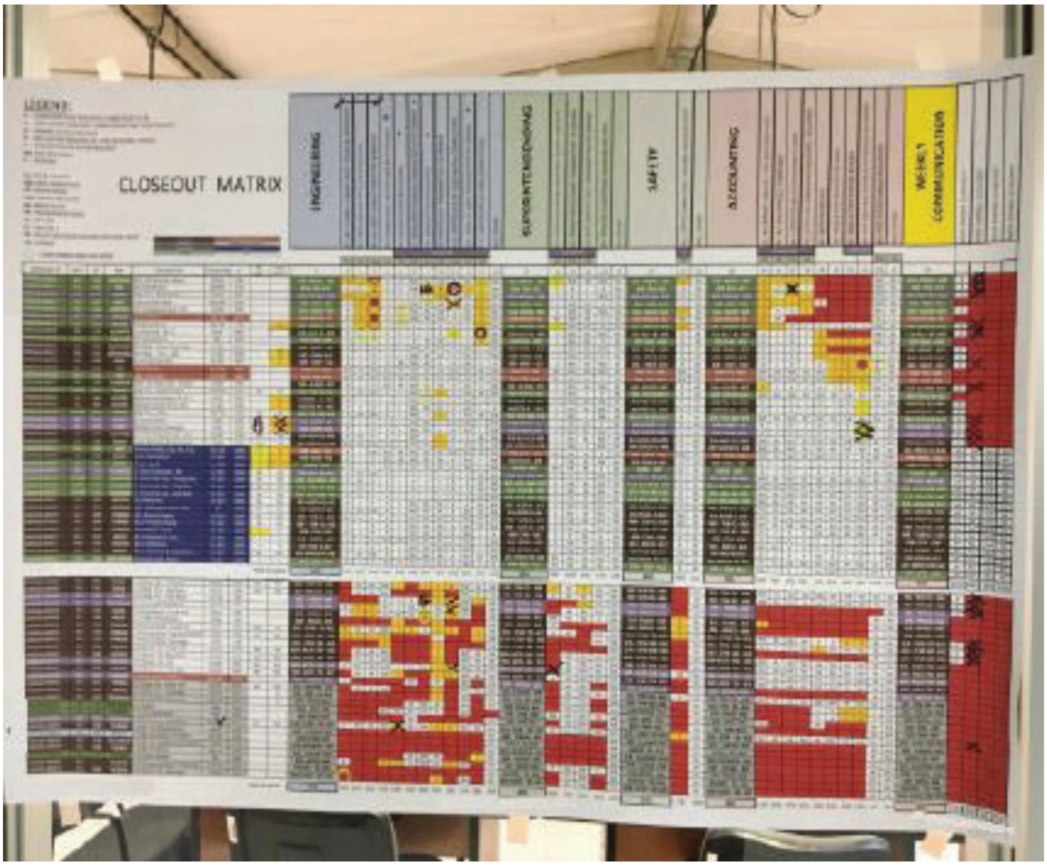


Figure 3: The Closeout Visual Tool Attached to The Office Wall

DATA COLLECTION

After the completion of phase 2, to conduct the comparison, data was extracted from closeout checklists of various contractors for phase 1 and 2. The checklists recorded the date each step of closeout was performed, and when the closeout process was concluded. This checklist records various items as obligations for different stakeholders, however, there are five key milestones which drive the completion of the closeout phase. These items are defined as follows:

- **Substantial Completion:** As discussed previously, substantial completion is a standard term which defines the date when scope of work is completed, turned over and/or occupied by the client. This milestone is considered as the baseline of our data since the closeout stage starts after this event.
- **Final Completion:** Final Completion is not only a term and milestone but is also certified as a document executed by different stakeholders when all the punchlist and engineering document transmittals are completed. This milestone shows the time when all the construction activities of any type are concluded by the contractor.
- **Safety Documentation (STPS):** According to Mexican regulations, the companies are obligated to submit their safety documents to the authorities including but not limited to: incident reports, man power reports, certifications and safety plans. This

report can be completed when all the construction activities are concluded, and series of reviews conducted by the construction manager and the client.

- **Social Security Documentation (IMSS):** Similar to safety documentation, contractors are obligated to submit their financial and man power documentation to the social security authorities in Mexico. When documents are submitted, the authorities will conduct reviews and determine the payment amount to be processed by the contractors. This process can take several months dependant on complexity and number of sub-subcontractors.
- **Final Payment Request:** When all the closeout items on the checklist are completed, the final payment request is submitted to the client to authorize the release of contractors' retentions for final payment. This milestone represents the last step of the closeout process.

To evaluate the effectiveness of a visual management approach, the above milestone dates were extracted from checklists that were completed for contractors in both phases. To quantify progress, substantial completion was set as the baseline and for the other 4 milestones, the number of days from substantial completion was calculated.

For this study, 10 contractors with different types and scopes of work were randomly selected from each phase and data were extracted from their closeout checklist. The data are presented as follows:

DATA

Table 1: Phase 1 Closeout Items (Number of Days from Substantial Completion)

Subcontractors Phase 1	Substantial Completion	Safety Documentation	Final Completion	Social Security Documentation	Final Pay Request
Contractor A	9/21/2015	554	564	618	623
Contractor B	9/21/2015	234	525	891	892
Contractor C	2/26/2016	165	471	529	599
Contractor D	6/22/2016	49	181	398	482
Contractor E	8/9/2016	128	133	331	345
Contractor F	7/22/2016	244	285	277	290
Contractor G	8/12/2016	235	406	361	447
Contractor H	6/8/2016	162	272	292	302
Contractor I	10/6/2016	247	196	259	287
Contractor J	9/21/2016	229	239	782	813

Table 2: Phase 2 Closeout Items (Number of Days from Substantial Completion)

Subcontractors Phase 2	Substantial Completion	Safety Documentation	Final Completion	Social Security Documentation	Final Pay Request
Contractor A*	7/18/2017	128	144	173	391
Contractor B*	2/6/2017	52	91	142	164
Contractor C*	11/14/2017	5	30	247	251
Contractor D*	5/22/2017	3	47	78	133
Contractor E*	8/7/2017	34	241	450	458
Contractor F*	2/2/2017	61	95	187	242
Contractor G*	2/6/2017	32	91	150	164
Contractor H*	2/6/2017	100	100	101	119
Contractor I*	2/6/2017	38	142	386	387
Contractor J*	6/6/2017	37	77	231	251

DISCUSSION

DATA ANALYSIS

Data extracted from the checklists for phase 1 has shown the average of 508 days for the closeout process whereas this number is reduced to 256 days for phase 2 which shows an overall 50% reduction in contract closeout time. The largest improvement in this milestone concerned STPS with about 78%. Moreover, the final completion milestone improved by about 68%, and Social Security documents with about 55% improvement. These results show that using the visual management tool assisted phase 2 closeout to be accomplished at a faster pace. However, factors such as lessons learned, improved experience and familiarity of the project team with the environment and culture should be considered. On the other hand, improvements in some of these milestones are related to the preceding milestones and do not necessarily show overall improvement in that specific process. For instance, most of the time spent on the IMSS process was not under the consortium team's control, however, completing the documentation and resolving the cost claims in a timely manner, helped to reduce the total duration for this process.

GENERAL OBSERVATIONS

The matrix gave the team a visual dashboard to gauge the status of closeout items. The matrix presence on a large size paper on the office wall increased the engagement of the project team as they would stop, look, take photos and notes, and ask questions to determine the outstanding items for the closeout process. In addition, the project engineers and project managers were using markers to update the matrix as they progressed on the closeout with a contractor.

Additionally, distributing the weekly report increased upper management's awareness of the progress by giving them a summary report of percentages complete for each area. On the first phase, in some cases, the closeout was mainly underestimated by the management team and usually the only tactic used to complete the process was terms such as "it should be done as soon as possible". In the second phase, by receiving visual reports like the closeout matrix, the management team focused more on the number of circles as they showed weekly progress and the size of the red cell mass on the matrix as this showed areas that needed more attention.

Using colors to visualize the closeout process, improved communication with contractors in their weekly meeting with the construction manager as they had a better understanding of where they were compared to other companies and what items were preventing them from receiving their final payment. Whereas, on the previous phase due to a lack of understanding and clear communication, the contractors would have seen the delay in the final payment mainly as the construction manager and client's fault.

Equally important, implementation of this tool did not solve all the issues regarding the closeout process and did not eliminate unnecessary delays to contractors' final payment. Complication of Mexican regulations and prolonged administrative processes caused major delays to final payments to contractors in both phases. Also, challenges like moving personnel with closeout experience out of the project and shortage in administrative manpower were still main issues.

CONCLUSIONS

The construction industry is a complicated area with unique problems for each individual project depending on its size, location, culture and duration. One of the biggest issues with almost any construction project phase are delays in the closeout process. The issues are proven to cause tension between various stakeholders which would have direct and indirect financial impact on their business. A few studies have been conducted that tried to determine the root causes and solutions to this problem, however, there are not many studies considering visual management tools which have been proven to have positive impacts on communication and decision making at the construction phase of a project.

This study assessed the implementation of lean visual management tools on a large-scale multi-cultural construction project in Mexico to examine the effect of such tools on improving communication and cultural hindrances on the closeout phase of this project. The visual management tools were developed after conducting thorough analysis on the root causes of the issues and studying the current resources and tools that had been used on the project. Consequently, a matrix was created along with procedures to engage employees and track the progress for the closeout process.

To experiment with this tool, the updated matrix was fully implemented for the second phase of the project. In addition, to quantify the effectiveness of this process, data were extracted by randomly selecting contractors from the initial phase that were managed during the development phase of the matrix and the later phase which totally utilized the new visual management system. The result of the study demonstrated improvement in 4 major closeout milestones along with a 50% reduction for the total duration of the process. In addition, the tool increased the engagement of employees, enhanced the levels of communication between all stakeholders, and improved the information quality for use of executive management.

To conclude, lean visual management is an effective tool to improve communication and overcome cultural differences in the closeout phase of large-scale construction projects. However, this tool alone cannot eliminate all issues associated with project closeout.

REFERENCES

Architects, American Institute of. (2007). Document A201 - General Conditions of the Contract for Discussion Substantial Completion.

Arditi, D., Polat, G., & Makinde, S. A. (2008). Marketing practices of US contractors. Journal of Management in Engineering, 24(4), 255-264.

Bae, J. W., & Kim, Y. W. (2008). Sustainable value on construction projects and lean construction. Journal of green building, 3(1), 156-167.

Barbosa, G., Andrade, F., Biotto, C., & Mota, B. (2013). Implementing lean construction effectively in a year in a construction project. In Proceedings of the 21st Annual Conference of the International Group for Lean Construction (IGLC).

Brandalise, F.M.P. , Valente, C.P. , Viana, D.D. & Formoso, C.T. 2018, 'Understanding the Effectiveness of Visual Management Best Practices in Construction Sites' In:, 26th Annual Conference of the International Group for Lean Construction. Chennai, India, 18-20 Jul 2018. pp 754-763

Bust, P. D., Gibb, A. G. F., and Pink, S. (2008). “Managing construction health and safety: Migrant workers and communicating safety messages.” Saf. Sci., 46(4), 585–602.

Carson, C. W., Potter, J. C., Sanders, M. C., & Stauffer, J. J. (2009). The Great Debate: Planning and Scheduling from Substantial to Final Completion. AACE International Transactions.

Kaul, V. (2014). Excessive delays in closeouts can be removed with the adaptation of better practices.

Koskela, L., Tezel, A. & Tzortzopoulos, P. 2018, 'Why Visual Management?' In:, 26th Annual Conference of the International Group for Lean Construction. Chennai, India, 18-20 Jul 2018. pp 250-260

Laine, E. , Alhava, O. & Kiviniemi, A. 2014, 'Improving Built-in Quality by Bim Based Visual Management ' In:, Kalsaas, B.T., Koskela, L. & Saurin, T.A., 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014. pp 945-956

Loosemore, M., & Lee, P. (2002). Communication problems with ethnic minorities in the construction industry. International Journal of Project Management, 20(7), 517-524.

Matta1, G. , Herrera, R.F. , Baladrón, C. , Giménez, Z. & Alarcón, L.F. 2018, 'Using BIM-Based Sheets as a Visual Management Tool for on-Site Instructions: A Case Study' In:, 26th Annual Conference of the International Group for Lean Construction.Chennai, India, 18-20 Jul 2018. pp 144-154

Rogers, J. (2012). Opportunity Lost: Mismanagment of the Closeout Phase of Construction Projects.

Sacks, R., Treckmann, M., & Rozenfeld, O. (2009). Visualization of work flow to support lean construction. Journal of Construction Engineering and Management, 135(12), 1307-1315.

Tezel, A., & Aziz, Z. (2017). From conventional to IT based visual management: a conceptual discussion for lean construction. Journal of Information Technology in Construction (ITCon), 22, 220-246.

Tezel, A., Koskela, L., Tzortzopoulos, P., Formoso, C. T., & Alves, T. (2015). Visual management in Brazilian construction companies: taxonomy and guidelines for implementation. Journal of management in engineering, 31(6), 05015001.

Tezel, B. A., Koskela, L. J., & Tzortzopoulos Fazenda, P. (2013). Visual management in industrial construction: a case study.

Tezel, A., Koskela, L. , Tzortzopoulos, P. , Koskenvesa, A. & Sahlstedt, S. 2011, 'An Examination of Visual Management on Finnish Construction Sites' In:, Rooke, J. & Dave, B., 19th Annual Conference of the International Group for Lean Construction. Lima, Peru, 13-15 Jul 2011.

Valente, R. C., & Costa, D. B. (2014). Recommendations for practical application of transparency in construction site. IGLC & Akademika forlag, Norway.

Valente, C.P., Pivatto, M.P. & Formoso, C.T. 2016, 'Visual Management: Preliminary Results of a Systematic Literature Review on Core Concepts and Principles' In, 24th Annual Conference of the International Group for Lean Construction. Boston, USA, 20-22 Jul 2016.

Farzad, M.R., and Cameron, V.A. (2019). "Implementing Lean Visual Tools on The Closeout Phase of A Global-Scale Industrial Project." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 675 – 686. DOI: https://doi.org/10.24928/2019/0184. Available at: <www.iglc.net>

Mota, P., Machado, F., Biotto, C., Mota, R. and Mota, B. (2019). "BIM for Production: Benefits and Challenges for its Application in a Design-Bid-Build Project." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 687– 698. DOI: https://doi.org/10.24928/2019/0243. Available at: <www.iglc.net>.

BIM FOR PRODUCTION: BENEFITS AND CHALLENGES FOR ITS APPLICATION IN A DESIGN-BID-BUILD PROJECT

Paula Mota[1], Fernanda Machado[2], Clarissa Biotto[3], Ricardo Mota[4], Bruno Mota[5]

ABSTRACT

The poor management of the information flow in the AEC industry is a significant problem that might be overcome by the adoption of Building Information Modelling (BIM) and Lean Construction philosophy. Although the increasing use of BIM models by construction companies, the management of BIM models for production purposes still lacks a systematic investigation by scholars.

Thus, the paper presents a design-bid-build (D-B-B) project to investigate the necessary efforts of design and construction stakeholders in order to generate the BIM models for production. Moreover, the authors analysed the information flow, stakeholders' responsibilities and interactions in the BIM process.

The study finds that the effective use of BIM for production is impacted by the D-B-B route due to the lack of information for construction contained within the BIM models generated by designers. Likewise, the effort of modelling for production requires a new skilled professional with design and construction knowledge.

The study is limited to one case study outcomes; however, the constraints for the adoption of BIM for production are general to the AEC industry.

KEYWORDS

BIM, production, information flow, constructive model, design-bid-build, procurement.

INTRODUCTION

The management of the information flow in the AEC industry is a significant problem. Due to the inaccuracy, duplicity and inconsistency of building information, the stakeholders have to recollect information several times throughout the project life cycle, representing about 57% of wasting effort (NIBS 2018). Building Information Modelling (BIM) may mitigate this problem.

BIM is considered the current expression that best clarifies the digital innovation employed by the construction industry in recent decades (Succar and Kassem 2016). Its

[1] MSc, BIM Manager, SIPPRO Consultancy, Fortaleza, Brazil, Paula.Mota@sippro.eng.br
[2] MSc, BIM Manager, Núcleo de Inovação BIM - NIB, Salvador, BrFernanda.Machado@nucleobim.com
[3] Post-Doc Researcher, Federal University of Sao Carlos, Brazil, Clerwice@gmail.com
[4] Civil Eng, CEO, SIPPRO Consultancy, Fortaleza, Brazil, Ricardo.Mota@sippro.eng.br
[5] Civil Eng., Lean Consultant, LogiKal, Birmingham, UK, Bmota@logikalprojects.com

robustness facilitates the building information management, allowing an integrated flow and project delivery through the use of virtual models (Underwood and Isikdag 2011).

Due to BIM triggers the process and product innovation in organisations, previous studies have identified and demonstrated the synergy between BIM and Lean Construction (Ma et al. 2018; Oskouie et al. 2012; Sacks et al. 2010). Moreover, several authors have highlighted the potential benefits in implementing both initiatives (Dubler et al. 2010; Mandujano et al. 2015; Nascimento et al. 2018). This synergy has been explored by scholars since 2010 (Sacks et al. 2010), including BIM and Last Planner™ System (Bhatla and Leite 2012; Tillmann and Sargent 2016; Toledo et al. 2016); BIM and IT solutions for construction management (Dave et al. 2011; Gurevich and Sacks 2014; Sacks et al. 2010), among other uses. In order to achieve a successful use of both Lean & BIM, their processes must have compatible workflows (Sacks et al. 2018).

Despite the outstanding contributions and relevance of BIM to support the lean philosophy in the construction industry, it still lacks systematic discussions about the management of BIM models for production. Thus, it is necessary research on the design and construction interface to explore the influence of procurement routes, and stakeholders' responsibilities and interactions in the BIM process to guarantee a lean workflow. In this scenario, it is relevant to stress the importance of managing the design and construction data in the BIM models (Chen and Luo 2014), and to make additional modelling efforts to provide further consistency to the constructability analysis and to use in the production phase (Leite et al. 2011; Wang et al. 2016).

Therefore, this paper investigates a design-bid-build (D-B-B) project regarding the efforts and information flow among project participants in the design and construction interface in order to generate the BIM models for production purposes.

The authors used an exploratory literature review of the main foundations and studies about D-B-B procurement route, lean construction and BIM to support the descriptive case study (Yin 2003; Yin 2014) analysis. This research strategy allows an in-depth analysis of a real phenomenon inside an organisational context. Initially, the efforts of modelling were analysed the production uses. Secondly, a set of charts were generated based on the information flow among the stakeholders to examine the players who required, generated and modelled the information for production. Thirdly, the authors observed the project organisation and the D-B-B procurement route to find out the challenges for the successful implementation of BIM and lean in the project.

LITERATURE REVIEW

The New Product Development (NPD) process in the AEC industry comprehends the activities undertaken by companies to capturing the client's requirements and translating it into finished products. The NPD process includes a series of stages, for instance, design and construction. The procurement routes adopted in the construction projects affect the sequence and/or the degree of overlap between these phases.

The procurement routes establish contractual relationships between parties. The traditional route, such as Design-Bid-Build, has a single-stage tender, in which the design is completed before the construction starts. A consultant team develops the detail design for the client, and a contractor is appointed, usually under a lump-sum construction contract. In theory, it presents the least risky approach for the client, due to proper certainty about design, cost and duration (Morledge and Smith 2013). The contractor suffers penalties for late completion but has no responsibility for design. Hence, in this sort of procurement route, the full implementation of BIM throughout the AEC companies may be limited (Abd Jamil and Fathi 2018).

LEAN & BIM

Lean construction does not necessarily need any technology to be implemented. However, some technological tools may support it, such as BIM tools (Sacks et al. 2018). Among the various BIM model uses (Succar et al. 2016), the interaction between Lean and BIM comprises: (a) constructability analysis of systems and subsystems (Gómez Cabrera et al. 2015); (b) physical-financial project scheduling (Sánchez-Rivera et al. 2017); (c) dynamic project control based on visualisation of the constructive process, through the integration of models to the Last Planner System (LPS) (Bhatla and Leite 2012); (d) production design, planning and control by means of 4D simulation tools (Biotto et al. 2015; Harris and Alves 2013); (e) production system management through the implementation of concepts such as KanBIM (Sacks et al. 2012), digital solutions such as VisiLean (Dave 2013), and a framework aligned with enabling technologies of Industry 4.0 (Dave et al. 2016), and; (f) communication platform for on-site teams, aiming to increase productivity in the field (Zhang et al. 2018) through BIM-stations (Vestermo et al. 2016) or BIM-kiosks (Bråthen and Moum 2016).

Although these different uses to support Lean, few BIM tools were explored to designing a production system before its operation. The use of BIM models is already supporting the production planning and control of on-site activities (Sacks et al. 2018). However, the content of the BIM models to attend the production is still unclear.

The production system design (PSD) is a managerial activity constantly neglected by the construction industry. It involves designing the production process to build a product through compatible technologies and resources (Biotto et al. 2017). It incurs a set of interdependent decisions related to the production organisation, and the study the best alternatives aligned with the project strategy (Schramm et al. 2004). The PSD should exist in concurrence with the product design stage, in order to integrate decisions about the building constructability and its production organisation (Biotto 2019).

BUILDING INFORMATION MODELLING

A BIM model is a rich representation of the building data, object-oriented, intelligent and parameterised, from which appropriate visions and data needs of multiple users can be extracted and analysed to generate information that can be used to make decisions and improve the delivery process of the building (AGC 2011). “There is a wide range of BIM applications in the construction industry, including constructability analysis, design verification and analysis of the product lifecycle (Leite et al. 2011); quantitative take-off, cost estimation, environmental comfort simulations, customer requirement modelling (Nisbet and Dinesen 2010); simulation of energy use, lighting, computational dynamics fluid and checking of building codes (GSA 2007).”

BIM pulls a technological and procedural change that tends to affect everyone involved in the construction industry (Succar et al., 2007 cited in Guillermo et al. (2009)). The implementation of BIM systems requires drastic changes in current business practices (Aouad and Arayici 2009).

According to Succar (2009), BIM has three stages of maturity, going from the Pre-BIM, passing through: 1) Object-based modelling; 2) Model-based collaboration; and 3) Network-based integration, and achieving the ultimate goal in the Integrated Project Delivery:

- **Stage 1:** Stakeholders deploy object-based 3D parametric software tools to generate sing-disciplinary models. Unsynchronised communication;
- **Stage 2:** Stakeholders collaborate and exchange information with other disciplinary players. Model-based collaboration may occur within one or between two stages of the product development: design-design stakeholders, or design-construction, etc. Unsynchronised communication. Requires some contractual arrangements;
- **Stage 3:** Integration and collaboration of stakeholders across the project lifecycle phases. Synchronised communication. complex analysis about constructability, operability and safety, and other nD modelling. Requires reconsiderations of contractual relationships, risk-allocation and workflows.

PROJECT DESCRIPTION

The study of this paper is the BS Design Corporate Towers, a commercial offices building located at Fortaleza, CE – Brazil. It is composed of 2 connected towers of 17 stores, plus 4 stores for public use and 5 basement floors for parking, totalising 10,000 sqm.

The design phase started in 2012, as a 2D CAD process. In 2014, the developer/owner hired a BIM manager company, called SIPPRO, to generate the 3D BIM models for clash detection, quantitative take-offs, structural analysis, studies of lighting, manufacturing pre-casted elements, and so on. In total, 18 disciplines were modelled.

Previously to the beginning of the construction phase in 2015, there was not any participation of the builder and contractors. They were engaged in the BIM process only during the construction phase, mainly to support the BIM modelling for production. In the latter, they provided detailed construction and assemblage information according to demands from the construction phase were emerging.

STAKEHOLDERS' RELATIONSHIP

The stakeholders' relationship during the design and construction phases occurred as the Traditional Design-Bid-Build Procurement Route. The owner contracted the main agents, such as designers, builders and the company responsible for the BIM Modelling - SIPPRO. The builder was in charge of hiring contractors, subcontractors and suppliers for the construction phase. In addition, the builder also had limited powers with all designers and SIPPRO. In this project, the design, tendering and construction phases were planned as sequential and linear processes. However, due to late critical design changes, the three phases suffered time extensions, overlapping each other. Figure 86 shows the comparison between the planned and actual D-B-B. The overlap was seen as an opportunity for builder and manufacturers require constructive detailing and information clarification from designers.

Figure 86: Planned and actual design, tendering and construction phases in the project.

DEVELOPMENT

The information flow between the design and construction phases is represented in Figure 87, which includes the main modelling processes, related inputs and outputs. In the design phase, SIPPRO considered the Employer's Information Requirements (EIR) and defined the deliverables with the designers. The design team provided the 2D drawings as input to the initial development of BIM models, that lately was approved by the owner. It was an iterative modelling and discussions among all agents involved in the design phase.

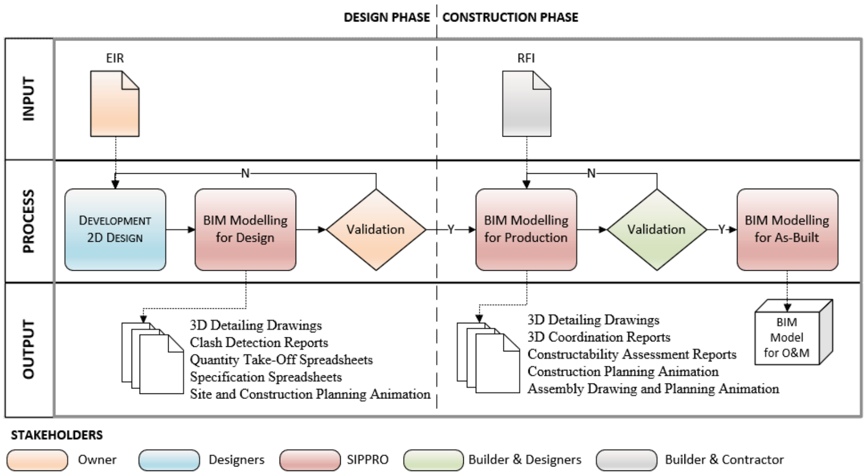


Figure 87: Information flow for BIM modelling process.

This article analyses data from 29 design solutions modelled by SIPPRO in the project during the design and construction processes. However, it is presented below 16 demands that had relation to the production, and intended to facilitate the PSD.

Demands from Design

The designers received 15 demands for new design information. It was necessary to increase the level of development of each building system, and create new BIM objects for simulation and analysis. In total, 66% of those fifteen model uses were directly related to production as detailed and illustrated below.

The **model use for lean process analysis** (Figure 88) supported the excavation and construction site planning, as well as served as a basis for defining the flow of soil excavated and grounded by the construction team. Another BIM functionality was the **model use for spatial analysis** (Figure 89) supported the optimisation of equipment positioning, which resulted in a significant cabling savings of R$600,000 (Brazilian currency). Moreover, the **model use for selection and specification based on**

constructability analysis (Figure 90) comprised materials definition and requirements, i.e., new modelling efforts were necessary to analyse façade fixing, a situation not previously foreseen in the project. The **model uses for visual communication, and clash detection** (Figure 91) supported the identifying and reporting of design inconsistencies, enabling earlier collaboration and problem-solving among the stakeholders.

The **model uses for both quantitative take-off, and construction planning** (Figure 92) supported the project feasibility analysis, as well the cost estimation and monitoring during design and construction phases. The quantitative take-off reports aided the project schedule by the budgeting team. The **model use for construction logistics** (Figure 93) supported construction planning simulation for both construction site and building. The first case enabled the equipment positioning and reduced internal changes. The second case facilitated the steel structure assemblage planning, plus the equipment acquisition.

Figure 88: Model used for lean process analysis.

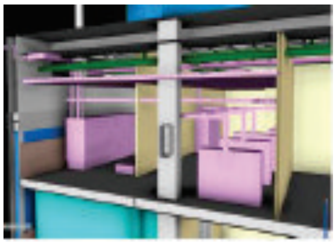


Figure 89: Spatial analysis.

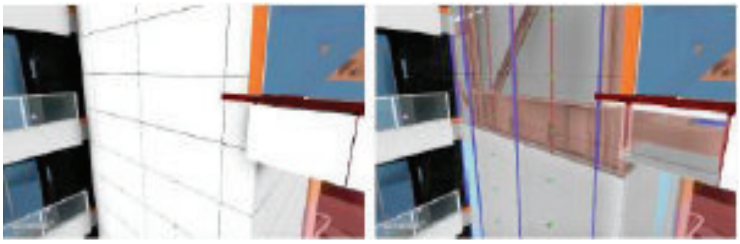


Figure 90: Model used for selection and specification, and constructability analysis.

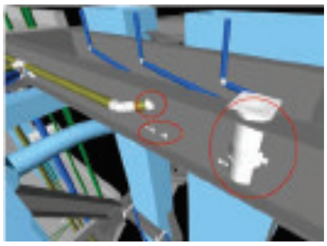


Figure 91: Visual communication, and clash.

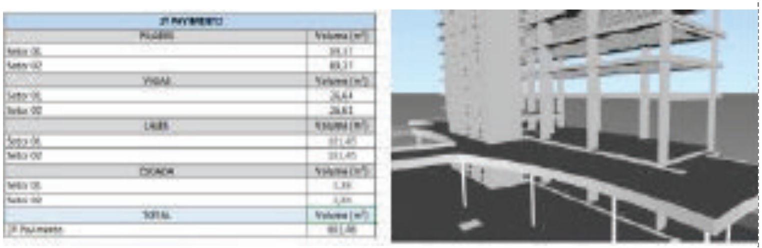


Figure 92: Model for quantity take-off, and construction planning.

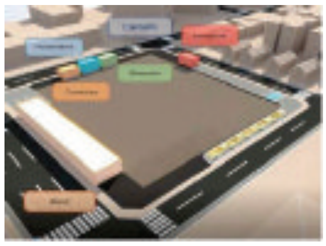


Figure 93: Construction logistics.

DEMANDS FROM MANUFACTURING

Validated models in the design phase were not detailed enough to meet the RFI specificities of the manufacturing phase. The demands for the pre-fabrication of steel beams, guard-rails, and cladding plates also reflected the increase of geometric and non-geometric data in the BIM models. Again, 66% of the model uses resulting from this phase were directly related to the production.

The **model uses at this phase involved sheet steel forming and site set-out** (Figure 94) **both based on constructability analysis** (Figure 95). In the first case, to coordinate the interface between steel structure and MEP/HVAC systems, SIPPRO provided more than 2800 mark-ups holes in the steel beams, saving R$1,128,000. since the execution of mark-ups on the factory floor is free of charge. This practice facilitated both the stage of assemblage and the passage of installations on-site. Yet, in the second case, more than one solution was considered to enable the installation of 6km of guard-rails. The chosen solution increased the productivity of the respective crew on the construction site.

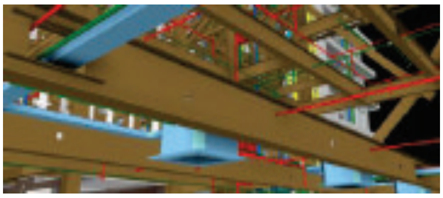


Figure 94: Model use for Sheet Metal Forming & Site Set-out.

Figure 95: Model Use: Constructability Analysis.

DEMANDS FROM CONSTRUCTION

Finally, incremental changes were also required in the construction phase. The model uses that effectively aided production corresponded to 55% of the RFI to SIPPRO. These uses ensured the quality, accuracy, and safety of the workforce.

The model use for constructability analysis (Figure 96 and Figure 97) supported the analysis of fixing the metal structure in the concrete structure through the application of chemical inserts. The model enabled a case-by-case analysis to generate execution templates preventing conflicts between the inserts and the reinforcement or pretension cables. This use involved the structural engineer in reviewing the position of each insert. Moreover, **the model uses for quantity take-off** (Figure 98) **and structural analysis based on constructability analysis** (Figure 99) included (i) the metallic inserts modelling necessary to assist the assembly of the transition beam of the concrete structure to the metallic structure; (ii) the modelling and quantifying of complementary metal-sheets in the U-beams, aiming the assembly of elevators; and (iii) the definition of the crane structure for lifting the main and transition metal beams, considering the simulation of equipment flow and the structural analysis of reinforcement.

The model use for field BIM (Figure 100) supported the production control through the slicing of BIM models for use in the construction site through mobile devices. Among the various application examples, we highlight the isolation of an HVAC model consisting of exhaustion, smoke extraction and stair pressurizing objects for on-site assembly monitoring of their pipeline and equipment.

The model use for construction planning (Figure 101) involved the 4D simulation and planning that supported demands that occurred during construction to verify and analyse the time and critical path of site activities. Considering that, the decision-making was assisted by the integration of BIM models to construction, assembly, and subcontractors' schedules.

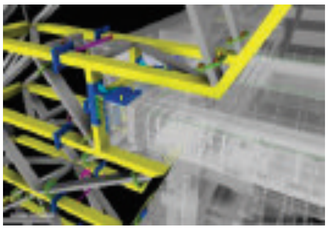


Figure 96: Constructability analysis.

Figure 97: Constructability analysis.

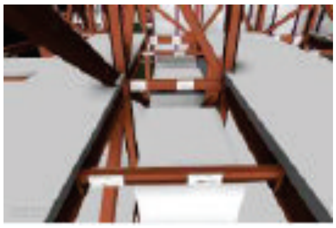


Figure 98: Quantity take-off & constructability analysis.

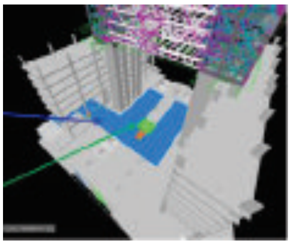


Figure 99: Structural analysis.

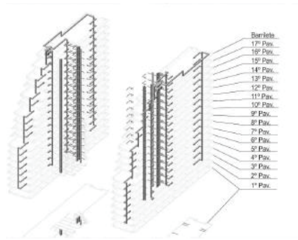


Figure 100: Field BIM.

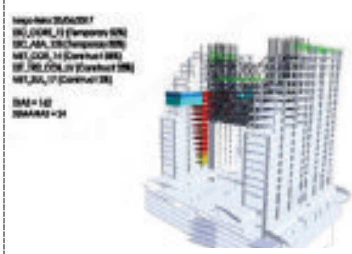


Figure 101: Construction planning.

RESULTS ANALYSIS

The data from 29 design solutions modelled by SIPPRO in the project was classified into seven categories: 1. If the solution was part of the design process, or if it was requested as extra information out of the design development; 2. The nature of the solution: if it regarded the manufacturing, construction or design process; 3. In which phase of the product development process the solution was generated: during design or construction; 4. Who requested the development of the solution (builder, designers or SIPPRO); 5. Who generated the solution (builder, designers, SIPPRO or manufacturer); 6. Who validated the solution (builder, designers, SIPPRO, manufacturer or developer); and, 7. If the effort to develop the solution was part of the contract between SIPPRO and the developer.

Figure 102 depicts that only 31% of the BIM modelling effort for design solutions was part of the design development process. It means that 69% of the requested solutions was beyond the design development. Figure 103, shows that almost half of the solutions generated concerned to design, 38% to construction and 10% to the manufacturing process of prefabricated elements. In Figure 104, the construction phase is the period when 90% of all solutions were generated.

Figure 105 depicts that, as a BIM model for production, 79% of solutions modelling were requested by the builder, whilst 17% by the designers, followed by 3% by SIPPRO. The next chart, Figure 106, presents outstanding data: the player responsible for generating and modeling the solutions was the consultancy company, SIPPRO, in 69% of the cases. It was the case of solutions for production, in which the designers did not detain the constructability knowledge.

Figure 107 shows that the validation of the solutions was performed by the builder and designers in 45% of the time for both, followed by the developer, SIPPRO and manufacturer.

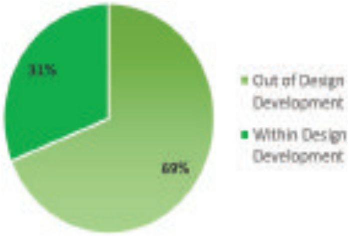


Figure 102: Solutions requested and developed out of the design phase.

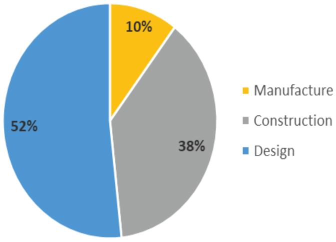


Figure 103: Nature of solutions: manufacture, construction or design origin.

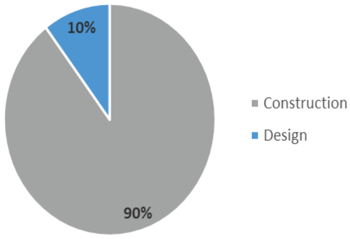


Figure 104: Phase when the solution was developed: design or construction.

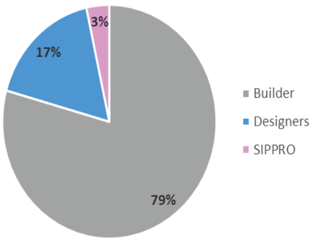


Figure 105: RFI requester.

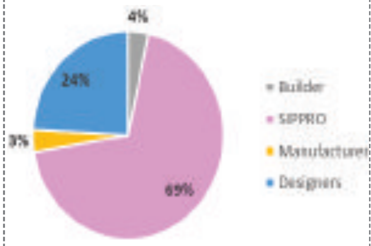


Figure 106: Solution developer.

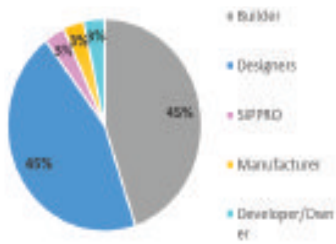


Figure 107: Solution validator.

Figure 108 illustrates one interesting fact: 41% of the design solutions were requested during the construction phase, despite the efforts to produce solutions during the design phase in order to have better designs ready for construction. Only 10% of the design solutions were developed during the design phase. As expected, 38% of construction solutions and 10% of manufacturing solutions were requested throughout the construction.

As the leading developer of design and construction solutions for the project, SIPPRO had many extra works, for instance, in Figure 109, 83% of all solutions were not in the scope accorded in the contract between SIPPRO and the Owner.

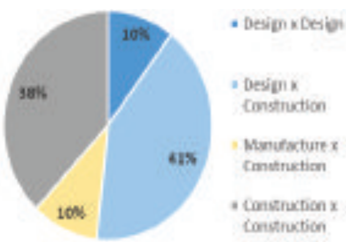


Figure 108: Crossing the nature of solution v.s. the phase it was requested.

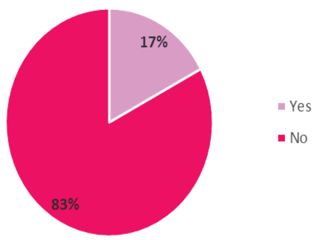


Figure 109: Solutions part of the SIPPRO's contract scope.

CONCLUSIVE DISCUSSION

This paper presented a descriptive case study of a D-B-B project which used BIM in the design and construction stages. From a total of 29 BIM modelling efforts, 16 were related to the be used for the PSD purpose. The model uses analysis showed that several demands from design, manufacturing and construction occurred due to the lack of detailed information in the drawings/models, which caused a high volume of design solutions been developed during the construction phase.

The set of charts generated based on the information flow among the stakeholders demonstrated that the main responsible for generating new design solutions for production was the consultant company SIPPRO. Thus, it is important to define a new skilled player to generate the BIM for production models, because SIPPRO's participation enhanced the production analysis which also created new design demands enabling gains and avoiding wastes during construction. These gains were extensive due to the early involvement of SIPPRO since the design phase. However, the gains could have been higher if the project adopted an EIR from the beginning of the design phase, planning the BIM deliverables and the players involved in construction demands.

Through the observation of the project organisation and the procurement route, the authors find out that the D-B-B was not the most suitable route for the successful development of constructive models. The D-B-B stimulates Stage 1 of BIM Maturity, although the project achieved Stage 2 (Succar, 2009). Other procurement routes that promote concurrent engineering should be adopted to implement BIM throughout the design and construction phases. Furthermore, the AEC industry needs to overcome contractual issues, i.e., to predict an early contractor involvement to design the production system aligned to the product design.

REFERENCES

Abd Jamil, A. H., and Fathi, M. S. (2018). "Contractual challenges for BIM-based construction projects: a systematic review." *Built Environment Project and Asset Management*, 8(4), 372-385.

AGC (2011). "The Contractors' Guide to BIM.", Associated General Contractors of America.

Aouad, G., and Arayici, Y. (2009). *Requirements Engineering for Computer Integrated Environments in Construction*, Wiley-Blackwell, Oxford, UK.

Bhatla, A., and Leite, F. (2012). "Integration Framework of BIM with the Last Planner System." *Proc., 20th Annual Conference of the International Group for Lean Construction*, San Diego, USA.

Biotto, C. (2019). "Integration of overlapped design and construction stages through location-based planning tools." Doctorate, University of Huddersfield, Huddersfield.

Biotto, C., Kagioglou, M., Koskela, L., and Tzortzopoulos, P. (2017). "Comparing Production Design Activities and Location-Based Planning Tools." *Proc., 25th Annual Conference of the International Group for Lean Construction*, Heraklion, Greece, 705-712.

Biotto, C. N., Formoso, C. T., and Isatto, E. L. (2015). "Uso de modelagem 4D e Building Information Modeling na gestão de sistemas de produção em empreendimentos de construção." *Ambiente Construído*, 15(2), 79-96.

Bråthen, K., and Moum, A. (2016). "Bridging the gap: bringing BIM to construction workers." *Engineering, Construction and Architectural Management*, 23(6), 751-764.

Chen, L., and Luo, H. (2014). "A BIM-based construction quality management model and its applications." *Automation in Construction*, 46, 64-73.

Dave, B., Boddy, S., and Koskela, L. (2011). "Visilean: Designing a production management system with lean and BIM." 477-487.

Dave, B., Kubler, S., Främling, K., and Koskela, L. (2016). "Opportunities for enhanced lean construction management using Internet of Things standards." *Automation in Construction*, 61, 86-97.

Dave, B. A. (2013). "Developing a construction management system based on lean construction and building information modelling." PhD thesis, University of Salford.

Dubler, C. R., Messner, J. I., and Anumba, C. J. (2010). "Using Lean Theory to Identify Waste Associated with Information Exchanges on a Building Project." *Construction Research Congress 2010*, 708-716.

Gómez Cabrera, A., Quintana Pulido, N., and Orlando Ávila Díaz, J. (2015). "Simulación de eventos discretos y líneas de balance, aplicadas al mejoramiento del proceso constructivo de la cimentación de un edificio." *Ingeniería y Ciencia*, 11, 157-175.

GSA (2007). "GSA Building Information Modeling Guide 01 - BIM Guide Overview."

Guillermo, A. M., John, C., Agustin, C., and Thomas, F. (2009). "Building information modelling demystified: does it make business sense to adopt BIM?" *International Journal of Managing Projects in Business*, 2(3), 419-434.

Gurevich, U., and Sacks, R. (2014). "Examination of the effects of a KanBIM production control system on subcontractors' task selections in interior works." *Automation in Construction*, 37, 81-87.

Harris, B., and Alves, T. d. C. L. (2013). "4D Building Information Modeling and Field Operations: An Exploratory Study." *Proc., 21th Annual Conference of the International Group for Lean Construction*, Fortaleza, Brazil, 811-820.

Leite, F., Akcamete, A., Akinci, B., Atasoy, G., and Kiziltas, S. (2011). "Analysis of modeling effort and impact of different levels of detail in building information models." *Automation in Construction*, 20(5), 601-609.

Ma, X., Chan, A. P. C., Wu, H., Xiong, F., and Dong, N. (2018). "Achieving leanness with BIM-based integrated data management in a built environment project." *Construction Innovation*, 18(4), 469-487.

Mandujano, M. G., Alarcón, L. F., Kunz, J., and Mourgues, C. (2015). "Use of Virtual Design and Construction, and Its Inefficiencies, From a Lean Thinking Perspective." *Proc., 23rd Annual Conference of the International Group for Lean Construction*, Perth, Australia, 836-845.

Morledge, R., and Smith, A. (2013). *Building Procurement*, John Wiley & Sons, Incorporated, Hoboken, UK.

Nascimento, D., Caiado, R., Tortorella, G., Ivson, P., and Meiriño, M. (2018). "Digital Obeya Room: exploring the synergies between BIM and lean for visual construction management." *Innovative Infrastructure Solutions*, 3(1), 19.
NIBS (2018). "Building Information Modeling (BIM)." <http://www.wbdg.org/building-information-modeling-bim>. (02/02/2019).
Nisbet, N., and Dinesen, B. (2010). "Constructing the Business Case: Building Information Modelling." *British Standards Institution, London*.
Oskouie, P., Gerber, D. J., Alves, T., and Becerik-Gerber, B. (2012). "Extending the Interaction of Building Information modeling and lean construction." *Proc., 20th Annual Conference of the International Group for Lean Construction*, San Diego, USA.
Sacks, R., Barak, R., Belaciano, B., Gurevich, U., and Pika, E. (2012). "KanBIMWorkflow Management System:Prototype implementation and field testing." *Lean Construction Journal 2013*, 19-25.
Sacks, R., Korb, S., and Barak, R. (2018). *Building lean, building BIM : improving construction the Tidhar way*, Routledge, London.
Sacks, R., Koskela, L., Dave, B. A., and Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." *Journal of Construction Engineering and Management*, 136(9), 968-980.
Sacks, R., Radosavljevic, M., and Barak, R. (2010). "Requirements for building information modeling based lean production management systems for construction." *Automation in Construction*, 19(5), 641-655.
Sánchez-Rivera, O. G., Galvis-Guerra, J. A., Porras-Díaz, H., Ardila-Chacón, Y. D., and Martínez-Martínez, C. A. (2017). "ßrIM 5D models and Lean Construction for planning work activities in reinforced concrete bridges." *Revista Facultad de Ingeniería*, 26, 39-50.
Schramm, F. K., Costa, D. B., and Formoso, C. T. (2004). "The Design of Production Systems for Low-Income Housing Projects." *Proc., 12th Annual Conference of the International Group for Lean Construction*.
Succar, B. (2009). "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in Construction*, 18(3), 357-375.
Succar, B., and Kassem, M. (2016). "Building information modelling: Point of adoption." *Proc., CIB World Conference Proceedings*.
Succar, B., Saleeb, N., and Sher, W. (2016). "Model uses: foundations for modular requirements clarification language." *Australasian Universities Building Education (AUBEA2016)*.
Tillmann, P., and Sargent, Z. (2016). "Last Planner & Bim Integration: Lessons From a Continuous Improvement Effort." *Proc., 24th Annual Conference of the International Group for Lean Construction*, Boston, USA.
Toledo, M., Olivares, K., and González, V. (2016). "Exploration of a Lean-Bim Planning Framework: A Last Planner System and Bim-Based Case Study." *Proc., 24th Annual Conference of the International Group for Lean Construction*, Boston, USA.
Underwood, J., and Isikdag, U. (2011). "Emerging technologies for BIM 2.0." *Construction Innovation*, 11(3), 252-258.

STREAM 12: LEAN SUPPLY CHAIN AND MODULAR CONSTRUCTION

Dargham AS., Assaf S., Faour K., Hamzeh, F. (2019). "Optimizing Material-Related Costs Using Dynamic Site Layout and Supply Chain Planning." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 699–710. DOI: https://doi.org/10.24928/2019/0135. Available at: <www.iglc.net>.

OPTIMIZING MATERIAL-RELATED COSTS USING DYNAMIC SITE LAYOUT AND SUPPLY CHAIN PLANNING

Sarah Abou Dargham[1], Sena Assaf[2], Karim Faour[3], and Farook Hamzeh[4]

ABSTRACT

Understanding a construction site layout is a crucial step before allocating resources to it; space is a critical factor that impacts both labour productivity and ease of material reach when needed. There is little research performed on the cost aspect of material management on site in compliance with the schedule and the type of supply chain strategy. The process of delivering bulk Glass Reinforced Concrete (GRC) units based on a push-supply system to a congested site with limited storage space all the way to their storage and installation on site is studied in this paper. The resources' cost, deterioration cost, transportation-delay cost, and the corresponding space turnover rate associated with the process are also addressed. The aim of this paper is to incorporate lean thinking to develop, model, and simulate an optimized and dynamic site layout that allows for a smooth flow of materials to the site thus minimizing their accumulated logistics and handling costs using the simulation software EZStrobe. Results showed 16% reduction in the total cost and 15% in the total simulation time from the base model of the process under study by adopting a pull-based supply chain of GRC units and combining certain activities of the process.

KEYWORDS

Dynamic site layout planning, lean construction, supply chain management, material handling cost, workflow.

INTRODUCTION

Planning how a site reacts to the materials it receives every day is a critical part of planning and scheduling. Materials should arrive to the site when they are needed, at the quality level desired, and in the quantities desired. This then helps to reduce the non-value adding activities, thus reducing the accompanied costs and consequently adding value to the

[1] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Lebanon, Phone +961 76 547 177, sra26@mail.aub.edu

[2] Graduate Student, Civil and Environmental Engineering Department, American University of Beirut, Lebanon, Phone +961 71 834 900, saa127@mail.aub.edu

[3] Civil Engineering Graduate, Civil and Environmental Engineering Department, American University of Beirut, Lebanon, Phone +961 71 112 886, knf03@mail.aub.edu

[4] Associate Professor, Civil and Environmental Engineering Department, University of Alberta, Canada, hamzeh@ualberta.ca

process (Lange & Schilling, 2015). Moreover, it is important to continuously assess how a site reacts to the multiple material inflows and outflows within it in order to better understand how to efficiently integrate the overall supply chain with the project schedule.

Space on site is usually used to accommodate temporary facilities, material storage areas, as well as the ongoing construction works (Said & El-Rayes, 2013). However, space availability is often considered limited in several construction projects. Projects with congested sites require an even more detailed planning of logistics (Mossman, 2007) and must be addressed early on in the planning phase to help in decisions regarding off-site laydown areas and off-site construction (Tommelein and Zouein, 1993). As a result, construction managers aim at developing site layout plans that utilize the space use on site. In fact, this utilization is optimum when it considers the dynamic change of the construction project, and if it takes into account the critical activities of the project's schedule.

Site layout planning in construction sites could be classified into static or dynamic layouts. The "static site layout planning" simplifies the site layout model since it does not allow materials and facilities to change their location over the project duration. On the other hand, "dynamic site layout planning" incorporates the complexity of material procurement, storage, and handling based on site and schedule needs (Said & El-Rayes, 2013). Alternative layout designs are often evaluated based on the material handling cost. As a result, facilities in a production system are to be located based on minimal material handling cost which accounts for material flow quantity and the distance separating the facilities (Turanoglu & Akkaya, 2017).

In order to tackle the problem of managing materials within a congested site, Said and El-Rayes (2013) proposed computational algorithms to model interior space allocation and the impact of space utilization on activity scheduling. The resulting model provides optimal logistics layout plans based on the least logistics cost and project schedule.

Moreover, the lean construction community has addressed the concepts of space allocation on site and site layout planning. A space scheduling program known as LOSite was developed by Bascoul and Tommelein (2017) based on visual management techniques. Its aim was to visualize the completed works per trade in the interiors phase of a project. The program was proven to be beneficial for subcontractors working on large scale projects since it simplifies planning for manpower. It has also helped the general contractor to spot errors in the schedule and to avoid space overlap between concurrent activities thus coordinating the work flow. Superintendents were also able to follow up on the commitments of resources from subcontractors. Moreover, MovePlan -a graphical and interactive program- was developed by Tommelein and Zouein (1993) for the purpose of developing dynamic site layouts over discrete time intervals. It allows the user to move and position resources on site to develop and assess several site layout alternatives.

The theory of production revolves around three key areas: transformation, flow, and value generation (TFV) (Bertelsen and Koskela, 2002). Koskela (2000) identified seven groups of resource flows that are necessary to complete a certain task. Those include: construction design, components and materials, workers, equipment, space, connecting works, in addition to external conditions. Moreover, various types of flow have been identified that tackle the issue of flow from various perspectives. One type of flow is called "even flow" that includes leveling resources with the goal of enhancing production rates and making the production process smoother (Kraemer et al., 2007).

Tiwari et al. (2018) addressed the issue of the lack of proper communication between a fabrication shop and the construction site that could result in material waste, material overproduction, and logistic-related problems leading to overall delays. For those reasons, they developed a software application that ensures smooth information flow and lean material flow from the fabrication shop to the site.

A huge portion of construction costs is attributed to the construction materials and equipment being used. In fact, these comprise 60 to 70 percent of the total direct project cost, with the remaining 30 to 40 percent being allocated for labor costs (Patel & Vyas, 2011). Total project costs accumulate whenever material is being moved from one place to another on and off site. Material movement includes bringing material into the site from surrounding laydown areas and storage facilities or transporting material that are on-site/off-site to their respective assembly or installation areas (Tommelein, 1994). Another main sources of waste in construction sites is directly related to the push nature of activities. Push systems are based on scheduled dates for releasing work into the following process disregarding the system's current state (Alves, Tommelein, & Ballard, 2006).

Optimizing any construction process requires a lean approach to obtain enhanced results. Given that simulation tools allow better decision-making capabilities, integrating lean methods enables better system configurations with the inputs available (Uriarte, Moris, & Oscarsson, 2015). On the other hand, production systems can employ simulation techniques to address and resolve many of the inherent deficiencies as stated by Standridge and Marvel (2006). Hamzeh et al. (2007) employed simulation to show the reduced amount of inventory needed in a system when integrating logistics centers into a contractor's supply chain. As a matter of fact, Tommelein (1997) showed the importance of the information that can be generated by using Discrete Event Simulation (DES) through studying construction processes of both discrete and bulk materials. Such information could be used to better design those processes in a leaner way. This was done by analyzing the simulation models based on lean construction concepts that were incorporated within the models: waste, push versus pull, uncertainty, conversion and flow.

Stroboscope is a discrete event simulation software used to model complex processes (Martinez,1996). This software was used by several practitioners to model construction operations since it can provide the resources' states and properties and take relevant actions (Alves, Tommelein, & Ballard, 2006). EZStrobe is a simplified version of stroboscope characterized by simple programming and real-time simulation results (Martinez, 1996).

As previously shown, methods and models in the literature that have tackled material handling on site have accounted for on-site congestion, logistics cost, project schedule, material flow to the site, in addition to dynamic site layout planning. However, the impact of how all those individual factors act and interact with one another in a single production system to incur material moving costs is understudied. Therefore, the aim of this paper is to incorporate lean thinking into developing a simulation model that determines an optimized dynamic site system with regards to minimizing material-related costs.

METHODOLOGY

This paper summarizes an empirical research addressing dynamic site layout planning to minimize costs associated with material transportation while following a project schedule. The research involves conducting a case study. First, the construction site was identified based on space limitation and material overflow. Then, information was gathered through three in-depth interviews with construction managers and foremen regarding space usage allocation on site, description of the bulk Glass Reinforced Concrete (GRC) units used in the facade, their quantities, their procurement process, their installation process and schedule, the time associated with each activity of the processes, the supply chain stakeholders, in addition to the unit costs of the resources used in this process. These inputs were used to identify limitations of the current strategies and possible cost-related inefficiencies associated with material transport around site.

After that, site-related variables were identified such as site area, number of temporary facilities, laydown areas, number of crews available for work, and types of equipment present on site as well as their usage costs. Then a schedule for the project phase under study is prepared and critical activities were identified. Afterwards, space availability was mapped according to critical activities with material handling costs (related to labor, equipment, and storage) being recorded at every allocation and re-allocation of material around site. This information was then used to model the construction process under study on EZStrobe. The developed simulation model aims to minimize costs associated with material delivery and transport around the site for the first eight weeks of the project under study taking into account the overlap between the activities.

DEFINING THE PROJECT

Based on the interviews, the construction project under study is a static, congested site with a limited storage space leading to challenges regarding material handling of bulk GRC units as part of the façade. These units are of various shapes and each has an average area of 13 m^2 with custom made racks for storage on site where each can fit ten pieces of GRC. They are manufactured off-site then transported to the site where they are placed on specified racks. After that, they undergo a series of operations such as cleaning and inter-site transportation to reach their desired installation area, which is one of the eight installation zones. *Figure 1* below illustrates the zone distribution for the project. *Figure 2* shows a rack holding GRC units.

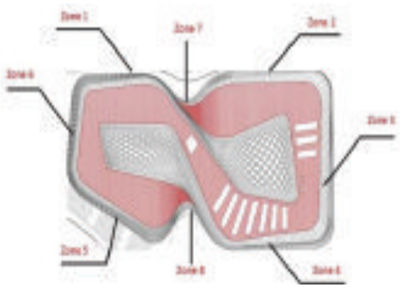


Figure 110: GRC Installation Zones

Figure 111: GRC Units Held on Rack

Table 1 shows the quantities of GRC units needed to be installed per zone.

Table 36: GRC Quantities and GRC Area Equivalent Per Zone

Zone Number	Number of GRC units (QZ_i,i=1:8)	Total GRC per zone (m2)
Zones 1,3,5	350	4550
Zones 2,4,6	700	9100
Zones 7,8	175	2275

After interviewing the project construction managers and foremen, a preliminary schedule regarding this project's GRC installation was obtained as shown in *Figure 3* below.

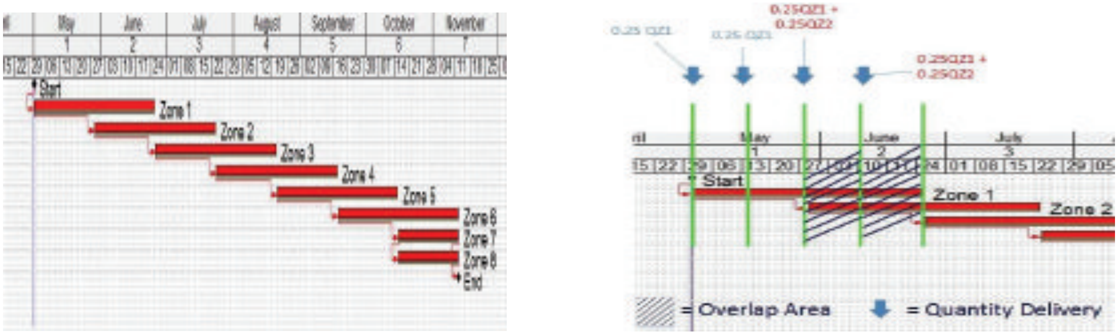


Figure 112: Preliminary GRC Installation Schedule (left) and Current Delivery Schedule (right)

Zones one till six have an eight-week installation period, whereas the smaller zones, seven and eight, have a four-week installation period. The overlap between the consecutive zones is shown in the schedule and is due to the fact that the irregular shape of the façade does not allow the complete installation of one zone unless the adjacent zone has started.

BASE MODEL

The base case model consists of the project's current site conditions. Information regarding the current site layout and procurement methods were obtained from the interviews. Currently, the available laydown space on site is 800m^2 distributed among the GRC racks, an electric generator, an equipment room, and one tower crane. Taking into consideration the area occupied by the motor, equipment room, and tower crane, the remaining space available for GRC units on site is constricted to 600m^2 equivalent to a total area of 1300m^2 in terms of GRC units (100 units). All material delivery orders arrive to the site on biweekly basis based on a push system. This is illustrated in *Figure 3*; green vertical lines equivalent to one-fourth of the quantity that needs to be delivered with regards to the zone under installation. For example, zone one has four scheduled deliveries, represented by blue arrow heads. At week zero and week two of the façade schedule, 0.25*QZ_1 will arrive on site since installation is only concerned with zone one. However, at the onset of week four, GRC installation of zone two will commence, and therefore must have its $0.25*QZ_2$ delivered to it. There will then be an overlap between zones one and two in terms of deliveries, thus delivering on week four a total quantity of $0.25*QZ_1+0.25*QZ_2$. The same logic applies at the onset of week six. However, it should be noted that each delivery will require the use of four trucks. Each truck can deliver 22 GRC units to the site due to its limited capacity, therefore, these four trucks will move to the site carrying a total of $0.25*QZ_1$. When modelling the current push system on EZStrobe, it is important to define the model assumptions, activities, parameters, and outputs.

The main assumptions concerning the model under study are:

- A GRC unit surface area was assumed uniform with an average of 13 m^2.
- The labor productivity was taken to be almost constant with slight variability which was portrayed in the distribution of the time duration of each activity.
- The trucks' capacity was assumed to be on average 286 m^2 of GRC units (22 units).
- The area around the site could accommodate for a queue of four trucks.
- The total process duration of erecting GRC is 56 weeks. This duration was then divided into seven periods with each period equivalent to eight weeks and then modelled.
- The cost of the entire process was assumed to be the sum of the individual period cost.

Table 2 describes the main activities in the model and their duration distribution. The durations of each activity were recorded for a period of one month then fitted to the best statistical distribution.

Table 37: Model Activities

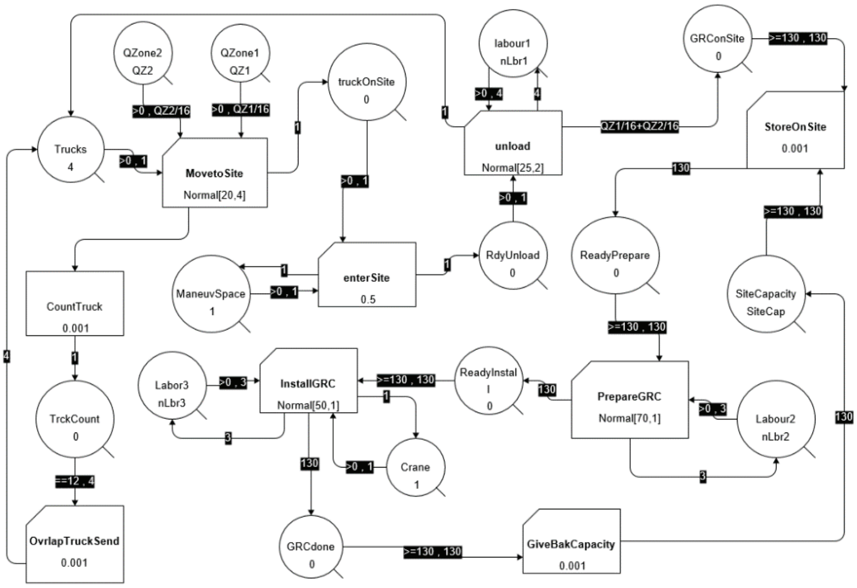
Activity	Description	Time (minutes)
MovetoSite	Transporting GRC from manufacturer to site	Normal [20,4]
EnterSite	Trucks arriving to site and entering it only if there's an available maneuvering space	0.5
Unload	Unloading GRC units from trucks on site	Normal [25,2]
PrepareGRC	Cleaning GRC units to ensure that they could be safely hoisted to a crane	Normal [70,1]
InstallGRC	Installing GRC units on the roof	Normal [50,1]

The unit cost of the model parameters are as follows: Truck cost is 30$/hr, the cost of a helper is 20$/hr, that of a skilled labor is 25$/hr, the crane operator's cost is 35$/hr, and the crane cost is 40$/hr. The deterioration cost of a GRC unit is assumed to be 1$/hr, and a 10$/hr fee is considered for truck delays. These inputs were based on the conducted interviews and were integrated into EZStrobe to deliver cost expenditures after the simulations performed ended.

The model outputs obtained after running the simulation which covers a two-month period of the project are described as follows: Total Cost ($) is the summation of the total costs of the trucks used, labor, crane, in addition to the GRC units' deterioration cost, and truck delay cost. Resources Cost ($) is obtained by adding the cost of the used resources: trucks, labors, and cranes. The Deterioration Cost ($) is the cost of the total time a GRC unit spends on site before its final installation. The Turnover Rate (hours/occurrence) of the space is the time needed for the storage space on site to be replenished by a new GRC rack. Finally, the Truck Delay Cost ($) is the cost incurred by trucks waiting to be unloaded instead of performing another delivery.

The flow of GRC units in the current static site layout following a push system was modelled on EZStrobe as shown in *Figure 4*. The process starts by receiving the units on site, storing them in allocated areas, preparing them for installation, and finally installing them.

Figure 113: Current Model



IMPROVED MODEL

In the improved model, three improvement cases were considered:

<u>Case A:</u> This case adopts a pull system by reducing the lead time of GRC units from two weeks to one week. This is done by having two trucks deliver units to the site every week instead of four trucks every two weeks.

<u>Case B:</u> This case adopts a new improved model, as shown in *Figure 5*, to quantify the cost effect of merging two activities, the "*Cleaning of GRC*" and "*GRC Installation*" into one activity "*PrepGRC*". Combining the two activities would require less time than proceeding with each of the two mentioned activities separately. This is done by permitting the crane to transport one GRC rack, equivalent to ten GRC units, rather than one individual GRC piece at a time; workers clean the units on the rack while other workers hoist the rack itself to the crane. This reduces the number of times the activity of hoisting material (whether GRC units or racks) is executed. This is expected to improve resource utilization and to decrease the overall process time.

Case AB: This case combined the changes made in cases A and B, and was implemented to test their combined effect.

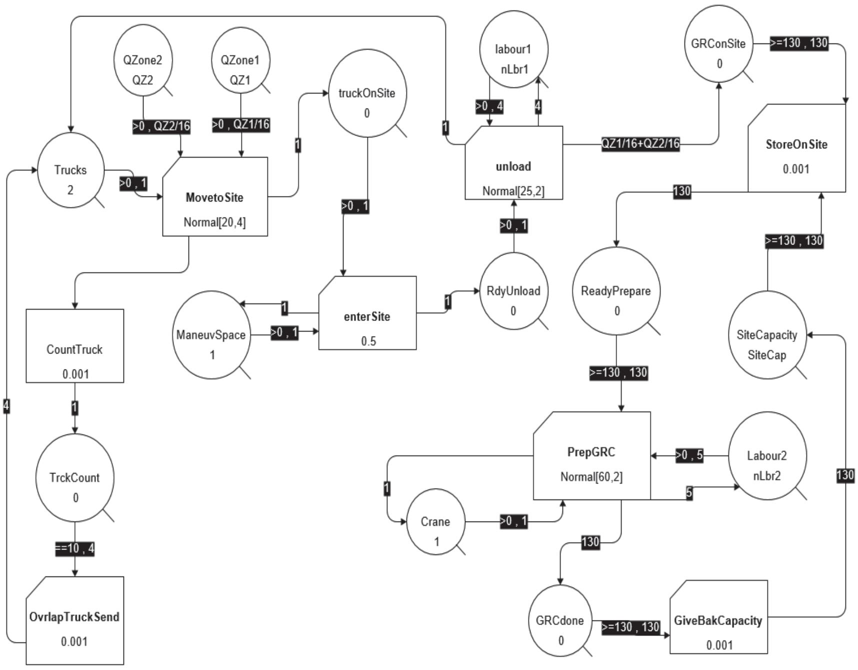


Figure 114: Final Optimized Model

SIMULATION RESULTS AND ANALYSIS

Results obtained upon simulating the three mentioned scenarios on EZStrobe in terms of total project costs, transport delay cost, material deterioration cost, material turnover in terms of inventory space, and total simulation time are shown in *Table 3.*

Table 38: Optimization Statistics

	Cases	Percent Improvement

	Original	A	B	AB	A	B	AB
Total Cost ($)	$ 420,253	$ 414,576	$ 358,552	$ 353,925	1	15	16
Truck Delay Cost ($)	$ 148	$ 66	$149	$ 66	56	0	56
Deterioration Cost ($/unit)	$ 37	$ 37	$ 31	$ 31	0	16	16
GRC Turnover (hr/occurrence)	11.9	11.9	10.1	10.1	0	15	15
Total Hours (hr)	83	83	71	71	0	15	15

Decreasing the lead time by one week (case A) contributed to a 56% decrease in truck delay cost and a 1% decrease in total process cost. Changing the sequence of two activities in near locations and minimizing unnecessary material movement on site (case B) reduced the project cost and duration by 15% each, and decreased the GRC turnover rate by 15% and thus their deterioration cost by 16%.

Furthermore, the improved model (case AB) did not only reduce the waste generated by unnecessary movement of GRC material between activities but also, it added value by maintaining the quality of the material through reducing time spend on-site which is shown in the increased turnover rate of GRC (15% improvement). This can be quantified in the reduced deterioration cost from 37$/GRC to 31$/GRC (16%). The improved system (case AB) performed well in terms of the total cost savings (16%) and time savings (15%). Decreasing the lead time showed a decrease in transportation delay cost (56%) which is expected since a smaller number of trucks arrive at the same time and location and there is a higher spread time between truck arrival.

So, for the purpose of optimizing the costs associated with the supply and handling of GRC units, cases B and AB yielded the best results in terms of cost and time savings and are both recommended for diminishing the proposed process costs.

MODEL LIMITATIONS

One of the limitations of the suggested model is that the results proposed are associated with the first eight weeks of the schedule which corresponds to the erection of the first two zones on the project while the rest of the cost is assumed to be the sum of the seven eight-week period costs accumulated together. Another limitation is the fact that the model does not present the supply chain of GRC in its big picture; it only observes the material from the point of delivery on site to the point of installation on site. Therefore, the proposed optimization is limited to sub-optimizing part of the supply chain related to the end-customer which is the construction site in this case.

CONCLUSIONS AND RECOMMENDATIONS

Space availability is a constraint in congested sites, so adopting a dynamic site layout is an efficient means to effectively allocate resources on site. A case study was conducted on a congested site in its finishing phase where GRC units were being delivered for installation on site. The simulation base model was developed based on the current state of the process. Then, three scenarios were discussed. The first scenario illustrates the benefits of adopting a pull system, the second involves combining and re-engineering activities with the purpose of decreasing material related expenses, and the third combines the latter with the former. Both the second and the third scenarios generated the most prominent results having a percent improvement of cost from the base model by 15% and 16%, respectively in addition to 15% time saving. Thus, incorporating lean tools and allowing smooth flow of materials to the site within the simulation model proved to be beneficial for a congested site that adopts a dynamic site layout strategy.

Assumptions and limitations of the model were addressed and minimized as possible. Future work aims at improving the existing model to better reflect the actual site conditions regarding labor productivity and truck capacity of the site and developing it even further to include more activities to account for the interaction between different tasks on site.

REFERENCES

Alves, T. d. C. L., Tommelein, I. D., and Ballard, G. (2006). "Simulation as a Tool for Production System Design in Construction." *Proc. of the 14th Ann. Conf. of the Int'l. Group for Lean Construction*. Santiago, Chile, 341-353.

Bascoul, A.M. & Tommelein, I.D. (2017). "Visualizing Daily On-site Space Use." *Proc. of the 25th Ann. Conf. of the International Group for Lean Construction.* Heraklion, Greece, 597-604.

Bertelsen, S., & Koskela, L. (2002). "Managing the three aspects of production in construction." *Proc. of the 10th Ann. Conf. of the Int'l Group for Lean Construction*. Gramado, Brazil.

Hamzeh, F.R., Tommelein, I.D., Ballard, G., and Kaminsky, P. (2007). "Logistics Centers to Support Project-Based Production in the Construction Industry", *Proceedings of the 15th Annual Conference of the International Group for Lean Construction, IGLC 15,* 18-20 July, East Lansing, Michigan, USA, pp. 181-191.

Koskela, L. (2000). "*An Exploration Towards a Production Theory and its Application to Construction*." PhD Dissertation, Helsinki University of Technology.

Kraemer K., Henrich G., Koskela L. and Kagioglou M. (2007) "How Construction Flows Have Been Understood In Lean Construction." *4th International SCRI Symposium, as part of the 4th International Research Week (IRW proceedings).* Rotherdam, 121-132.

Lange, S., & Schilling, D. (2015). "Reasons for an Optimized Construction Logistics." *Proc. of the 23rd Ann. Conf. of the Int'l Group for Lean Construction.* Perth, Australia, 733-742.

Martinez, J. C. (1996). "*State and Resource Based Simulation of Construction Processes*." PhD Dissertation, University of Michigan.

Mossman, A. (2007). "Lean Logistics: Helping to Create Value by Bringing People, Information, Plant and Equipment and Materials Together at the Workface." *Proc. of the 15th Ann. Conf. of the Int'l Group for Lean Construction.* Michigan, USA, 198–211.

Patel, K. V., & Vyas, C. M. (2011). "Construction materials management on project sites." *National Conference on Recent Trends in Engineering & Technology*. India, 1-5.

Said, H., & El-Rayes, K. (2013). “Performance of Global Optimization Models for Dynamic Site Layout Planning of Construction Projects.” *J. of Automation in Constr.*, *36*, 71-78.

Standridge, C. R., & Marvel, J. H. (2006). “Why lean needs simulation.” *Proc. Of the 38th Conf. on Winter simulation*. California, USA, 1907-1913.

Tiwari, S., Pawar, G., Luttmann, E., Trujillo, R. & Sreekumar, A. (2018). “Visual Planning for Supply Chain Management of Prefabricated Components in Construction.” *Proc. of the 26th Ann. Conf. of the Int’l Group for Lean Construction.* Chennai, India, 1150-1159.

Tommelein, I. D., and Zouein, P. P. (1993). ‘‘Interactive dynamic layout planning.’’ *J. Constr. Eng. Manage*., 119 (2), 266–287.

Tommelein, I. D. (1994). “Materials Handling and Site Layout Control.” *Proc. of the 11th Int. Symposium on Automation and Robotics in Construction*, 297-304.

Tommelein, I. D. (1997). "Discrete-Event Simulation of Lean Construction Processes." *Proc. f the 5th Ann. Conf. of the Int’l Group for Lean Construction,* 121-136.

Turanoglu, B., & Akkaya, G. U., (2017). “The Dynamic Facility Layout Problems with Closeness Rate: A Fuzzy Decision Support System Approach.” *Selçuk Üniversitesi Mühendislik, Bilim ve Teknoloji Dergisi*

Uriarte, A. G., Moris, M. U., Ng, A. H., & Oscarsson, J. (2015). “Lean, Simulation and Optimization: a Win-Win Combination.” *2015 Winter Simulation Conference*, IEEE, Huntington Beach, California, USA, 2227-2238.

Gusmão Brissi, S., Debs, Luciana. (2019). "Lean, Automation and Modularization in Construction." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.)*, Dubai, Ireland, pp. 711–724. DOI: https://doi.org/10.24928/2019/0177. Available at: <www.iglc.net>.

LEAN, AUTOMATION AND MODULARIZATION IN CONSTRUCTION

Sara Gusmão Brissi[1] and Luciana Debs[2]

ABSTRACT

The architecture, engineering and construction (AEC) industry lags behind the manufacturing industry, both in terms of innovation and productivity, mainly due to its heterogeneous, fragmented nature and the uniqueness of its projects. This paper analyzes three effective processes and technologies which are carrying out great benefits to the construction industry: lean construction, automation, and modularization (LAM). The research consists of a systematic literature review and assesses previously published work related to the three combined topics LAM in construction with two main goals: (1) identify the relevance of the three topics combined for both the AEC industry and the academy, and (2) identify in the papers investigated the main themes related to the combination of LAM in construction. Findings reveal only 31 publications meeting the criteria within the two sources investigated. The most frequent areas of LAM identified in the papers were lean production management, optimization algorithm and prefabrication, respectively related to lean construction, automation in construction and modular construction. The results reveal a need to better investigate the interactions of LAM in construction as a way to promote the continuous improvement of the AEC industry.

KEYWORDS

Lean construction, automation, modularization, off-site construction, continuous improvement.

INTRODUCTION

Over the last decades the productivity of the architecture, engineering and construction (AEC) industry has stagnated at low levels, with no sign of improvement, as opposed to several other industry sectors, such as manufacturing or the automotive industry (McKinsey Global Institute 2017). During the same time, many concepts, technologies, systems and materials have been introduced to the industry, but performance has not increased at the expected level (World Economic Forum 2016). Research suggest that this fact is due to two main reasons: the historical resistance of the AEC industry to embrace innovation into its traditional processes, and the lack of a holistic view to address the

[1] PhD Student, School of Construction Management Technology – Purdue University, West Lafayette, Indiana, USA, sgusmaob@purdue.edu

[2] Assistant Professor, School of Construction Management Technology – Purdue University, West Lafayette, Indiana, USA, ldecresc@purdue.edu

problems identified in this fragmented sector (McKinsey Global Institute 2017; World Economic Forum 2016).

When applied to the AEC industry as a holistic system, the effectiveness of strategies involving lean construction, automated technologies and modular building systems has been confirmed by research (Altaf et al. 2018; Tillmann et al. 2015). Individually, each of these strategies aims to increase the productivity and quality of the construction industry. However, to this date, there is a lack of research to evaluate how those three strategies combined can boost the overall performance of the AEC industry.

INTERACTIONS BETWEEN LEAN CONCEPTS, AUTOMATION, AND MODULARIZATION IN THE AEC INDUSTRY

The industrialization of the AEC industry, involving modular construction strategies and automated process have the potential to dramatically increase productivity in the construction industry (Jensen et al. 2012). As in other industrial sectors, industrialized construction processes build on some important concepts: (1) production planning and control; (2) mechanization and automation of production processes, and (3) standardization or products and processes. These three concepts are closely related to lean construction, automation in construction, and modular construction, respectively.

Thinking of a construction project as a temporary production system, the goal of lean construction (LC) is to deliver a quality product built on value maximization and waste minimization, which means quality and productivity improvement (McGraw Hill Construction 2013). In fact, three key concepts are important to better understand lean constructions: value, flow and pull (Ballard and Howell 2003). In LC the meaning of "value" is not only cost, but mainly the customers' satisfaction. Flow refers to the movement of information and materials through all professionals involved with the project, including the production crews as well. Pull is related to planning techniques that control the flow of information and materials in a collaborative way, constantly monitoring the project schedule (Ballard and Howell 2003; Koskela et al. 2002). It is important to emphasize that construction in lean construction refers to the entire design and construction process and not only to the construction phase, as defined in the transformation-flow-value (TFV) theory (Koskela 2000).

The goal of automation is to reduce time, cost and human induced error in production processes, therefore, similarly to the lean concepts, automation should result in enhanced quality and productivity. Considering the AEC industry, automation can greatly enhance the design, construction, operation and maintenance processes of buildings. However, the construction industry is still reluctant to adopt new automation technologies capable of boosting its productivity, enhancing quality of its products and streamlining its project management procedures (McKinsey Global Institute 2017). Robotics applications, BIM tools, automated assembly lines of prefabricated modules, 4D simulations for planning and scheduling and laser scanning are some examples of important technologies whose use in AEC industry could be much more significant.

Modularization in construction is closely related to prefabrication because the modules are prefabricated, i.e. manufactured under controlled factory conditions, which assures better quality products, and more efficiency in processes and resources use. (McGraw-Hill

Construction, 2011; McKinsey Global Institute, 2017). Modular buildings can bring together the advantages of both standardization and customization, as a result of the flexible use of standardized modules combined in various ways. Research suggests that breaking down complex systems into smaller components is a good problem-solving strategy in many domains, including the AEC industry, where modules designed independently must be integrated to work together in a complex structure such as a building, considering factors such as off-site manufacturing processes, transportation and on-site assembly (Jensen et al. 2012; Sharafi et al. 2017). Thus, modularization must also be closely linked to standardization, involving a holistic standardized production process to reduce not only the variability of each module, but also the complexity of the control processes.

Individually, the areas related to LAM in the AEC industry have been extensively researched in recent years. However, to date, there is little research dedicated to analyzing the relationships between these three areas at the same time. This study will provide an overview of the main topics related to the combination of lean, automation and modular construction that have been published in the last years and which topics are the most relevant ones.

METHODOLOGY

Our purpose is to explore, through a systematic literature review, the interactions between three effective processes and technologies applied to the construction industry which are carrying out great benefits to the sector: lean construction, automation in construction, and modular construction. That said, we address the following research questions:

- How much attention has the academy and the AEC industry devoted to the study of the combined topics lean construction, automation in construction and modular construction?
- What are the most relevant issues presented on publications that simultaneously investigate the topics related to lean, automation and modularization in construction?

DATA COLLECTION AND DATA ANALYSIS

This study examines relevant papers which simultaneously analyze the topics related to LAM in the AEC industry between the years 2000 and 2018.

First, the researchers defined the terms associated to lean, automation and modularization in construction which should be used as keywords in the data selection and data analysis. The lean construction terms were defined according to Koskela's (2000) concepts of transformation, flow and value. The terms associated to automation and modularization in construction were also identified based on the literature. The main keywords identified are: (1) lean – continuous improvement, elimination waste, generation of value, optimization of process, last planner system, flow, lead time, just in time, JIT, six sigma, etc.; (2) automation: RFID (and related terms), BIM (and related terms), robotics (and related terms), sensing, algorithm, simulation, parameterization, etc.; (3) modular construction – modular, module, prefabrication, precast, parametric design, etc.

The two sources selected to collect papers were the Automation in Construction (AIC) international research journal and the International Group for Lean Construction (IGLC) website. By considering these two contrasting sources of data, the study allows for a good overview of the current scenario of published papers that simultaneously cover the topics LAM in construction.

A total of 326 papers were retrieved from the AIC and IGLC websites using the following search criteria:

Automation in Construction – returned a total of 240 papers.

- Years: 2000-2018 (from January to December, including papers available online before published).
- Article type: review articles and research articles.
- Keywords: lean, modular building, modular construction, prefabrication, prefabrication AND lean, prefabrication AND modular.

International Group for Lean Construction – returned a total of 86 conference papers.

- Years: 2000-2018 (from January to December)
- Keywords: automated, automation, BIM, modular, prefab.

The selected papers were imported into NVivo and text mining queries were performed as follows (parameters – no spread and grouping with stemmed words):

- Considering that all the 86 papers from the IGLC are related to lean in construction, the researchers ran multiple text search queries using the keywords related to automation and modularization. After eliminating the duplicated papers, the content of each paper was manually assessed by the first author, who first looked for the defined keywords in the Title, Abstract and Keywords of each paper and then, if the related terms were not identified, the researcher assessed the full content of the paper. As a result of this process, a total of 12 papers with the joint content on LAM in construction were selected.
- Considering that all the 240 papers from the AIC are related to automation in construction, the researchers ran text search queries using the keywords related to lean construction and modularization. Here again the content of each paper was manually assessed, resulting in 19 papers with the joint content on lean, automation and modularization in construction.

A total of 31 papers addressing lean, automation and modularization in construction resulted from this selection.

Following, aided by NVivo and based on the defined keywords, the first author manually identified the topics of each paper related to LAM in construction. Based on the thematic analysis method (Braun and Clarke 2009), the researcher identified the themes emerging from the papers. The papers were then clustered by lean construction themes, based on the transformation-flow-value theory (Koskela 2000) and in the value, flow and pull concepts defined by Ballard and Howell (2003).

RESULTS AND DISCUSSION

Results from our research indicate that in recent years, especially in 2018, AIC has published a growing number of papers that cover all three LAM topics – lean, automation and modular construction (Figure 1). However, for the IGLC the number of papers published that satisfy this criterion was more expressive in 2015 and have stabilized since 2017 with a couple per year (Figure 2).

The relation between the total number of papers published and the number of papers addressing the combined topic LAM in construction suggests a low degree of interest from both research and practice in exploring the interactions of LAM in construction. For example, the following numbers present the proportion of LAM papers that were published by AIC and IGLC in 2018:

- AIC magazine: in 2018 (Jan-Dec), 6 out of 313 (1.92%) published papers addressed the combined topic LAM in construction.
- IGLC website: in 2018 (Conference IGLC 26 - Chennai, India), 2 out of 134 (1.49%) published papers addressed the combined topic LAM in construction.

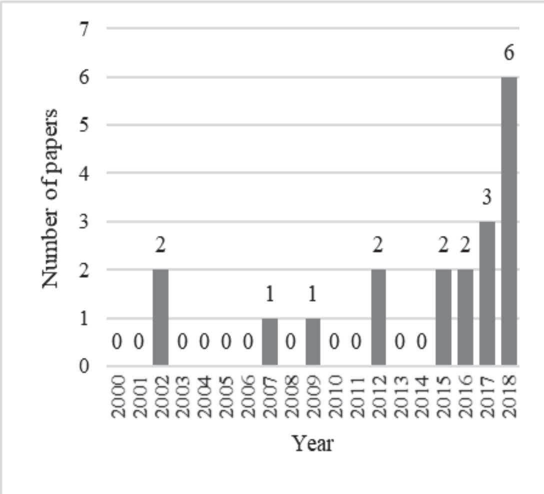


Figure 1: AIC LAM papers (n=19)

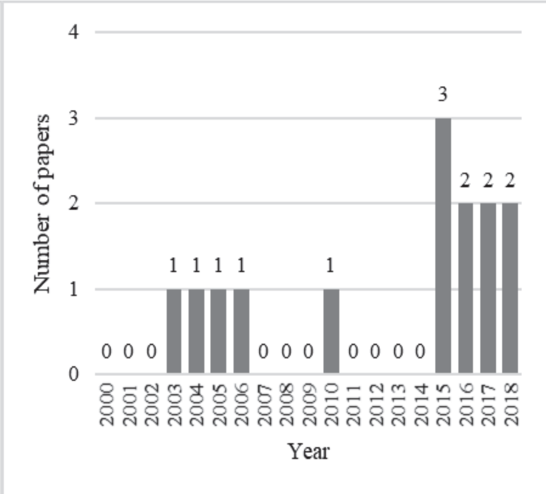


Figure 2: IGLC LAM papers (n=12)

The topics related to LAM in construction, grouped by lean construction themes are presented in Table 1, with the most frequent topics related to lean construction, automation and modularization in construction shaded in grey.

Table 1: Main topics related to lean, automation and modularization in construction

Author	Lean Construction Topics	Automation in Construction Topics	Modular Construction Topics
		LC Theme: Lean Management	

Author	Lean Construction Topics	Automation in Construction Topics	Modular Construction Topics
Altaf et al. 2018	Production planning and control	RFID, RANSAC model optimization algorithm	Panelized wall production facility for prefabricated homes
Arashpour et al. 2015a	Production planning and control	Autonomous production tracking	Off-site construction plant: precast concrete tanks
Bataglin et al. 2017	Logistics planning and control	4D BIM modelling	Logistics: Engineer-to-order (ETO) concrete prefabricated structures
Bortolini et al. 2015	Logistics planning and control: in construction sites	4D BIM modelling	Logistics: ETO prefabricated building systems
Gerber et al. 2010	Lean construction principles: look ahead planning, design and construction integration	BIM: fabrication processes, design and construction integration	Prefabricated components: various
Murphy et al. 2018	Lean construction principles: predictability	VDC methods and Reality Capture	Prefabrication: interior wall panels
Peñaloza et al. 2016	Integrated production control	4D BIM: physical flows, control of assembly process	ETO prefabricated concrete systems
Cheng and Chen 2002	Controlling and monitoring construction progress	Automated schedule monitoring system	Precast building construction
Sacks et al 2003	Lean production and delivery: monitoring	Real-time automatically monitoring & 3D modelling	ETO: precast concrete pieces
Tillmann et al. 2015	Lean principles: lead time, production planning and control	BIM: integrated management	ETO components
Zhong et al., 2017	Monitoring: visibility and traceability in manufacturing, logistics and on-site assembly	Internet-of-Things & BIM real-time automated monitoring	Prefabricated construction: manufacturing, logistics and on-site assembly
Arashpour et al. 2016	Scheduling: resource sharing and job sequencing	Optimization modeling algorithm	Off-site construction plant of concrete panels
Kong et al. 2017	Scheduling: cost and time constraints integrating manufacture, transportation and on-site assembly (JIT)	Dynamic programming algorithm: maximum production efficiency	Precast construction: manufacturing, transport, delivery, on-site assembly
LC Theme: Flow – Increase Flexibility			
Arashpour et al. 2015	Multi-skilled resources: flexibility, process integration	Optimization modeling algorithm - SIMAN code	Off-site construction plant

Arashpour et al. 2018	Process integrations and multi-skilled resources	Optimization modeling algorithm	Off-site construction plant
Isaac et al. 2016	Flexibility: product adaptability	Clustering algorithm: design graph-based analysis	Modularization of building design
LC Theme: Waste Elimination (non-value-adding activities)			
Banihashemi et al. 2018	Waste reduction workflow	Generative algorithm and Modular coordination	Parametric design and modular coordination integration
Cheng et al. 2015	Waste reduction: construction and demolition	BIM: automated quantity take-off, planning, design reviews, clash detection and digital fabrication	Digital prefabrication
Yuan et al. 2018	Lean construction: simplify design, manufacture and assembly to reduce time and costs	Design for Manufacture and Assembly-oriented parametric design with BIM	Prefabricated building design, parametric components, precast components
Author	**Lean Construction Topics**	**Automation in Construction Topics**	**Modular Construction Topics**
LC Theme: Lean layout			
Chen et al. 2018	Facility layout planning: minimize production time and maximize workstation use	Automated guided vehicle-based flow production system and genetic algorithm	Precast factory layout: modular prefabricated manufacturing system
Cheung et al. 2002	Site precast yard layout to minimize transport cost	Genetic algorithm model	Precast: on site layout arrangement
Nasereddin et al. 2007	Lean construction: factory more flexible, responsive, and efficient	Automated modeling	Modular home manufacturing industry
LC Theme: Pull System – Controlling Resources Flow			
Liu and Lu 2017	Supply chain management	Constraint programming-based optimization algorithm	Supply chain and module assembly plan
Chin et al. 2004	Supply chain management	RFID: product and information flow management	Supply chain: curtain walls
Tiwari et al. 2018	Supply chain management and job sequencing	BIM: real-time sequencing and digital fabrication	Supply chain: light gauge metal stud panels
LC Theme: Visual Management – Transparency			
Han et al. 2012	Lean production: Value Stream Mapping (VSM)	Automated post-simulation visualization	Modular building production line

LC Theme: Value – Customer Satisfaction (Quality, Cost and Time)			
Benros and Duarte 2009	Customer satisfaction and mass customization	Automated production	Mass customized housing, prefab building system
Said et al. 2017	Flexibility and customer value: mass customization and platform design	Algorithm: platform design optimization	Mass customization: exterior panelized walls, module design for prefabrication,
Jensen et al. 2012	Customization: flow of information - customer/engineer/ production	Design automation: CAD and manufacturing CAD tools	Parameterization of building components and customization
LC Theme: Miscellaneous			
Pasquire et al. 2006	Lean construction principles	Digital construction	Digital Prefabrication
Xu et al. 2018	Lean construction: service-sharing platform	Integrated cloud-based IoT platform	Prefabricated construction: production, logistics and on-site assembly

A summary of the most frequent themes related to lean construction, automation and modularization in construction found by the thematic analysis is presented as follows:

Lean Construction:

- Lean Management – 11 papers. Related topics: planning, control, scheduling, monitoring, predictability, etc. Related terms: production, supply chain, logistics, multi-skilled resources, time, cost, process integration, resources, etc.)

Automation in Construction:

- Optimization Algorithm – 11 papers. Related topics: programming algorithm, genetic algorithm, generative algorithm, clustering algorithm, etc. Related terms: programming, modelling, constraint programming, etc.

Modularization in Construction:

- Prefabrication – 9 papers. Related topics: prefabricated construction, prefabricated building design, digital prefabrication, precast components, etc. Related terms: manufacturing, logistics, assembly, parametric design, etc.

Following, we discuss how the lean construction theme – Lean Management – connects to automation and modularization themes in the AEC industry domain.

INTERACTIONS OF LEAN MANAGEMENT WITH AUTOMATION AND MODULARIZATION IN CONSTRUCTION THEMES

Lean Construction Theme: Lean Management

Lean Management encompasses planning (Lean Work Structuring – LWS) and control (Last Planner System – LPS). Considering the papers analysed and the lean construction concepts (Koskela 2000; Koskela et al. 2002), LWS and LPS purposes are: (1) design and plan the whole construction process – manufacturing, transport and assembly; (2) identify repetitive processes; (3) implement standard process; (3) stablish collaborative schedules (pull scheduling); (4) define work plans; (5) eliminate workflow variability; (6) monitor productivity evolution; (7) actively control the workflow; (8) improve performance – increase value.

According to previous research these goals are built on solid collaboration among the project stakeholders and constant monitoring and control, which fosters a sense of teamwork and transparency (Koskela 2000; Koskela et al. 2002).

Automation and Modularization in Construction Themes

The papers grouped under the lean management theme were clustered in four themes related to automation in construction: (1) algorithm; (2) BIM; (3) automated monitoring and tracking systems; and (4) virtual design and construction (VDC).

As for the modularization in construction themes, we have: (1) off-site construction facilities; (2) prefabrication; and (3) engineered-to-order (ETO) components.

Two papers discussed how algorithms can automate production processes, optimizing planning, control and scheduling in off-site construction facilities. The solution implemented in a prefabricated homes factory is based on an optimization algorithm which enables real-time scheduling and performance monitoring using the production data collected by radio frequency identification (RFID), whose noisy is automatically removed by a RANSAC model before being used in a simulation model and then, integrated with the optimization algorithm (Altaf et al. 2018). The other paper uses an optimization modelling algorithm to define the optimal product sequencing considering resource sharing and job sequencing for a concrete panels factory (Arashpour et al. 2016). Algorithm enhancing lean construction was also explored by Kong et al. (2017), who presents a dynamic algorithm that optimize scheduling for manufacturing, transportation and assembly of precast construction.

Prefabrication theme has many synergies with lean construction and BIM. BIM allows for automating many processes in the AEC industry, such as: drawing review, design coordination, scheduling, cost control, work monitoring, etc. In addition, BIM is paramount for automating construction processes by using robots and CNC process. The two papers addressing prefabrication and lean management interactions use BIM strategies to implement lean principles in the construction processes. BIM is used to automate fabrication processes, enhance design and construction integration and enable look ahead planning in projects using precast components for façades (Gerber et al. 2010). The internet of things (IoT) and BIM are presented as enablers of prefabrication process and lean management by automatically monitoring the manufacturing, logistics and on-site assembly processes (Zhong et al. 2017).

BIM and engineered-to-order (ETO) components interactions are discussed in five papers. 4D BIM modelling is used for planning and control logistics operations in ETO prefabricated building components (Bataglin et al. 2017; Bortolini et al. 2015). Integrated production control (design, manufacturing and assembly) in ETO prefabricated concrete building systems is automatically enabled by 4D BIM simulations (Peñaloza et al. 2016).

The use of lean principles in the design-production interface of ETO components is presented as a means of leveraging BIM, which is used as support to management practices (Tillmann et al. 2015). Engineered-to-order (ETO) components synergies with lean management are enhanced by using 3D modelling and real-time monitoring (Sacks et al. 2003).

An automated schedule monitoring system enhances control and monitoring of precast building construction progress by integrating Geographic Information System (GIS) with a database management system (Cheng and Chen 2002). An autonomous production tracking mechanism for production management enables real-time scheduling updates (Arashpour et al. 2015a).

Finally, virtual design and construction (VDC) methods and reality capture technology are presented as a means to enhance design coordination, increase the predictability and provide feedback for site conditions in prefabricated wall panel design process (Murphy et al. 2018).

CONCLUSIONS

This study investigated the relevance of the combined topics lean, automation and modularization (LAM) in construction for research and practice. The authors performed a systematic literature review on papers from two sources, AIC journal and IGLC website, between 2000 and 2018. Results revealed a low number of papers (n=31) approaching all LAM topics combined. In addition, published work connecting the three topics under analysis were found to be mainly focused on the following themes: (1) Lean construction – lean production management; (2) Automation in construction – optimization Algorithm; (3) Modularization in construction – prefabrication. The results reveal the existence of great research potential exploring the interactions of the set lean practices, automation and modularization in the AEC industry, as a way to enhance the industry performance and engage it in a process of continuous improvement.

The limitations of this study are related to the exploratory nature of this research and related to: (1) only using published papers from two sources; (2) findings were limited to the keywords used in the process of paper selection; and (3) the thematic analysis was carried out by only one researcher. An expanded research, considering published work from a larger number of academic sources, different keywords used to select the papers and two researchers working the thematic analysis is under way and may reveal a slightly different picture or confirm what was found in this study.

Recommendations for future research on the interactions of lean, automation and modularization in the AEC industry would include assess topics that are gaining more relevance in today's construction scenario – such as robotics (automation), integrated project delivery (lean), and parameterization of modules (modularization) – and the results of possible combinations of these topics for the AEC industry improvement.

REFERENCES

Altaf, M. S., Bouferguene, A., Liu, H., Al-Hussein, M., and Yu, H. (2018). “Integrated production planning and control system for a panelized home prefabrication facility using simulation and RFID." *Automation in Construction*, Civil and Environmental Engineering, University of Alberta, Edmonton, Canada, 85, 369–383.

Arashpour, M., Kamat, V., Bai, Y., Wakefield, R., and Abbasi, B. (2018). "Optimization modeling of multi-skilled resources in prefabrication: Theorizing cost analysis of process integration in off-site construction." *Automation in Construction*, Elsevier B.V., 95, 1–9.

Arashpour, M., Wakefield, R., Abbasi, B., Lee, E. W. M., and Minas, J. (2016). "Off-site construction optimization: Sequencing multiple job classes with time constraints." *Automation in Construction*, Elsevier B.V., 71, 262–270.

Arashpour, M., Wakefield, R., Blismas, N., and Maqsood, T. (2015a). "Autonomous production tracking for augmenting output in off-site construction." *Automation in Construction*, 53, 13–21.

Arashpour, M., Wakefield, R., Blismas, N., and Minas, J. (2015b). "Optimization of process integration and multi-skilled resource utilization in off-site construction." *Automation in Construction*, Elsevier B.V., 50, 72–80.

Ballard, G., and Howell, G. A. (2003). "Competing Construction Management Paradigms." *Contruction Research Congress, Winds of Change: Integration and Innovation in Construction, Proceedings of the Congress*, 1(October), 321–328.

Banihashemi, S., Tabadkani, A., and Hosseini, M. R. (2018). "Integration of parametric design into modular coordination: A construction waste reduction workflow." *Automation in Construction*, 88, 1–12.

Bataglin, F. S., Viana, D. D., Formoso, C. T., and Bulhões, I. R. (2017). "Application of Bim for Supporting Decisionmaking Related to Logistics in Prefabricated Building Systems." *25th Annual Conference of the International Group for Lean Construction*, Heraklion, Greece, 71–78.

Benros, D., and Duarte, J. P. (2009). "An integrated system for providing mass customized housing." *Automation in Construction*, Elsevier B.V., 18, 310–320.

Bortolini, R., Shigaki, J. S.-I., and Formoso, C. T. (2015). "Site Logistics Planning and Control Using 4D Modeling: A Study in a Lean Car Factory Building Site." *23rd Annual Conference of the International Group for Lean Construction*, O. Seppänen, V. A. González, and P. Arroyo, eds., Perth, Australia, 361–370.

Braun, V., and Clarke, V. (2009). "Thematic analysis." *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological.*, 2(August), 57–71.

Chen, C., Tran Huy, D., Tiong, L. K., Chen, I. M., and Cai, Y. (2018). "Optimal facility layout planning for AGV-based modular prefabricated manufacturing system." *Automation in Construction*, Elsevier B.V., 1–12.

Cheng, M., and Chen, J. (2002). "Integrating barcode and GIS for monitoring construction progress." *Automation in Construction*, Elsevier B.V., 11, 23–33.

Cheung, S. O., Tong, T. K. L., and Tam, C. M. (2002). "Site pre-cast yard layout arrangement through genetic algorithms." *Automation in Construction*, Elsevier B.V., 11, 35–46.

Chin, S., Yoon, S. W., Jung, S. 0., Kim, Y. S., Kim, C. D., Choi, Y. K., Chun, J. Y., and Lim, H. C. (2004). "An Analysis of the Life-Cycle Curtain Wall Process Through Supply Chain Management." *12th Annual Conference of the International Group for Lean Construction*, S. Bertelsen and C. T. Formoso, eds., Helsingør, Denmark.

Gerber, D. J., Becerik-Gerber, B., and Kunz, A. (2010). "Building Information Modeling and Lean Construction: Technology , Methodology and Advances From Practice." *Proceedings IGLC 18, Technion, Haifa, Israel*, 683–693.

Han, S. H., Al-Hussein, M., Al-Jibouri, S., and Yu, H. (2012). "Automated post-simulation visualization of modular building production assembly line." *Automation in Construction*, Elsevier B.V., 21(1), 229–236.

Isaac, S., Bock, T., and Stoliar, Y. (2016). "A methodology for the optimal modularization of building design." *Automation in Construction*, Elsevier B.V., 65, 116–124.

Jensen, P., Olofsson, T., and Johnsson, H. (2012). "Configuration through the parameterization of building components." *Automation in Construction*, 23, 1–8.

Kong, L., Li, H., Luo, H., Lieyun, D., Luo, X., and Skitmore, M. (2017). "Optimal single-machine batch scheduling for the manufacture, transportation and JIT assembly of precast construction with changeover costs within due dates." *Automation in Construction*, Elsevier B.V., 81, 34–43.

Koskela, L. (2000). "An exploration towards a production theory and its application to construction." *VTT Publications*, (408).

Koskela, L., Ballard, G., Howell, G., and Tommelein, I. (2002). "The foundations of lean construction." *Design and Construction: Building in Value*, (December 2015), 211–226.

Liu, J., and Lu, M. (2017). "Optimization on Supply-Constrained Module Assembly Process." *25th Annual Conference of the International Group for Lean Construction*, Heraklion, Greece, 813–820.

McGraw Hill Construction. (2013). *Lean construction - Leveraging collaboration and advanced practices to increase project efficiency*. *SmartMarketReport*, Bedford.

McKinsey Global Institute. (2017). *Reinventing construction: A route to higher productivity*. *McKinsey & Company*.

Murphy, Z., Saripally, D., Dhakla, S., Trujillo, R., Luttmann, E., and Sreekumar, A. (2018).

"Leveraging Advanced VDC Methods and Reality Capture to Increase the Predictability for Prefabrication." *26th Annual Conference of the International Group for Lean Construction*, Chennai, India, 101–111.

Nasereddin, M., Mullens, M. A., and Cope, D. (2007). "Automated simulator development: A strategy for modeling modular housing production." *Automation in Construction*, Elsevier B.V., 16, 212–223.

Pasquire, C., Soar, R., and Gibb, A. (2006). "Beyond Pre-Fabrication - the Potential of Next Generation Technologies to Make a Step Change in Construction Manufacturing." *14th Annual Conference of the International Group for Lean Construction*, Santiago, Chile, 243–254.

Peñaloza, G. A., Viana, D. D., Bataglin, F. S., Formoso, C. T., and Bulhões, I. R. (2016). "Guidelines for Integrated Production Control in Engineer-to-Order Prefabricated Concrete Building Systems: Preliminary Results." *24th Annual Conference of the International Group for Lean Construction*, Boston, USA.

Sacks, R., Akinci, B., and Ergen, E. (2003). "3D Modeling and Real-Time Monitoring in Support of Lean Production of Engineered-to-Order Precast Concrete Buildings." *11th Annual Conference of the International Group for Lean Construction*, Virginia, USA.

Said, H. M., Chalasani, T., and Logan, S. (2017). "Exterior prefabricated panelized walls platform optimization." *Automation in Construction*, Elsevier B.V., 76, 1–13.

Sharafi, P., Samali, B., Ronagh, H., and Ghodrat, M. (2017). "Automated spatial design of multi-story modular buildings using a unified matrix method." *Automation in Construction*, 82, 31–42.

Tillmann, P., Viana, D., Sargent, Z., Tommelein, I., and Formoso, C. (2015). "BIM and Lean in the Design-Production Interface of ETO Components in Complex Projects." *23rd Annual Conference of the International Group for Lean Construction*, O. Seppänen, V. A. González, and P. Arroyo, eds., Perth, Australia, 331–340.

Tiwari, S., Pawar, G., Luttmann, E., Trujillo, R., and Sreekumar, A. (2018). "Visual Planning for Supply Chain Management of Prefabricated Components in Construction." *26th Annual Conference of the International Group for Lean Construction*, Chennai, India, 1150–1159.

World Economic Forum. (2016). *Shaping the Future of Construction - A Breakthrough in Mindset and Technology. World Economic Forum (WEF)*, Geneva.

Xu, G., Li, M., Chen, C. H., and Wei, Y. (2018). "Cloud asset-enabled integrated IoT platform for lean prefabricated construction." *Automation in Construction*, Elsevier B.V., 93(September 2017), 123–134.

Yuan, Z., Sun, C., and Wang, Y. (2018). "Design for Manufacture and Assembly-oriented parametric design of prefabricated buildings.” *Automation in Construction*, Elsevier B.V., 88, 13–22.

Zhong, R. Y., Peng, Y., Xue, F., Fang, J., Zou, W., Luo, H., Thomas Ng, S., Lu, W., Shen, G. Q. P., and Huang, G. Q. (2017). “Prefabricated construction enabled by the Internet-of-Things.” *Automation in Construction*, Elsevier B.V., 76, 59–70

Ng, Ming Shan and Hall, Daniel M. (2019). "Toward Lean Management for Digital fabrication: A Review of the Shared Practices of Lean, DfMA and dfab." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.)*, Dublin, Ireland, pp. 725–736. DOI: https://doi.org/10.24928/2019/0204. Available at: <www.iglc.net>.

TOWARD LEAN MANAGEMENT FOR DIGITAL FABRICATION: A REVIEW OF THE SHARED PRACTICES OF LEAN, DFMA AND DFAB

Ming Shan Ng[1] and Daniel Mark Hall[2]

ABSTRACT

Digital Fabrication (dfab) is emerging as a new technical and computational approach for the architecture and construction industry. However, managing dfab requires processes to account for integrated design and construction processes. Lean construction management and design for manufacture and assembly (DfMA) offer two potential strategies for managing dfab. Although dfab, DfMA and lean have each been of wide interest among scholars, little research has examined their potential synergies. This paper conducts a literature review of all papers based on the authors' knowledge that discuss at least two of the three topics, and identifies common practices shared between the lean, DfMA and dfab. Two practices – design to target value and concurrent engineering – are found to be shared by all the three topics. Further, seven practices shared by two of the three topics: pull-planning, design-to-cost, standardisation, Jidoka, Just-in-Time, design-to-construct and knowledge sharing. This paper demonstrates the opportunities for synergies between lean, DfMA and dfab, and concludes with suggestions for future research to further investigate implementation of lean management for dfab in construction.

KEYWORDS

Lean Construction, Design Management, DfMA, Digital Fabrication, Literature Review

INTRODUCTION

There is slow technological development, productivity improvement and adoption of innovation in the construction industry (Hall et al. 2018; World Economic Forum 2016). Despite the great potential to boost productivity through advanced construction technologies such as digital fabrication (dfab), this requires a commitment of change in the industry. This includes technology, operations, and strategies to enhance integration and cooperation across the value chain. There is currently acceleration in digitalisation and computational development in research and in practice. Dfab, however, is still in an early

1 PhD student, Chair of Innovative and Industrial Construction, Dept. Civil, Env. and Geo. Eng., ETH Zurich, Stefano-Franscini-Platz 5, 8093 Zurich, Switzerland, +41 44 633 44 25, mng@ethz.ch.

2 Assistant Professor, Chair of Innovative and Industrial Construction, +41 44 633 34 90, dhall@ethz.ch.

stage of research. It lacks developed processes that can enable industry adoption at full-scale for projects.

Digital fabrication refers to data-driven production, which literally and technically turns data into things and things into data (Gershenfeld 2012). It includes the fields of robotics, drone-based technologies, rapid prototyping and additive manufacturing. Dfab is developed from Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) technologies, which started in the 1980s. Together with digital management system, dfab allows great freedom of design (Bock 2008). Dfab and construction automation in construction process enable digitalisation of design, delivery and project management on-site and off-site, and save time and effort by eliminating coordination steps of handing over shop drawings to the craftsmen (Fischer 2006; O'Connor et al. 2014; Bonwetsch 2012). Parametric modelling tools such as CATIA streamlines data exchange to manufacturing tools such as Computer Numerical Control (CNC), enabling the industry to accurately control production from digital models with digital-based interfaces between planning, engineering and production (Egan 1998; Buswell et al. 2007). There is a potential of dfab to improve productivity and return on investment by reducing wastes in time, materials and human resources in construction, in particular for bespoke or highly-customised building components (Bock 2004, 2008; de Soto et al. 2018a). Nevertheless, the industry is not yet familiar with full-scale implementation of dfab; dfab requires new approaches to project delivery and collaborative work systems to cope with the integrated design and construction processes (de Soto et al. 2018b).

Lean management has been introduced to the construction industry since 1990s to solve the problem of fragmentation and improve integration in design and construction processes. Adopted from the Toyota Production System, lean is a whole system approach which aims at value-adding, waste reduction, quality improvement, stakeholder's early involvement and supply-chain integration to optimise the entire process (Koskela et al. 2002; Womack & Jones 1996; Ballard 2008). Studies show that poor control in early design stages reduce the overall performance and efficiencies (Hansen and Vanegas, 2003). This can be due to poor communication, missing information, scope changes, inadequate techincal knowledge of designers, or lack of early contractor's involvement (ECI) in the design development and procurement. Poor design management causes a snowball effect and incurs rework, delay, budget over-runs and reduced values in later stages of a project (Reifi and Emmitt 2013). In order to improve delivery of project values and performances, Ballard and Koskela (1998) proposed the agenda for lean design management research, of which approaches include Concurrent Engineering (CE), Set-based Design and Choosing by Advantage. These provide systematic requirements in early design stage to help stakeholders in communicaion and decision-making.

On the basis of lean, Macomber et al. (2012) and Ballard (2012) introduced the concept of Target Value Design (TVD). TVD is an integrative project management tool to keep the design and costs aligned with the client's target from early design phase (Kim and Lee 2010; Ballard 2011, Jung et al. 2012; Miron et al. 2015). Many research and case studies have demonstrated the benefits and effectiveness of lean implementation in conventional and integrated project delivery procurements, such as design-and-build and Integrated Project Delivery respectively.

Design for manufacture and assembly (DfMA), which has also been introduced to the construction industry, helps to solve the problem of fragmentation in the industry and break the wall between design and construction from early design stage. The foundamental goal of DfMA is ease of manufacture and ease of assembly (Boothroyd et al. 2002). It is a design approach to boost productivity, quality assurance and cost/time/waste reduction at both management and operational levels (Laing O'Rourke 2013; Montali et al. 2018; Belay 2009; O'Brien et al. 2000; Fox et al. 2001; Bogue 2012). This requires communication, collaboration and concurrent knowledge transfer among different professions (Pasquire and Connolly 2003; Ulrich and Eppinger 2008; Bogus et al. 2006; Gerth et al. 2013). DfMA has also been proposed for automation, namely Design for Automation (DfA), to identify innovations in design with new technologies and digital system. DfA relies on not only accuracy and constrains of the machinery, but also coordination between design and production teams to assure design meets the needs and requirements of automation (Bridgewater 1993; Bogue 2012; Goulding et al. 2014).

METHODOLOGY

Although lean management, DfMA and dfab represent three different areas of research and implementation in construction, there is some evidence that they share similar principles and practices in their objectives to improve productivity and solve problems of fragmentation in the industry. The concept of practices refers to the "shared routines of behaviours" leading to the process of practical understanding and social structure development (Hall et al. 2018; Whittington 2006; Smets and Jarzabkowski 2013). However, the authors find little research that formally identifies and describes these shared principles and practices in specific detail.

This paper conducts a literature review to identify the common practices of lean, DfMA and dfab. To do so, the authors perform seach queries using Scopus and Google scholar databases. Search terms include the key words used in lean, DfMA and dfab scholarship (see Table 1). Additional selected papers are included based on the authors' knowledge. Journal articles and conference proceedings are included; books are excluded. It is because this paper focuses particularly on dfab technologies instead of the broader topics of digitalisation and computational design, papers about Building Information Modelling (BIM) and digital modelling are also excluded. In total, the authors identify ninteen papers that contain at least two of the keywords found in Table 1. These ninteen papers are categorised into two tiers; Tier 1 includes literatures with keywords of all three topics and tier 2 includes those of two of the three topics.

Table 1: Keywords used in the literature search

LEAN CONSTRUCTION	DfMA	DIGITAL FABRICATION
Pull-Planning	Customisation	Automation
Just-in-Time	Modularisation	Robotics
Concurrent Engineering	Design for Automation	

FINDINGS

Given the principles of the three topics, the authors identify several practices that are used within each of the three approches (see Figure 2).

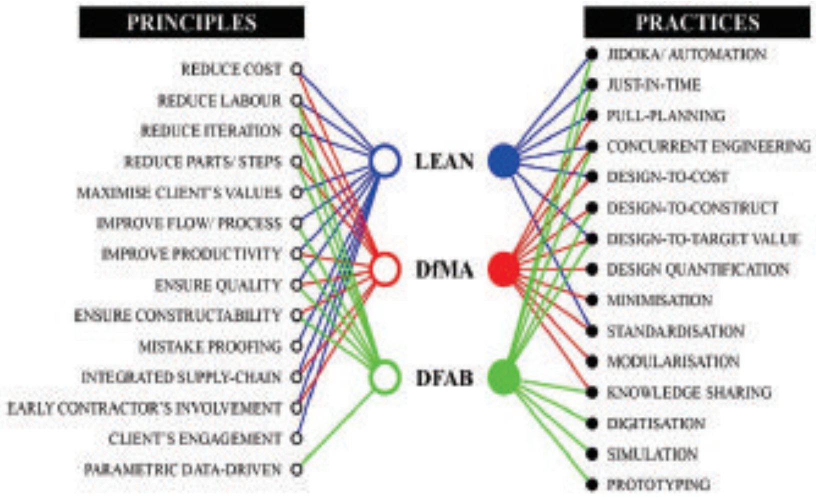


Figure 2: Principles and practices of lean, DfMA and dfab

PRACTICES OF LEAN CONSTRUCTION

Based on literatures, lean practices include Just-in-Time (JIT), Jidoka, mistake proofing, standardisation and pull-planning to improve quality and productivity and reduce waste in cost, labour and iteration (Gerth et al. 2013; Fischer 2006); concurrent engineering (CE) (Koskela et al 2002; Koskela and Huovila 1997), client's engagement and early contractor's involvement (ECI) to manage design to meet cost and target values (Kim and Lee 2010; Miron et al. 2015). Integrated supply-chain also ensures stakeholder's collaboration to improve process from design to construction (Jung et al. 2012).

PRACTICES OF DESIGN FOR MANUFACTURE AND ASSEMBLY (DFMA)

Through minimisation, standardisation and modularisation, DfMA quantifies design, reduces number of parts, steps of assembly and complexity, to reduce waste in materials, cost, time and labour, standardise components and reduce design variabilities (Boothroyd et al. 2002; O'Brien et al. 2000; Gerth et al. 2013; Bogue 2012; Fox et al. 2001; Gao et al. 2018). DfMA defines guidelines for constructability, knowledge sharing in manufacture (Ulrich and Eppinger 2008). Pull-planning can be applied for DfMA, upstream activities such as design decisions are made and pulled by downstream manufacturing process

(Pasquire and Connolly 2003). CE helps to develop the product together for design-to-cost and design-to-target value in early design stage (Belay 2009; Bogus et al. 2006; O'Connor et al. 1987; Gerth et al. 2013; Goulding et al. 2014).

PRACTICES OF DIGITAL FABRICATION (DFAB)

Dfab allows automated progress and material tracking, JIT production and quality control during fabrication and on-site assembly (Nahangi and Haas 2016). Parametric design and

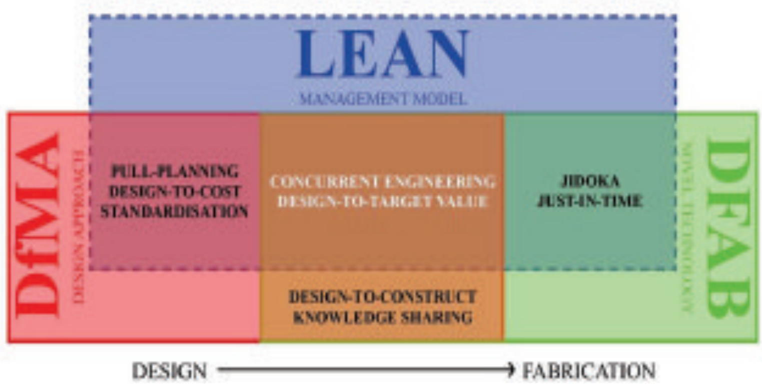


Figure 3: The shared practices of lean, DfMA and dfab.

manufacturing enables simultaneous design and fabrication data transfer, pre-construction simulation and prototyping, knowledge sharing and CE through object-oriented digital technologies to reduce production steps and ensure constructability and design to target-value (Martinez et al. 2008).

THE SHARED PRACTICES OF LEAN, DFMA AND DFAB

Amongst all, the authors identify two shared practices of lean, DfMA and dfab. They are design-to-target value and concurrent engineering (see Figure 3). The shared practices of lean and DfMA are pull-planning, design-to-cost and standardisation; those of DfMA and dfab are knowledge sharing and design-to-construct; and those of lean and dfab are Jidoka and Just-in-Time.

Tier 1 (Lean, DfMA and DFAB)

Three literatures are categorised in Tier 1. Fischer (2006) discusses the integration of lean and 4D visualisation for self-aware automation for design for construction, i.e. DfMA. The lean concepts of concurrent and pull-driven planning lead to less rework and less waste of resources. Self-aware construction supports collaborative development of DfMA, construction automation and lean management; this forms the basis for digital fabrication and robotics. The knowledge formalised further helps to emerge computational construction activities.

Martinez et al. (2008) discuss the topics of lean, DfMA and robotic construction in the housing industry. They first analyse the factors and advantages of implementing automation in prefabrication with lean and DfMA principles. They propose a mobile factory using robots for on-site pre-fabrication, which enables lean concepts of JIT and flexible adaptation, and DfMA principles to integrate dwelling construction modules and the associated sub-structure requirements in early design stage.

O'Connor et al. (2014) discuss implementation of lean, DfMA and dfab in a relatively subtle way. They present the concept of PPMOF (prefabrication, preassembly, modularization and off-site fabrication) with key technologies of robotics, sensor-based control, schedule automation, Virtual Reality (VR) simulation and BIM. They list out 21 critical success factors (CSFs) for PPMOF, which include lean concepts, such as CE, ECI, supply chain integration and early cost-estimation for project's drivers alignment, and DfMA techniques, such as early constructability review, design for fabricator capability, manufacture process knowledge integration and reduction of modular interface. The CSFs listed provide a comprehensive reference for the shared practices of lean, DfMA and dfab discussed in this paper. The three selected Tier 1 literatures, however, hardly investigate in details the process and result of implementing lean, DfMA and dfab in construction.

Tier 2 (Lean and DFAB)

There are three literatures about lean and dfab in Tier 2. Nahangi and Haas (2016) present an algorithm to quantitatively track discrepancies between design and as-built assemblies. This automated detection system helps to reveal errors for corrective actions. This aligns with the lean concept of mistake proofing, pull-signalling, Genchi Genbutsu and Jidoka, although the term "lean" is not clearly mentioned in the context. Mocerino (2018) discusses how additive manufacturing, in line with lean construction and robotics, could improve productivity and efficiency, and reduce errors and costs through BIM and lean construction. Based on the case study of the DFAB HOUSE in Switzerland adopting the Last Planner System and lean principles, de Soto et al. (2018b) explore the collaborative work culture with dfab and the new roles created for dfab in construction.

Tier 2 (Lean and DfMA)

For Tier 2, seven articles discuss lean and DfMA. Gann (1996) investigates implementation of lean in industrialised housing from manufacturing to the final point of assembly in Japan. "Dimensional coordination" with DfMA principles, based on the size of factory-made components, defines grids and modular of the building design. Pasquire and Connolly (2003) propose three steps of DfMA with pull system from design to construction stage, and demonstrate that DfMA with a pull system help to address customer's values, solve buildability issues, reduce lead time and achieve a better integration of design and construction. Based on client's values and manufacturability, Bogus et al. (2006), propose "overlapping design strategy", which includes overdesign, no iteration, optimisation, set-based design and decomposition. This strategy requires overlapping of upstream and downstream activities and helps to reduce costs and risks. Gerth et al. (2013) state that lean and DfMA share the same key principles of reducing waste and cost and collaborative work during the development process. They propose Design for Construction (DfC) based on DfMA. DfC complements lean development concepts to transform individual knowledge into organisational knowledge and increases product and production performances. They also use “5-Why” and Ishikawa diagrams to identify the evaluation criteria for the design for constructability for the external wall.

Goulding et al. (2014) study a new approach and business model of off-site production in three major areas of off-site construction, namely process, technology and people, and their impacts on design, manufacturing and construction. They suggest a close collaboration in design and construction; all stakeholders should be involved in the early design phase. They highlight the requirement of integrating CE and DfMA in the overall design process by means of collaborative tools such as BIM. O'Connor et al. (2014) present seven concepts to improve constructability in design and procurement stages. These concepts include construction-driven JIT schedule, standardisation and modularisation, co-review of specification among stakeholders and downstream participation in upstream decision-making. Gao et al. (2018) explore the factors influencing adoption of DfMA in Singapore, and find that DfMA could be viewed as a process, an evaluation method and a technology. The lean concepts mentioned, such as JIT, reduction of speed and improvement of site management and concurrent engineering (CE), account for the three most influential factors of DfMA adoption.

Tier 2 (DfMA and DFAB)

There are six articles about DfMA and dfab in Tier 2. Based on DfMA, Bridgewater (1993) proposes Design for Automation (DfA) for factory-based production and on-site automation, to minimise the number of components for dfab such as robotics. In addition, he proposes guidelines for redesign of building systems for DfA and a new form of construction contracts and legal requirements for DfA. Bonwetsch (2012) states that CNC allows direct and automated transfer of design information to fabrication machines. Robotics emphasises the integration of design and construction, and helps to reduce cost and time of construction and add value in design quality. He highlights with examples the process of DfMA for robotics and integration of codes and design in early design phase. The parameters derived by dfab could influence the design outcomes and the design process; all physical constraints of fabrication had to be considered in the design process. Martinez et al. (2013) illustrate the design of the robotised Field Factory System based on DfMA principles, and its layout for production lines. For instance, the factory layout coped with the size of an ABB robot and its moving range, the Service Core has been analysed to improve the overall assembly time and quality.

Montali et al. (2018) explored the Knowledge-Based Engineering (KBE) approach using digital tools to support design through automation of reusable knowledge on façade design with DfMA principles. They found the currently available 2D and 3D digital tools are incapable to address the current design-manufacturability gap in the façade construction sector. The DfMA-based KBE for design automation is proposed to guide design from early design stage to increase quality, reduce delivery time and costs, reduce rework and support product development in construction. Arashpour et al. (2018) study the principles of DfMA using CNC milling and additive manufacturing, where parametric modelling supports collaborative works facilitated implementation of DfMA. De Soto et al. (2018a) investigate productivity of on-site robotic fabrication technology and quantitative analysis of cost and time during construction. They also find that dfab is able to produce complex ornament structures without additional cost, because dfab could build a component in a more integrated way with early input in the design phase, this aligns with DfMA principles.

DISCUSSION

The synergy of lean, DfMA and dfab practices is a starting point to begin to study how lean as a management model, DfMA as a design approach and dfab as a novel technology can be connected together in research to boost construction innovation. Foundational to the three topics of lean, DfMA and dfab to construction is the view that construction can be managed as a production system as opposed to past views of construction management as a form of craft administration (Stinchcombe 1959). The concept of prefabrication defines construction as a process of on-site or off-site manufacture and on-site assembly, and diffuses the distinction between construction and production (Gibb and Isack 2003). This requires CE and ECI for collective resources of manufacture and assembly knowledge during design stage to drive systemic innovation (Hall et al., 2018).

Furthermore, the practices identified reinforce the principle that ECI and client’s engagement are the key enablers for implementing lean, DfMA and dfab. Contractors can provide commercially feasible design guidance since early stage to ease the following stages of manufacture and assembly (Vaz et al. 2008). The need of ECI in design is more significant for industrial construction, in particular with dfab. Pasquire and Connolly (2003) urge the need for client's engagement since design stage. During the design phase, clients need to express their concerns, make value assessments and decisions, freeze design early to provide reasonable lead time and take charge in supply-chain management for prefabrication (Gibb and Isack's 2003). Communication between clients and the supply-chain helps to understand the design intents, constructability and project requirements to meet target values (Stump and Badurdeen 2012; Goulding et al. 2014). It is important for the clients to early select suitable contractors with certain skillsets such as dfab, not merely based on price but the ability to develop knowledge, experience for DfMA and innovations (Vaz et al. 2008). Adopting dfab in construction is usually a top-down decision, research on clients' engagement for dfab is however limited.

Design management and construction management are important as they incur waste and thus the overall project costs (Gerth et al. 2013). DfMA, CE and downstream's participation in upstream's decision-making help to optimise project and life-cycle costs (Omigbodun 2011). The on-going novel technology development in the construction industry such as dfab requires a re-consideration of the construction process, a new business thinking and an organisation reform of workforce to maximise project values and foster innovations (Bock 2008; Goulding et al. 2014; de Soto et al. 2018a; Mocerino 2018). While the industry is adopting integrated design process, such as IPD, and advanced technologies, such as robotic fabricators, existing management tools such as lean and DfMA, which have been introduced and implemented for decades, have to catch up and be tested in field. The authors believe lean principles and management model could work hand in hand with advanced design management strategies and business models such as DfMA, ECI and IPD, to foster advanced technologies such as ICT, robotics, additive manufacturing and Internet of Things in the industry.

POTENTIAL FUTURE RESEARCH

Dfab is still in its early stage of development, and research on design management tools to control design and production for dfab is limited. From the literature review, the authors note that research studies about lean for dfab and co-occurrence of lean, DfMA and dfab are limited, in comparison to emerging research about advancing digital technologies, such as BIM, cloud-based robotic fabrication and Industry 4.0. Based on the study here, the authors propose the following potential directions for future research:

- Lean design management for dfab. Work is needed to understand how implementation of lean facilitates dfab design development in terms of construction time, costs, quality and systemic innovation adoption. This research would utilise the shared practices of design-to-target value and CE, and also require those of DfMA such as design-to-construct and pull-planning in the design process for dfab.
- DfMA for bespoke building systems. This requires modularisation of non-standard components, which is the reverse concept of mass customisation. The uses of dfab and lean principles become more effective and significant. This research would utilise shared practices of design-to-target value, design-to-cost, design-to-construct and CE.
- Reducing coordination costs of dfab. Scholars such as Bock (2004) suggests that construction robots could inherit high coordination costs, data processing requirements and energy consumption. Study on lean and DfMA to set up design guidelines to address the issues is needed. This would utilise shared practices of CE and knowledge sharing.
- Project organisation models for dfab. There is a need to understand how to adopt lean management, CE, client engagement and ECI for projects that use dfab. This could create new insights in business models and procurement methods. This would utilise shared practices of CE, pull-planning and knowledge sharing.

CONCLUSION

This paper reviews literatures which discuss lean, DfMA and dfab synchronously and identifies the common practices shared to demonstrate the potential synergies of them in the construction industry. Two shared practices are identified to be shared by lean, DfMA and dfab; they are: concurrent engineering and design-to-target value. Seven practices shared by two of the three topics are identified; they are: pull-planning, design-to-cost, standardisation, Jidoka, Just-in-Time, design-to-construct and knowledge sharing. Furthermore, this paper identifies lean design management for dfab, DfMA for bespoke building systems, coordination cost reduction for dfab, and project organisation models for dfab as future research areas.

REFERENCES

TIER 1 LITERATURE

Fischer, M. (2006). "Formalizing Construction Knowledge for Concurrent Performance-Based Design." *Intelligent Computing in Engineering and Architecture*, EG-ICE 2006, Smith, I.F.C. (ed.), 186-205. Lecture Notes in Computer Science, vol 4200. Springer, Berlin.

Martinez, S., Jardon, A., Gimenez, A., Balaguer, C., Navarro, J.M. and Barcena, C. (2008). "Robotized lean assembly in the Building Industry.", In: *Proc. of the 25th Int'l. Symposium on Automation and Robotics in Construction*, Vilnius Lithuania, 195-201.

O'Connor, J.T., O'Brien, W.J., Choi, J.O. (2014). "Critical Success Factors and Enablers for Optimum and Maximum Industrial Modularization." *Journal of Construction Engineering and Management*, 140(6).

TIER 2 LITERATURE

Arashpour, M., Miletic, N., Williams, N. and Fang, Y. (2018). "Design for Manufacture and assembly in off-site construction: Advanced production of modular façade systems." In: *Proc. 35th ISARC*, Berlin, Germany, 224-229.

Bogus, S., Molenaar, K.R. and Diekmann, J.E. (2006). "Strategies for overlapping dependent design activities." *Construction Management and Economics*, 24(8), 829-837.

Bonwetsch, T. (2012). "Robotic Assembly Processes as a Driver in Architectural Design." *Nexus Network Journal*, 14(3), 483-494.

Bridgewater, C. (1993). "Principles of design for automation applied to construction tasks." *Automation in Construction*, 2(1), 57-64.

O'Connor, J.T., Rusch, S.E. and Schulz, M.J. (1987). "Constructability concepts for engineering and procurement." *Journal of Construction and Engineering Management*, 113(2), 235-248.

Gann, D.M. (1996). "Construction as a manufacturing process? Similarities and Differences between industrialized housing and car production in Japan." *Construction Management & Economics*, 14, 437–450.

Gao, S., Low, S.P. and Nair, K. (2018). "Design for Manufacturing and Assembly (DfMA): a preliminary study of factors influencing its adoption in Singapore." *Architectural Engineering and Design Management*, 14(6), 440-456.

Gerth, R., Boqvist, A., Bjelkemyr, M. and Lindberg, B. (2013). "Design for construction: utilizing production experiences in development." *Construction Management and Economics*, 31(2), 135-150.

Goulding, J.S., Rahimian, P., Arif, M. and Sharp, M. (2014). "New offsite production and business models in construction: priorities for the future research agenda." *Architectural Engineering and Design Management*, 11(3), 163-184.

Martinez, S., Jardon, A., Victores, J.G. and Balaguer, C. (2013). "Flexible Field Factory for Construction Industry." *Assembly Automation*, 33(2), 175-183.

Mocerino, C. (2018). " Digital revolution in efficient self-organization of buildings: towards intelligent robotics." In: *Energy and Sustainability for Small Developing Economies*, Funchal, Portugal.

Montali, J., Overend, M., Pelken, P.M. and Sauchelli, M. (2018). "Knowledge-Based Engineering in the design for manufacture of prefabricated facades: current gaps and future trends." *Architectural Engineering and Design Management*, 14(1-2), 78-94.

Nahangi, M. and Haas, C. (2016). "Skeleton-based discrepancy feedback for automated realignment of industrial assemblies." *Automation in Construction*, 61, 147-161.

Pasquire, C.L. and Connolly, G.E. (2003). “Design for manufacture and assembly.” In: *Proc. 11th Ann. Conf. of the Int’l. Group for Lean Construction*, Blacksburg, U.S.A., 184-194.
de Soto, B.G., Augstí-Juan, I., Hunhevicz, J., Joss, S., Graser, K., Habert, G. and Adey, B.T. (2018a). "Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall." *Automation in Construction*, 92, 297-311.
de Soto, B.G., Augstí-Juan, I., Hunhevicz, J., Habert, G. and Adey, B.T. (2018b). "Rethinking the roles in the AEC industry to accommodate digital fabrication." In: *Proc. of the Creative Construction Conf*. 2018, Ljubljana, Slovenia, 82-89.

ADDITIONAL REFERENCE

Ballard, G. (2011). “Target Value Design: Current Benchmark.” *Lean Construction Journal*, 79-84. < www.leanconstruction.org/media/docs/lcj/2011/LCJ_11_009.pdf>.
Ballard, G. (2012). "Target Value Design." In: *Proc. Design 2012, the 12th Int'l Design Conf.*, Marjanovic, D., Storga, M. and Pavkovic, N. (ed.), Dubrovnik, Croatia, 11-20.
Ballard, G. and Koskela, L. (1998). “On the agenda of Design management research.” In: *Proc. 6th Ann. Conf. of the Int’l. Group for Lean Construction*, Guaruja, Brazil, 13-15.

Belay, A.M. (2009). "Design for Manufacturability and Concurrent Engineering for Product Development." *World Academy of Science, Engineering and Technology*, 49(1), 240-246.

Bock, T. (2004). "Construction robotics and automation: past-present-future." In: *Proc. Automation Congress*, World 15, 287-294.
Bock, T. (2008). "Construction automation and Robotics." Robotics and Automation in Construction, Balaguer, C. and Abderrahim, M. (ed.), InTech, 21-42.
Bogue, R. (2012). "Design for manufacture and assembly: background, capabilities and applications." *Assembly Automation*, 32(2), 112-118.
Boothroyd, G., Dewhurst, P. and Knight,W. (2002). Product Design for Manufacture and Assembly. 2nd ed. CRC Press Taylor & Francis, Boca Raton, U.S.
O’Brien, M., Wakefield, R. and Beliveau, Y. (2000). "Industrializing the residential construction site." Center for Housing Research, Virginia Polytechnic Insititute and State University Blacksburg, Virginia.

Buswell, R.A., Soar, R.C., GIbb, A.G.F. and Thorpe, A. (2007). "Freeform Construction: Mega-scale Rapid Manufacturing for construction." *Automation in Construction*, 16, 224-231.
Egan, J. (1998). Rethinking Construction. The Report of the Construction Task Force, London, U.K.
Fox, S., Marsh, L. and Cockerham, G. (2001). " Design for manufacture: a strategy for successful application to buildings." *Construction Management and Economics*, 19(5), 493-502.

Gershenfeld, N. (2012). "How to make almost anything: the Digital Fabrication Revolution." *Foreign A ffairs*, 91(6), 43-57.
Gibb, A. and Isack, F. (2003). "Re-engineering through pre-assembly: client expectations and drivers." *Building Research & Information*, 31(2), 146-160.
Hall, D.M., Algiers, A. and Levitt, R.E. (2018). “Identifying the Role of Supply Chain Integration Practices in the Adoption of Systemic Innovations.” *Journal of management in engineering*, 34(6).

Hansen, K.L. and Vanegas, J. (2003). "Improving design quality through briefing automation." *Building Research & Information*, 31(5), 379-386.

Jung, W., Ballard, G., Kim, Y.W., Han, S.H. (2012). "Understanding of Target Value Design for Integrated Project Delivery with the Context of Game Theory." *Construction Research Congress 2012: Construction Challenges in a Flat World*, 556-563.

Kim, Y. and Lee, H.W. (2010). "Analyzing User Costs in a Hospital: Methodological Implication of Space Syntax to Support Whole-Life Target Value Design." In: *Proc. 18th Ann. Conf. of the Int'l. Group for Lean Construction*, Haifa, Israel, 93-102.

Koskela, L., Ballard, G., Howell, G.A. and Tommelein, I.D. (2002). "The foundations of lean construction." *Design and Construction: Building in Value. Routledge*, 211-226.

Koskela, L. and Howell, G.A. (2002). "The theory of project management: explanation to novel methods." In: *Proc. 10th Ann. Conf. of the Int'l. Group for Lean Construction*, Gramado, Brazil, 6-8.

Koskela, L. and Huovila, P. (1997). "Foundations of concurrent engineering." *Concurrent Engineering in Construction* CEC'97. 1st Int'l. Conf., Anumba, C. and Evbuomwan, N. (ed.), London, U.K., 22-32.

Liang O'Rourke (2013). "The future of DfMA is the future of construction." Engineering Excellent Journal, 77,76.

Macomber, H., Howell, G. and Barberio, J. (2012). "Target Value Design: Nine Foundational Practices for Delivering Surprising Client Value". [White paper]. <www.leanproject.com/access-whitepapers>.

Miron, L.I.G., Kaushik, A. and Koskela, L. (2015). "Target Value Design: The Challenge of Value Generation." In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction,* Perth, Australia, 815-825.

Omigbodun, A. (2001). "Value Engineering and Optimal Building." *Journal of Architectural Engineering*, 7(2), 40-43.

Reifi, M.H.El. and Emmitt, S. (2013). "Perceptions of lean design management." Architectural Engineering and Design Management, 9(3), 195-208.

Smets, M. and Jarzabkowski, P. (2013). "Reconstructing institutional complexity in practice: A relational model of institutional work and complexity." *Human Relations,* 66(10), 1279-1309.

Stinchcombe, A. L. 1959. "Bureaucratic and craft administration of production: A comparative study." Adm. Sci. Q. 4 (2): 168–187.

Stump, B. and Badurdeen, F. (2012). "Integrating lean and other strategies for mass customization." *Journal of Intelligent Manufacturing*, 23(1), 109-124.

Ulrich, K.T. and Eppinger, S.D. (2008). Product design and development. McGraw-Hill, NY. U.S.

Vaz, D., Al Bizri, S., and Gray, C. (2008). "The management of the design of modern curtain wall cladding systems." In *ARCOM 24th Ann. Conf.*, 759-768.

Whittington, R. (2006). "Completing the Practice Turn in Strategy Research." *Organization Studies*, 27(5), 613-634.

Womack, James P. and Jones, Daniel T. (1996). *Lean Thinking*. Simon & Schuster, New York, U.S.

World Economic Forum (2016). "Shaping the future of construction: a breakthrough in mindset and technology." World Economic Forum, Switzerland.

Bridi, M. E., Ceolin, E. D., Granja, A. D., and Formoso, C. T. (2019). "Modularity in the Construction Industry: A Systematic Mapping Study." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.)*, Dublin, Ireland, pp. 737–748. DOI: https://doi.org/10.24928/2019/0178. Available at: <www.iglc.net>.

MODULARITY IN THE CONSTRUCTION INDUSTRY: A SYSTEMATIC MAPPING STUDY

Marcelle Engler Bridi[1], Eliká D. Ceolin[2], Ariovaldo D. Granja[3], and Carlos T. Formoso[4]

ABSTRACT

Modularity is a concept that has not been fully explored in the construction industry, as a mechanism to improve cost, quality, and schedule performance. However, currently it is strongly related to the idea of developing mass customized innovative products. Although modularization is widely used in the manufacturing industry, its application in construction-related opportunities seems to be difficult. This paper presents a Systematic Mapping Study (SMS) on the use of modularity in the construction industry, and attempts to make a connection with Lean principles. SMS is a research method that aims to provide an overview of a specific area, through systematic selection and analysis of the literature, starting from a research question. The steps used to conduct this research work are described, as well as the mapping of the topic areas already covered in literature. The main contribution of the paper is concerned with the connections between Modularity core ideas and Lean principles.

KEYWORDS

Modularity, construction industry, RLS.

INTRODUCTION

Modularity can be defined as the degree to which a system can be divided into subunits (modules) that can be joined and recombined in different ways (Simon 1991; Schilling 2000). A module is understood as an independent unit, which has its own functionality,

[1] Ph.D. Student, Construction Management Research Laboratory (LAGERCON), School of Civil Engineering, Architecture and Urban Design, University of Campinas, Campinas, SP, Brazil, marcelle.bridi@gmail.com

[2] Ph.D. Student, Building Innovation Research Unit (NORIE), Universidade Federal do Rio Grande do Sul, Porto Alegre 90035-190, Brazil, elikac@gmail.com

[3] Professor, Architecture and Construction Dept., Director of the Construction Management Research Laboratory (LAGERCON), School of Civil Engineering, Architecture and Urban Design, University of Campinas, 951 Albert Einstein Ave, P.O. Box 6021, Campinas, SP 13083-852, Brazil, Phone: +55 19 3788-2082, adgranja@fec.unicamp.br

[4] Building Innovation Research Unit (NORIE), School of Engineering, Universidade Federal do Rio Grande do Sul, Porto Alegre 90035-190, Brazil; formoso@ufrgs.br

and standardized interfaces that interact according to the systems' definition (Miller and Elgard 1998).

Although some characteristics of the construction industry make it difficult the adoption of modularity in some construction projects, there are potential benefits for its implementation (Doran and Giannakis 2011). Modular buildings can contribute to increase efficiency and improve cost performance, bringing a quick return on project´s investment, which may be an important factor to justify their adoption by the construction companies (Moghadam et al. 2012). However, there is still a lack of construction management studies that clearly address the complexity and scope of a modular application (Gosling et al. 2016).

Some empirical studies in the construction industry point out that there are different types of modularity: product, process, and supply chain modularities (Voordijk et al. 2006; Lessing 2006, Viana et al. 2016, Peltokorpi et al. 2018).

First, the product modularity occurs when the product is decoupled into parts and components (Gershenson et al. 2003). The idea is that a limited number of modules can be combined to produce a wide variety of products (Miller and Elgard 1998, Gosling et al. 2016). Unlike an integral product, a modular product has interchangeable components that have one or only a few functions (Voordijk et al. 2006). Also, the adoption of modularity facilitates the replacement or upgrading of individual components, supporting the development of innovations (Lennartson and Björnfot 2010). Therefore, the use of modularization can go beyond improving the time, cost and quality performance of the project. It can potentially enable the development of innovative products and create flexibility during the use and maintenance stages (Peltokorpi et al. 2018). In addition, several studies point to modularity as a strategy to deliver a customized product to clients (Miller and Elgard 1998, da Rocha 2011, Peltokorpi et al. 2018).

Second, the process modularity is concerned with the adoption of standardized operations with shared interfaces (Lennartson and Björnfot 2010). However, a modular process does not necessarily include standardized components, but rather standardized manufacturing, delivery, and assembly processes (Peltokorpi et al. 2018). Furthermore, a modular process allows the sharing of production technologies, parallel assembly, and the use of standardized work (Lennartson and Björnfot 2010).

The third category of modularity is related to the configuration of the supply chain, which can be defined as a network of companies that transform raw material into supplies, products, or modules, including its distribution (Cheng et al 2010). In construction supply chains, some transformation activities can be moved out from construction sites (Vrijhoef and Koskela 2000). Most construction supply chains are highly fragmented and are connected to a temporary organization, which is composed of a large variety of companies, mostly of medium and small size (Cheng et al. 2010).

In essence, in modular supply chains, management tends to occur outside the production sites (Doran and Giannakis 2011). The degree of modularity is influenced by the degree of separation between design and execution (Voordijk et al. 2006). In an integral SC the companies are more interdependent (Voordijk, et al. 2006). By contrast, in a less integral (loosely coupled) SC, participants have less interaction (Pero et al. 2015), may be geographically distant, and there is no involvement in the design phase (Voordijk *et al.* 2006). A lean-production system usually has a highly integral SC, except for the dimension of electronic proximity (Fine, 2000). A strong supply chain integration is necessary to overcome the negative characteristics associated with modular constructions (Doran and Giannakis 2011) and the integrality-modularity of product, process, and supply chain tend to be aligned (Fine 1998).

This paper presents a Systematic Mapping Study (SMS), which aims to understand the concepts of modularity that are applicable to the construction industry, and to identify opportunities for further research on this topic, regarding the construction industry. Furthermore, an analysis was carried-out to detect possible associations between the lean philosophy and modularity. SMS provides an overview of a specified area, based on the classification and identification of relevant research contributions (Petersen et al. 2015).

RESEARCH METHOD

SMS can be regarded as a preliminary step for a Systematic Literature Review. The research method adopted for this investigation was based primarily on the guidelines for conducting SMS proposed by Petersen et al. (2015), and on the adaptations proposed by Tranfield et al. (2003) to the field of management, from which the qualitative characteristics and the predominance of case studies to understand specifics phenomena are suggested as a way to differ from the applications in the field of Medical Sciences, for example.

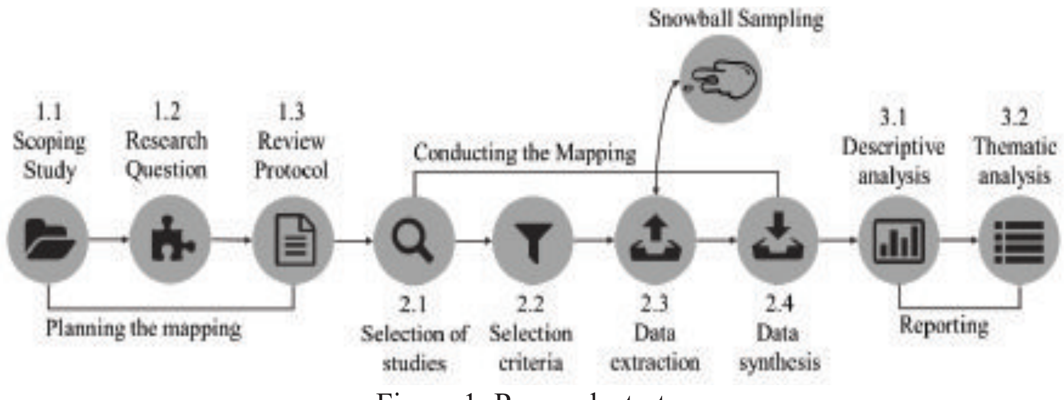


Figure 1: Research strategy

The Stage 1 (Planning the Mapping) was divided into the Scoping Study (1.1), in which the research question was defined (1.2) and the development of the Review Protocol (1.3). As a result, Stage 2 (Conducting the Mapping) consisted of the Search and Selection of Studies (2.1), applying the Selection Criteria (2.2), Data Extraction (2.3) and Synthesis (2.4). Finally, Stage 3 (Reporting) consisted of the classification and organization of evidence and was divided into two phases: Descriptive Analysis (3.1), and Thematic Analysis (3.2).

Still, between the extraction and synthesis steps, the search was complemented with a backward Snowball Sampling. This feature is indicated as an additional step for systematic mapping and literature reviews, from which new articles are added, based on the list of references or citations from an article (Wohlin 2014). The proposal in this study was to identify articles, through selected publications, which for some reason were not found in the search criteria, but have relevance in the field. Figure 1 presents the steps adopted in this study, which are explained in more detail in the following section

RESULTS

SMS PROCEDURES

Planning the Mapping

The initial phase was the Scoping Study, which consisted of the selection and reading of 8 papers considered to be seminal in the area by the research team. This phase was carried out with the aim of gaining greater familiarity with the theme, and also to identify the need for a systematic review and to define the research question. It included research studies from several areas related to modularity.

From the reading, the following question was defined for the SMS: “How modularity related concepts (topics) are covered in the construction industry literature?”. In addition, keywords and search strings were defined, as shown in Figure 2.

Modularity		Context
Module OR modularization OR modularity	AND	“Construction Industry” OR “Building Industry” OR “Building Construction”

Figure 2: Search String

The following step consisted in choosing the databases. Ten databases were initially listed, of which the compatibility with the theme and the availability of access were verified. From these, the following databases were chosen: (a) ScienceDirect / Elsevier; (b) Web of Science / Web of Knowledge; (c) Academic Search Complete (EBSCO); (d) Scopus and (e) Compendex.

INCLUSION	EXCLUSION
Only papers from journals	Not in the context of the construction industry
Qualitative, quantitative and multiple methods	Systematic mappings or literature reviews
It has to address modularity	Not Portuguese or English

Figure 3: Selection criteria

Regarding the review protocol, the inclusion and exclusion criteria were defined (Figure 3). The decision was made to restrict the search only to papers published in journals as a way to include a quality criterion in the classification, although, in a SMS it is not so important to apply a strict quality assessment (Petersen et al., 2015)

Conducting the Mapping

This step consisted of the execution of the research following the proposed Protocol. With the strings defined by the research team, searches were carried out at the selected databases. The files were downloaded in BibTeX format and imported into Mendeley. Also, filters were applied to limit the search to the inclusion/exclusion criteria (only papers from journals and in English or Portuguese) whenever the database allowed, which resulted in a substantial reduction in the number of papers for the following analysis. This study was limited to analyze only papers published in EN/PT, due to the need to understand and extract data from their main content by the authors.

The search resulted in a total of 3775 publications, from which 2149 were journal papers. Then, the selection criteria were applied, including the reading and analysis of title, abstract and keywords. Both the search for the papers and the selection criteria were performed in pairs by two members of the research team. Figure 4 shows the distribution of papers found in each database.

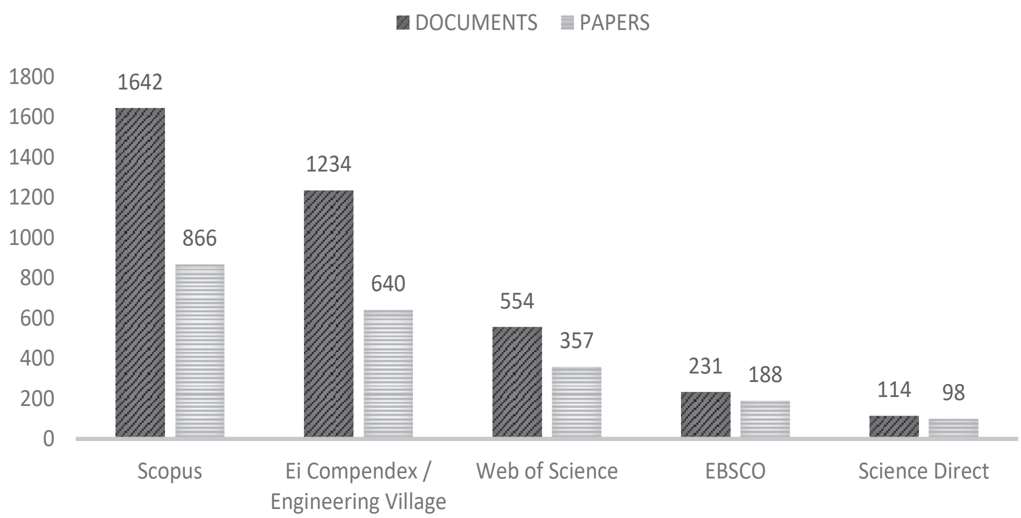


Figure 4: Database distribution

After applying the selection criteria, 236 papers were selected, from which 142 were available for reading and extracting the data.

The data extraction form was organized in Excel and contained the following parameters: Authorship, Title, Year of Publication, Journal, Authors Keywords, Method, Sample, Summary, Gaps, Country, Main Contributions, Approach Classification and Connection with Lean.

Through full-text review, 43 articles that did not meet the research criteria were rejected, and 14 articles were included through Snowball Sampling, resulting in a total of 113 papers. Table 1 summarizes the number of papers in each step of this phase.

It is observed that there was a significant reduction after the screening, resulting in about 13% of relevant papers considering the analyzed papers.

Table1: Screening steps

Papers founded	ENG / PT Only	NOT duplicated	After Title/abstract/Keywords analysis	Available for download	Snowball Sampling	Final selection
2149	1742	843	236	142	14	113

DESCRIPTIVE ANALYSIS

Figure 5 shows the distribution of publications per year. In the 1990s until the mid-2000s, few publications were found, the first being in the year of 1989. From the early 2000s, there has been a substantial increase in the number of publications. Table 2 shows the top five journals in which the papers were published, the number of papers found (N) and the authors and year of publication. Most papers have been published in journals related to construction engineering and management.

.

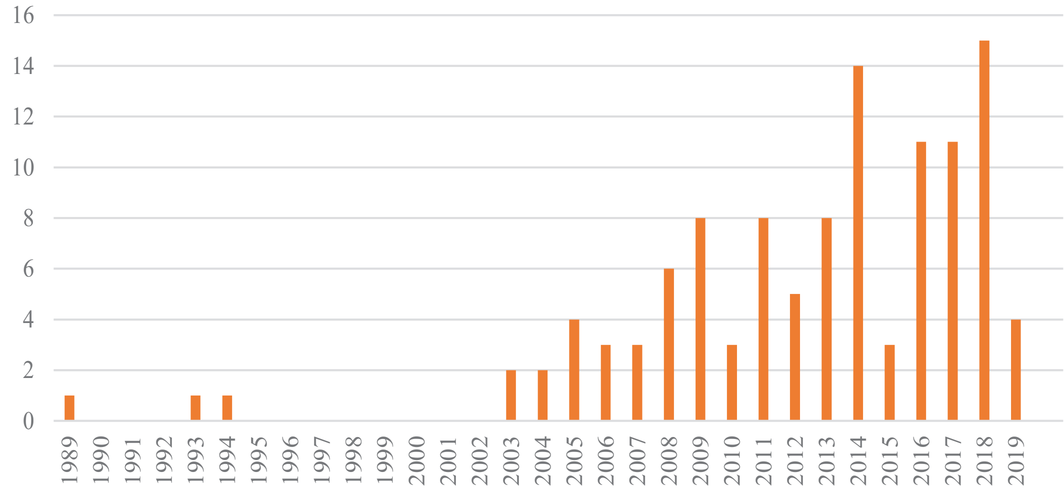


Figure 5: Distribution of relevant papers per year

Table 2: Most cited journals

JOURNAL	N	PAPERS
Journal of Construction Engineering and Management	15	Blacud et al. (2009); Choi et al. (2016); Dzeng et al. (2005); Dzeng et al. (2004); Gill et al. (2005); Goodrum et al. (2009); Gosling et al. (2016); Ikuma et al. (2011); Larsson et al. (2016); Lee and Hyun (2019); Murtaza et al. (1993); Nahmens and Bindroo (2011); O´Connor et al. (2014); Ramaji and Memari (2016); Song et al. (2005)
Construction Management and Economics	10	Agren et al. (2014); Brodetskaia et al. (2011); da Rocha and Kemmer (2018); Jaillon and Poon (2010); Johnsson and Meiling (2009); Meiling et al. (2014); Pan et al. (2008); Peltokorpi et al. (2018); Schmidt III et al. (2014); Wikberg et al. (2014)
Automation in Construction	6	Eastman (1994); Hsu et al. (2018); Martinez et al. (2019); Nasereddin et al. (2007); Olearczyk et al. (2014); Said et al. (2017)
Journal of Management in Engineering	6	Choi et al. (2019); Hall et al. (2018); Hyari and El-Rayes (2006); Liu et al. (2017); Tatum (1989); Yu et al. (2013)

Canadian Journal of Civil Engineering	5	Kim et al. (2005); Li et al. (2013); Moghadam et al. (2012); Wang et al. (2009); Westover et al. (2014)

Figure 6 shows the distribution of papers per country. Most of the studies are concentrated in the United States, followed by the United Kingdom and Australia. Canada, China, Sweden and Korea had also produced some papers.

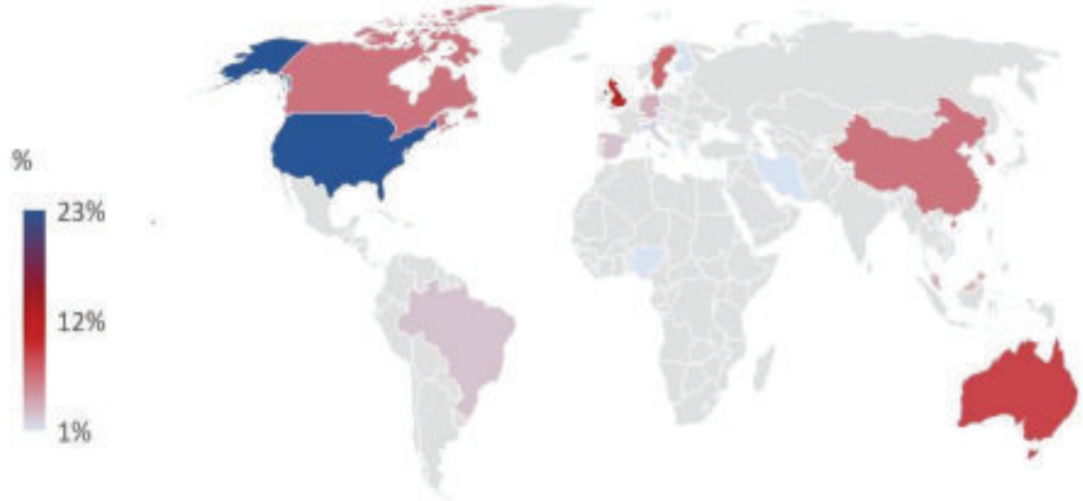


Figure 6: Distribution of papers per country

Finally, the main research methods were classified (Figure 7). Most of the papers are Case Studies, followed by Surveys. 13% of papers were found to have more than one strategy (e.g. Choi et al. (2019) carried out a literature review, a survey, and interviews). These cases were grouped as Multiple Methods. Still, 3% of the selected articles did not make clear the methodology adopted and could not be classified.

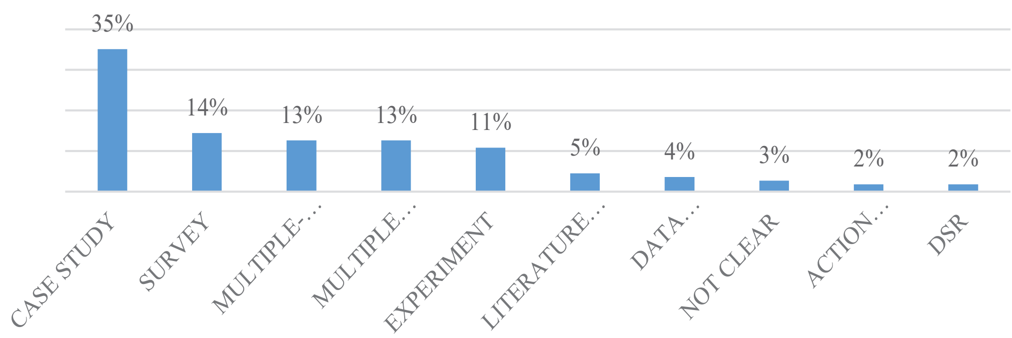


Figure 7: Research Methods

THEMATIC ANALYSIS

In order to analyse the main topic areas covered in the literature on modularity, the following classification was proposed, based on the IGLC 2019 proposed themes (Table 3).

Table 3: Description of the proposed topic areas

Topic Area	Description
Product Development and Design Management	Papers related to the development of modular products, components, or to the management of the design process.
Contract and Cost Management	Papers related to the decision-making process, including risk analysis, real estate market and stakeholders.
Production Planning and Control	Papers related to the process of planning and control of modular projects.
Theory	Theoretical or literature review about modularity, including authors who have identified best practices in the construction industry.
Sustainability	Papers related to the environmental impact of modular buildings and green technologies.
Production System Design	Papers related to the design and execution of modular building systems, including assembly techniques and automation.
Off-Site Construction	Papers related to the manufacturing process of modules or modular component and transportation.
Supply Chain Management	Papers related to the modular construction supply chain.
Safety, Quality, and Health	Papers that investigated the relationship between the use of modularity and safety performance.
Lean and BIM	Papers that specifically addressed the use of BIM and/or Lean in modular construction.

A total of 10 categories were proposed in order to group the diversity of topics addressed by the selected papers. This classification was made in a suggestive way by the authors. The aim of this division into categories was to identify future trends and knowledge gaps (scarce evidences). Figure 8 shows the distribution of the topics covered by previous studies. The category "Product Development and Design Management" had around 40% of the papers.

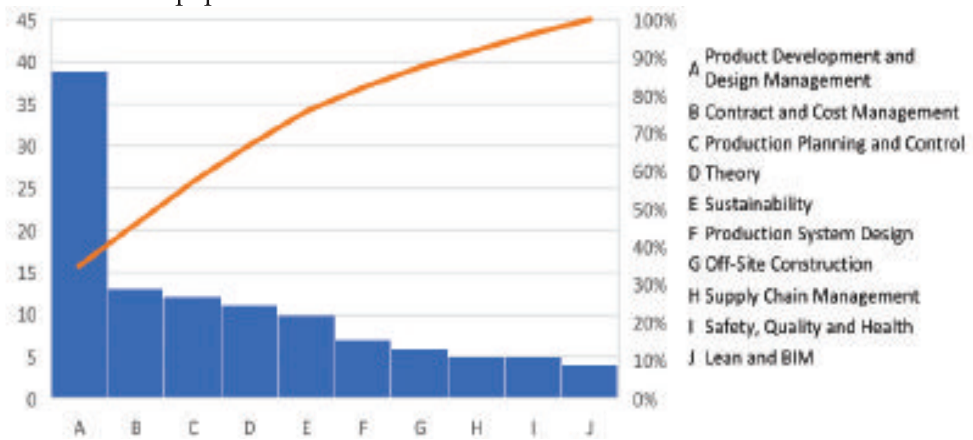


Figure 8: Distribution of papers according to topic area

LEAN PHILOSOPHY AND MODULARITY

An analysis was made on the association between the Lean Philosophy and Modularity. The core ideas that explained that association are presented in Table 4, and these were classified in topics.

Table 4: Core ideas that associated the Lean Philosophy and Modularity

Topic	Description	Authors
Autonomation	Concepts of lean construction and design for manufacture and assembly, enable the development of modular products by robotics systems onsite.	Martinez et al (2008)
	A higher automation level is desirable to increase the productivity level.	Martinez et al (2008) Orlowski et al (2018)
Elimination of waste	Big modules transportation and assembly offsite are a significant waste of space, against lean philosophy. Production like kit-of-parts and onsite assembly in temporary factories can reduce waste of time and space of big modules.	Martinez et al (2008)
	Consumer-oriented approaches in which quality and value for money drive the requirements to reorganize production.	Barlow et al (2003)
	On-site re-design, waste costs, time savings can be achieved by the design of products to be manufactured and assembled during the design stage.	Martinez et al (2013)
Flexibility	Improvements in quality and meet the individual needs of different customers have been driven by consumer-oriented approaches.	Barlow et al (2003)
	Lean production is applied to the design of new materials and products with different levels of finishing that make modular assembly possible. The design of new materials and products with different finishing are enabled by concepts related to lean production, making modular assembly possible.	Martinez et al (2008)
	There are high levels of customization in buildings, making building modules one of a kind, this variety can be supported by lean principles.	Yu et al (2013)
	Ease of training, ease of change, paced implementation and the opportunity for strategic alignment would seem to dominate processing efficiency and consistency arguments of large-scale ERP proponents.	Arif et al (2011)
General	Carry out an extended analysis which investigates the impact modularization has on other organizational initiatives such as lean.	Hvam et al (2017)
	Full implementation of Lean in the industrialized housing industry may further improve processes in terms of both efficiency and safety.	Nahmens and Ikuma (2009)
	Construction practitioners argue that construction is distinct from auto manufacturing and that lean production is not applicable. The research approaches lean focusing on balancing the production line process stability rather than improving productivity	Yu et al (2013)
	Offsite prefabrication/preassembly depends on the lean concept of moving the work to the workers in a controlled production environment.	Said et al (2017)
	Relates the lean principles and techniques, such as standardized work and visual management to organize the workplace in construction.	Yu et al (2013)
	Utilize simulation as a decision tool to assist the design of a new factory to incorporate lean principles as flexibility, responsivity and efficiency.	Nasereddin et al (2007)

KAIZEN	The case study applies the lean production tool, Kaizen, in a modular housing manufacturing facility.	Ikuma et al (2011)
	Evaluates the impact of Kaizen in workers safety at a modular homebuilder.	James et al (2014)
	5S proved to be an effective way to get people involved in lean initiatives and enthused about lean by realizing immediate results.	Yu et al (2013)

Table 4 (cont.): Core ideas that associated the Lean Philosophy and Modularity

Topic	Description	Authors
	A set of lean principles are used to reduce waste over a range of factory activities. It is proposed a modularization production method to improve modular factory production flow based on work activity relationship.	Lee et al (2017)
Sustainability	Relates large-scale lean efficiencies in the design and construction process to sustainability.	Zakaria et al (2018)
	Management based on lean principles optimize carbon emission.	Gong et al (2015)
	By improving the delivery process of modular houses, lean strategies improve the economic, social and environmental dimensions.	Nahmens and Ikuma (2011)

There are different approaches involving the Lean Philosophy and Modularity. To summarize the different lean concepts related to modularity examined by the papers, the ideas presented by the authors were classified into topics, as proposed in Table 4. Of the 113 papers, 34 mention lean principles (30%), although only 19% specifically related lean principle to modularity.

From the analysed papers, lean principles are mainly associated to efficiency in modular construction. It is associate to improvements in production through autonomation (Martinez et al. 2008; Orlowski et al. 2018; Yu et al. 2013), Kaizen (Lee et al. 2017; Ikuma et al. 2011; James et al, 2014; Yu et al, 2013) and flexibility (Barlow et al, 2003; Martinez et al, 2008; Yu et al. 2013; Arif et al. 2011). Authors also link some design process improvements in modular construction to lean: flexibility enables the design of new materials and products (Martinez et al. 2008) and reduction of waste reduces re-design (Martinez et al. 2013). Authors also bring customization, one of a kind modules (Yu et al. 2013) and customer oriented-approach (Barlow et al, 2003) as strategies supported by lean concepts as flexibility (Yu et al. 2013). Other general aspects from lean philosophy are pointed out as enablers of modularization as standardized work, visual management (Yu et al. 2013) and responsivity (Nasereddin et al. 2007).

CONCLUSIONS

This paper presents the results of a SMS regarding modularity in the construction industry, as a preliminary stage of a future Systematic Literature Review effort. The purpose of this study was to identify the primary areas covered by the existing literature and, in addition to, identify the relationship of those studies with Lean Philosophy.

In response to the stated research question, the conclusion was made that most of the papers selected were related to the development of modular products. However, this category involves a great diversity of aspects, since it encompassed both the design process and the development of modules or modular components.

Regarding the Lean Philosophy, only 19% of the papers properly explained the connection of modularity and Lean, although intrinsic characteristics of lean production systems can be found in several papers. The aforementioned Lean topics were grouped into the following proposed categories: (a) Sustainability; (b) Autonomation; (c) Elimination of waste; (d) Flexibility; (e) Kaizen and (f) General.

The next steps of this research will deepen the literature review, identifying the main contributions of these research studies and possible gaps.

REFERENCES

Cheng, J. C., Law, K. H., Bjornsson, H., Jones, A., and Sriram, R. (2010). "A service oriented framework for construction supply chain integration." Automation in construction, 19(2), 245-260.

Choi, J. O., O'Connor, J. T., and Kim, T. W. (2016). "Recipes for Cost and Schedule Successes in Industrial Modular Projects: Qualitative Comparative Analysis." Journal of Construction Engineering and Management, 142(10), 04016055.

Da Rocha, C. G. (2011) "A conceptual framework for defining customisation strategies in the house- building sector. "Porto Alegre, 2011. Thesis (Ph.D. in Engineering) – Escola de Engenharia, Programa de Pós-Graduação em Engenharia Civil, UFRGS, Porto Alegre.

Doran, D., and Giannakis, M. (2011). "An examination of a modular supply chain: a construction sector perspective." Supply Chain Management: An International Journal, 16(4), 260–270.

Fine, C. H. (2000). "Clockspeed-based strategies for supply chain design." Production and operations management, 9(3), 213-221.

Fine, C. H. (1998)."Clockspeed: using business genetics to evolve faster than yourcompetitors." Little, Brown and Company, London.

Gershenson, J. K., Prasad, G. J., and Zhang, Y. (2003). "Product modularity: Definitions and benefits." Journal of Engineering Design, 14(3), 295–313.

Gosling, J., Pero, M., Schoenwitz, M., Towill, D., and Cigolini, R. (2016). "Defining and Categorizing Modules in Building Projects: An International Perspective." Journal of Construction Engineering and Management, 142(11), 04016062.

Kitchenham, B. (2004). "Procedures for Performing Systematic Reviews.". Keele, UK, Keele University, 33, 1-26.

Lennartsson, M., and Björnfot, A. (2010). "Step-by-step modularity – A roadmap for building service development." Lean Construction Journal, Lean Construction Institute, 2010, 17–29.

Lessing, Jerker. (2006)."Industrialised house-building. Concept and Processes."

Miller, T. D. and Elgård, P. (1998). "Defining Modules, Modularity and Modularization." Proceedings of the ASME Design Engineering Technical Conference.

Moghadam, M., Al-Hussein, M., Al-Jibouri, S., and Telyas, A. (2012). "Post simulation visualization model for effective scheduling of modular building construction." Canadian Journal of Civil Engineering, 39(9), 1053–1061.

Peltokorpi, A., Olivieri, H., Granja, A. D., and Seppänen, O. (2018). "Categorizing modularization strategies to achieve various objectives of building investments." Construction Management and Economics, 36(1), 32–48.
Pero, M., Stößlein, M., &Cigolini, R. (2015). "Linking product modularity to supply chain integration in the construction and shipbuilding industries." International Journal of Production Economics, 170, 602-615.
Petersen, K., Vakkalanka, S., &Kuzniarz, L. (2015). "Guidelines for conducting systematic mapping studies in software engineering: An update." Information and Software Technology,64, 1-18.
Simon, H. A. (1991)"The architecture of complexity. In: Facets of systems science." Springer, Boston, MA. p. 457-476.
Schilling, M. A. (2000) "Toward a general modular systems theory and its applicationto interfirm product modularity". Academy of management review, v. 25, n. 2, p. 312-334.
Tranfield, D., Denyer, D., and Smart, P. (2003). "Towards a methodology for developing evidence-informed management knowledge by means of systematic review". 14, 207–222.
Viana, D. D.; Tommelein, I. D.; Formoso, C. T. (2016) Using modularity toreduce complexity of industrialized construction projects: a case study. In: ZEMCH2016 International Conference, Kuala Lumpur. ZEMCH 2016 InternationalConference.
Voordijk, H., Meijboom, B., & de Haan, J. (2006). "Modularity in supply chains: a multiple case study in the construction industry. "International journal of operations & production management, 26(6), 600-618.
Vrijhoef, R., &Koskela, L. (2000). "The four roles of supply chain management in construction. "European journal of purchasing & supply management, 6(3-4), 169-178.
Wohlin, C. (2014). "Guidelines for Snowballing in Systematic Literature Studies and A Replication in Software Engineering.". In Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering. p. 38.

Chauhan, K., Peltokorpi, A., Lavikka, R., and Seppänen, O. (2019). "Deciding Between Prefabrication and on-site Construction: A Choosing-by-Advantage." In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.),* Dublin, Ireland, pp. 749–760. DOI: https://doi.org/10.24928/2019/0158. Available at: <www.iglc.net>.

DECIDING BETWEEN PREFABRICATION AND ON-SITE CONSTRUCTION: A CHOOSING-BY-ADVANTAGE APPROACH

Krishna Chauhan[1], Antti Peltokorpi[2], Rita Lavikka[3] and Olli Seppänen[4]

ABSTRACT

Several academic and industrial studies have documented the benefits of prefabrication compared to on-site construction. However, key construction project actors find it difficult to analyse whether prefabrication would be beneficial for their project with specific circumstances and targets. This research aims to develop a process to evaluate the impact of prefabrication in projects. First, based on the literature review and focus group discussion, we define the impact factors of prefabrication. Second, we apply Choosing by Advantage (CBA) approach together with Cost-Benefit-analysis to define a process for prefabrication impact measurement which considers various impact factors and their importance in the project. Finally, we validate the process with the industry experts. The paper contributes to knowledge on robust decision-making processes about production methods in situations in which all impact factors are not easily comparable but require a subjective valuation.

KEYWORDS

Prefabrication, on-site construction, choosing-by-advantage, lean construction

INTRODUCTION

How could the construction project actors decide whether to use prefabricated products in their project? It is widely assumed in the construction industry that the adoption of prefabrication is the next step towards the industrialization of construction (Lu et al. 2018). However, making a decision between the prefabricated products and on-site construction is often complicated as several direct and indirect factors need to be considered (Antillon et al. 2014).

The impact of prefabrication is a debated topic. For example, Hong et al. (2018) discuss the impact of prefabrication on construction project costs. Prefabrication is argued to lower

[1] Doctoral Candidate, Department of Civil Engineering, Aalto University, Finland, Krishna.chauhan@aalto.fi

[2] Assistant Professor, Department of Civil Engineering, Aalto University, Finland, Antti.peltokorpi@aalto.fi

[3] Post-doctoral Researcher, Department of Civil Engineering, Aalto University, Finland, rita.lavikka@aalto.fi

[4] Professor of Practice, Department of Civil Engineering, Aalto University, Finland, Olli.Seppänen@aalto.fi

the project costs due to faster project delivery, cheaper labour rates, minimal waste, and the avoidance of construction site hindrances. On the other hand, prefabrication is argued to increase project costs due to the requirements of highly skilled workers, high costs of prefabricated products, and additional transportation costs (Hong et al. 2018).

Previous studies have tried to define and evaluate the impact factors of prefabrication. For instance, Antillon et al. (2014) applied a value-based cost-benefit analysis when analysing prefabrication in hospital projects. Pasquire et al. (2005) illustrated the factors and sub-factors to be considered for the detailed evaluation in a proposed prefabrication impact measurement business toolkit. However, research is scant on transparent algorithms and processes, which could guide in the decision-making concerning whether to apply prefabrication in a single project context.

In the lean construction community, Choosing By Advantage (CBA) has been suggested as a method when comparing alternative options with different impact factors. CBA is a Multi-Criteria Decision making (MCDM) system based on the advantages of alternatives. The CBA method separates value and cost (Arroyo, 2014). CBA process has been successfully applied in several cases, for example, choosing the appropriate water treatment technologies (Arroyo & Molinos-Senate, 2018), choosing the bidder (Schöttle and Arroyo, 2017), or selecting the contract type for the road maintenance (Haapasalo et al. 2015).

The purpose of this research is to apply CBA method to develop a tool to evaluate the impact of prefabrication in a construction project. To achieve this purpose, the following research questions are answered:

RQ1: What are the impact factors of prefabrication and how to measure them?

RQ2: How could the 'Choosing by advantage' method be applied for deciding on the use of prefabrication in construction projects?

The first research question about impact factors will be answered based on the literature review, its synthesis and validation in focus group meetings. The focus group involves the consortium of Aalto University and 16 leading Finnish construction companies aimed at developing a vision of 2030 for the Finnish construction industry. The literature study first shortly introduces the literature on prefabrication in general and the major impacts of prefabrication. The impact factors of prefabrication and their measurement methods are validated with an industry expert focus group. After that, we focus more on analysing existing measurement and evaluation tools when deciding between prefabrication and on-site construction. To answer the second research question, we will first review the literature on choosing by advantage and then apply it in a prefabrication context with multiple impact factors. As a conclusion, an evaluation process which combines the CBA method and cost-benefit analysis will be presented.

THEORETICAL BACKGROUND

PREFABRICATION

Prefabrication means a practice of manufacturing the components of building or structure in factory circumstances and then transporting and assembling them onsite (Goodier & Gibb, 2007). Prefabrication can be understood at different levels, considering the production of small parts and components of a building or entire house or volumetric building block which can be manufactured in the factory (Neil and Deli, 2016). Later, Piroozfar & Farr, (2013) have defined modularization, industrialized building, mass production, and prefabrication as separate concepts. The industrialized building is a higher level concept, under which modularization enables the mass production and prefabrication of the components (Piroozfaz and Farr, 2013).

Numerous benefits of prefabrication which promote its implementation have been documented in several academic and industrial research papers (Chauhan et al. 2018; (Lavikka, et al. 2018; Eastmann & Sacks, 2008). The following benefits have been emphasized:

- To convert the traditional site base industry to the modern industrialized industry
- To improve the resource-efficiency and productivity
- To secure the completion of the project on time, on budget and with the targeted quality
- To improve the quality and environmental performance of construction
- To minimize material waste
- To improve safety and ergonomics

More specifically, research by Jaillon et al. (2009) indicates that 52% of material waste was reduced after the adoption of prefabrication. Similarly, Khanzode et al. (2008) illustrate that a 30 % decrease in labour was gained through the implementation of Mechanical, Electrical and Plumbing (MEP) prefabrication. Thus, the implementation of prefabrication has increased by 86% within the last two decades (Paudel et al., 2016).

PREFABRICATION IMPACT MEASUREMENT

Literature shows that several methods have been applied to facilitate decision making on prefabrication in projects. For instance, Lu et al. (2018) have developed a framework for deciding on the optimal level of prefabrication. The framework involves thirteen PEST (political, economic, social and technological) factors which together determine the optimal level of prefabrication. Li et al. (2014) have applied the system dynamics approach and scenario simulation as an instrument in evaluating the impact of prefabrication on material waste. Hong et al., (2016) propose the 'prefabrication rate' that calculates prefabrication volume to the total volume of the building materials. Similarly, Alinaitwe et al. (2006) propose a ratio of the value of work done onsite and offsite as an instrument to access the impact of prefabrication. However, those studies focus mostly on measuring single impacts factors, instead of multiple different factors which have to be considered in decision making.

In order to measure prefabrication impact with multiple dimensions, Pasquire et al. (2005) have presented the factors that are essential for the prefabrication impact measurement. The results of that study are part of the IMPREST toolkit. They presented the cost as the major factor followed by quality, time and safety. Furthermore, Cook (2013) (Cited in Antillon et al. 2014) has emphasised the cost as the major impact factor for the prefab impact measurement. Antillon *et al*. (2014) further presented several other value components for prefab impact measurement, such as prioritised time, waste, quality, safety, ergonomics. They conducted a value-based cost-benefit analysis approach to evaluate the impact of prefabrication on direct costs, safety and schedule in the hospital project. The authors were able to produce a cost-benefit-ratio for four prefabrication solution which would reveal which production method is more suitable.

Cost-benefit analysis is a promising method for evaluating multiple impacts of prefabrication in projects. However, as all impact factors are not easily converted to cost impacts (e.g. environmental effects, completion on time, quality), there is a need for an evaluation method which would combine monetary and non-monetary impacts. It can be even argued that some impact factors, such as time, should be in some cases to be considered both as monetary impact (reducing contractor's general costs) and non-monetary impact (shortening the schedule).

CHOOSING BY ADVANTAGES

Choosing by advantage (CBA) is a tool that could be adopted while deciding between alternatives. It is also known as a multidisciplinary decision-making method (MCDM) for selecting between alternatives based on the advantages between them. Major concepts in the CBA include *alternative*, *factor*, *criterion*, *attribute*, *advantages* and *importance of advantages* (Parrish and Tommelein, 2009). The glossary terms included in the CBA process has been defined by the Suhr (1999) as follows:

Alternatives: Different options between which has to be decided with the CBA process. A minimum of two options is required.

Factors: Common factors for all the alternatives, based on which best alternative could be decided.

Criteria: Criteria for judging based on factors, whether, e.g. higher value is better or less is better.

Attribute: Characteristics or values that resemble each alternative in each factor.

Advantage: Advantage of each alternative's attribute relative to that least-preferred one.

Arroyo (2014) has defined seven steps of the CBA method (Figure 1).

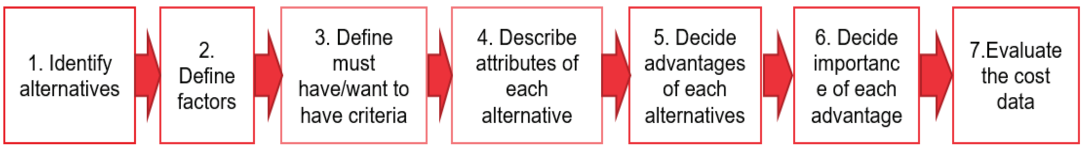


Figure 1. CBA steps (Arroyo, 2014)

CBA method has been already adopted to choose appropriate wastewater treatment technology (Arroyo and Senate, 2018), best construction flow option (Murguia & Brioso, 2017), and best HVAC system (Arroyo et al. 2016). However, CBA method has not yet been adopted when choosing a suitable construction method. We argue that the flexibility of the CBA method in the situation of multiple non-comparable factors makes it a promising method to apply when evaluating the impact of prefabrication compared to on-site construction in projects.

DEVELOPMENT OF AN EVALUATION PROCESS

Based on the literature, we were able to gather all the major impact factors of prefabrication into one table. After that, we organized two focus group discussions which both consisted of around 20 industry experts from construction companies, design offices and building product companies. In the first discussion, we validated the impact factors. New factors were not added, but some of them were revised based on the discussion. Majority of the participants involved in the discussion indicated that cost is a major motivating factor of the prefabrication implementation followed by project schedule, waste, quality and requirement from the site environment. For the second discussion, we prepared material about measurement method for each impact factor. Those methods were validated and modified based on the second focus group discussion.

The validated impact factors, their mechanism and measurement methods are presented in Table 1. Regarding the measurement method, we have also identified whether the factor can be measured as cost impact (€), other quantitative methods, or qualitative method. For example, project time can be measured as quantitative analysis or even as costs, but required design flexibility is a factor which can be measured only with qualitative methods, such as interviewing the customer or designers.

Table 1: The impact factors of prefabrication, mechanisms and possible measurement methods

Impact factor	**Prefabrication Expectation**	**Expected mechanism**	**Measurement method (€ / QUANTITATIVE / QUALITATIVE)**
Labour and material costs	Neutral or Lower	Decreases labor and material costs because trade bottlenecks are reduced, less material waste	Compare labour and material costs between trad & prefab projects (QUANT / €)
Waste and disposal	Reduced	Enables recycling and JIT material deliveries, components ordered to exact lengths	Compare the amount of waste between trad & prefab projects (QUANT / €)
Safety (worker and environment)	Improved	Reduces dangerous onsite working conditions (scaffolding, ladders), less traffic on site	Compare the number of work incidents between trad & prefab projects (QUANT)
Ergonomics	Better	Controlled work heights, tool weights, and environmental conditions	Worker surveys (QUAL)

Project schedule	Compressed	Speeds up the assembly time, reduces staging on site, better coordination between trades	Compare the completion times between trad & prefab projects (QUANT / €)
Quality	Equal or Better	Standardized working methods, clear quality control points in a stable environment, product certifications	Achievements of quality standards, Quality checks throughout the process, Quality errors, Fixing costs (QUANT / €)
Surrounding environment	Favorable	Less (noise, logistics) disturbance to neighbors, more environmental friendly	Surveys, interviews (QUAL/QUANT)
Design costs	May increase or decrease	Requires more detailed designs but enables reuse of existing designs	Compare costs and resources between trad & prefab projects (€/QUANT)
Design flexibility	Decreased	Late customer changes are not possible	Interview (QUAL)
CM/GC coordination costs	Reduced	Decreases needed coordination between subs, fewer coordination costs	Compare the size and costs of management team (€/QUANT)
Site deliveries and supplies	Reduced	Materials are delivered in bigger units	Compare the number of deliveries between trad&prefab projects (QUANT)
Sub-trade activity on site	Reduced	Reduces assembly work and number of sub-contractors	Compare the number of sub-contractors and workers on site between trad&prefab projects (QUANT)
Weather conditions	Controlled	Assembly is independent of weather, which can increase work efficiency and avoid damaged building materials	Compare the interruptions and problems related to weather conditions between trad&prefab projects (QUANT/QUAL)
Procurement	Favorable	Better productization (material and installation) and easier to purchase	Compare the actual costs of procuring and installing materials between trad&prefab projects (QUANT)

Maintenance	Equal of Favorable	Makes maintenance easier if maintenance is considered during the design of the prefabricated products	Evaluate implications on maintenance work (QUAL/QUANT)

After defining the impact factors and their measurement methods, we adopted CBA steps proposed by Arroyo (2014) for prefabrication context. In our case, we have assumed that after defining the impact factors, it is important to categorise which factors should be measured as a monetary factor, non-monetary factor or both. For instance, construction time is a factor which has a cost impact, but it can be valuable also in itself for the project to be completed in a short time (not just cost-effect). The modified evaluation process is presented in Figure 2 and the description of each step is presented in Table 2.

In the suggested process, prefabrication solutions and its counterpart in on-site construction are first defined. It is important to define accurately which materials, tasks and activities are included in the analysis. In the second step, the impact factors in the specific project context are defined. The importance of some factors, such as the surrounding environment, might vary a lot between projects. For simplicity of the analysis, some factors could be excluded from the analysis. In the third step, a decision is made which factors are considered in cost analysis and which in non-monetary CBA analysis. After that, an analysis of non-monetary factors follows typical CBA process. Regarding monetary factors (including impacts which could be converted to costs), the process includes steps to calculate direct costs of alternatives as well as indirect costs regarding other benefits, such as shortened project time, decreased defects or decreased injuries. In the end, the importance points of alternatives are visualized with total costs. The final decision could be made by a single manager or in a group of experts including, e.g. clients, designers and different trade contractors.

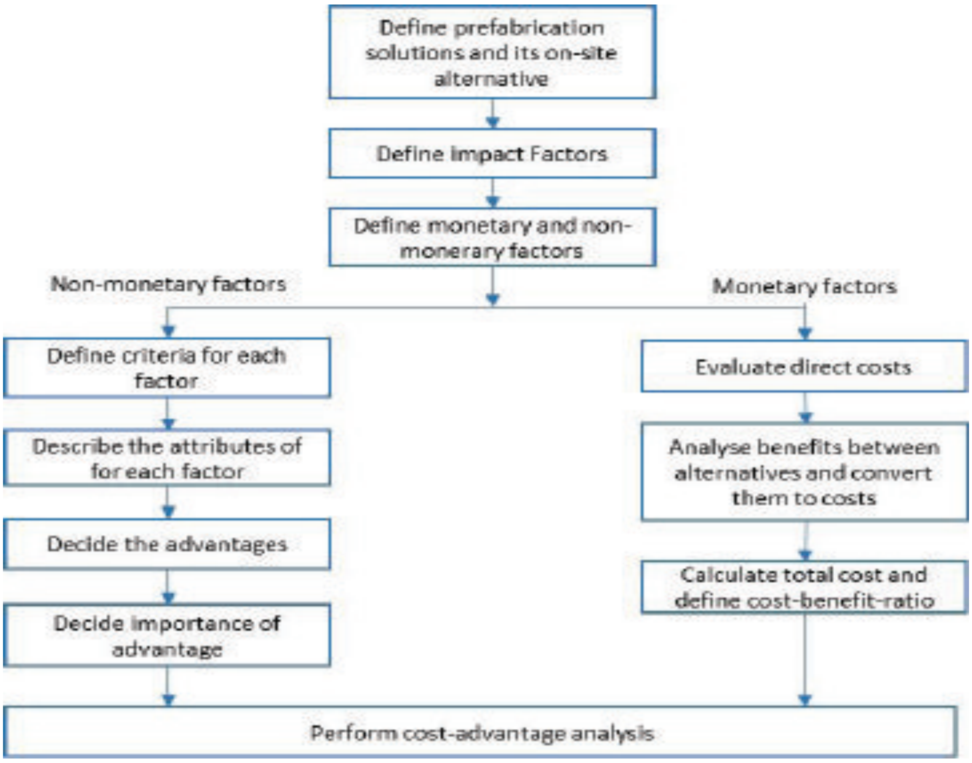


Figure 2. Combining CBA with a cost-benefit analysis for choosing between prefabrication and on-site construction

Table 2. Description of steps in the prefabrication evaluation process

Steps	Description
1. Define prefabrication solutions and its on-site alternative	Select potential prefabrication solution and its counterpart in on-site construction
2. Define impact factors	Define relevant impact factors for the selected prefabrication solution in the specific project context
3. Define monetary and non-monetary factors	Determine whether the impact factor should be measured as monetary impact, non-monetary impact or both
4. Define criteria for each factor	For non-monetary factors, decide the criteria for judging each factor; can include also must have/want to have criteria
5. Describe the attributes for each factor	For non-monetary factors, define the attributes of each alternative of each factor.
6. Decide the advantages	For non-monetary factors, define the least preferred attributes for each factor. Define the advantage for the other alternative compared to the least preferred attribute.

7. Decide the importance of each advantage	For non-monetary factors, first, based on subjective project criteria and each advantage, decide which single advantage is the most essential and give certain points for that. Then, based on subjective knowledge decide the (lower) points of the other advantages.
8. Evaluate direct costs	Direct costs include material, labour and transportation costs of prefabricated modules as well as responding costs in the conventional method.
9. Analyse benefits between alternatives and convert them to costs	This analysis takes into account indirect costs including other monetary factors cost implications, such as time-related costs, additional design costs, costs of injuries etc.
10. Calculate total cost and define cost-benefit-ratio	Sum up direct costs and indirect costs. Calculate cost-benefit-ratio by comparing total costs of prefabrication solution and on-site construction
11. Perform cost-advantage analysis	Finally, compare total costs with the CBA importance points of alternatives. Make the final decision.

CONCLUSION AND DISCUSSION

This paper developed a process to facilitate decision making between prefabrication and on-site construction in projects. The study identified the impact factors of prefabrication and proposes a way of applying Choosing by Advantage (CBA) combining with the cost-benefit analysis for selecting between prefabrication and on-site construction in different project circumstances. Based on the literature, we presented fifteen impact factors of prefabrication. Cost, project schedules, quality, design flexibility and the surrounding environment are the major factors. A focused group discussion (FGD) was used to validate the impact factors and discuss the process of applying CBA.

Based on our study, we argue that CBA combined with the cost-benefit analysis could be a suitable approach to decide on whether or not to apply prefabrication. It allows making transparent decisions based on several impact factors of which some can be converted to cost impacts, but others can be evaluated only as non-monetary impacts and their advantage comparison between the alternatives. The originality of this paper is that it presents a new process which supports decision making between production methods which have multiple different impacts in specific project contexts. The authors will conduct further research by testing the process in real-life projects which utilize different prefabrication products.

REFERENCES

Antillón, E.I. , Morris, M.R. & Gregor, W. 2014, 'A Value-Based Cost-Benefit Analysis of Prefabrication Processes in the Healthcare Sector: A Case Study' In: Kalsaas, B.T., Koskela, L. & Saurin, T.A., 22nd Annual Conference of the International Group for Lean Construction. Oslo, Norway, 25-27 Jun 2014. pp 995-1006

Alinaitwe et al. (2006). Assessing the degree of industrialisation in construction – a case of Uganda. Journal of Civil Engineering and Management, 12(3), 221–229.

Arroyo, p. (2014), 'Exploring Decision Making Methods for Sustainable Design in Commercial Buildings'. PhD Dissertation, Civil and Environmental EngineeringUniversity of California, Berkeley

Arroyo, P., & Molinos-Senate, M. (2018). Selecting appropriate wastewater treatment technologies using a choosing-by-advantages approach. Science of the Total Environment, 625(1), 819–827.

Arroyo, P., Tomelein, I. D., Ballard, G., & Rumsey, P. (2016). Choosing by advantages: A case study for selecting an HVAC system for a net zero energy museum. Energy and Buildings, 111(1), 26–36.

Chauhan, K., Peltokorpi, A., Seppänen, O and Berghede, K. (2018). "Combining Takt Planning with Prefabrication for Industrialized Construction." In: Proc. 26th Annual Conference of the International. Group for Lean Construction (IGLC), González, V.A. (ed.), Chennai, India, pp. 848–857.

Easmann, C., & Sacks, R. (2008). Relative Productivity in the AEC Industries in the United States for On-Site and Off-Site Activities. Journal of Construction Engineering and Management, 134(7), 517–526.

Goodier, C., & Gibb, A. (2007). Future oppertunities for offsite in the UK. Construction Management and Economics, 25(6), 858–595. https://doi.org/10.1080/01446190601071821

Haapasalo et al. (2015). 'Applying the choosing by advantages method to select the optimal contract type for road maitenance'. Int, J. Procurement management, Vol. 8, No.6.

Hong et al. (2016). Life-cycle energy analysis of prefabricated building components: an input–output-based hybrid model. Journal of Cleaner Production, 112, 2198–2207.

Hong, J., Shen, G., Li, Z., Zhang, B., & Zhang, W. (2018). Barriers to promoting prefabricated construction in China: A cost–benefit analysis. Journal of Cleaner Production, 172, 649–660.

Jaillon, L., Poon, C. ., & Chaing, Y. H. (2009). Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. Waste Management, 29, 309–320. https://doi.org/10.1016/j.wasman.2008.02.015

Khanazode, A., Fischer, M., & Reed, D. (2008). Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project. Journal of Information Technology in Construction, 13, 324–342.

Lavikka, R., Chauhan, K., Peltokorpi, A. and Seppänen, O. (2018) Fostering prefabrication in construction projects – case MEP in Finland in eWork and eBusiness in Architecture, Engineering and Construction, eds. Karlshoj, J. & Scherer, R. Taylor & Francis Group, London, UK. Proceedings of the 12th European Conference on Product and Process Modelling (ECPPM 2018), Copenhagen, Denmark, 12-14 September 2018.

Li et al. (2014). Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. Resources, Conservation and Recycling, 91, 27–39. https://doi.org/https://doi.org/10.1016/j.resconrec.2014.07.013
Lu et al. (2018). Searching for an optimal level of prefabrication in construction: An analytical framework. Journal of Cleaner Production, 201(10), 236–245.
Murguia, D., & Brioso, X. (2017). Using "Choosing by Advantages" and 4D Models to Select the Best Construction-Flow Option in a Residential Building. Procedia Engineering, 196, 470–477.
Neill,O.,& Organ, S. (2016). "A literature review of the evolution of British prefabricated low-rise housing", Structural Surveys,Vol. 34 Issue:2, pp. 191-214
Paudel, P., Dulal, S., Bhandari, M., & Tomar, A. K. (2016). Study on Prefabricated Modular and Steel Structures. International Journal of Civil Engineering(SSRG-IJCE), 3(5).
Parrish, K. & Tommelein, I.D. 2009, 'Making Design Decisions Using Choosing by Advantages' In:, Cuperus, Y. & Hirota, E.H., 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15-17 Jul 2009. pp 501-510
Piroozfar, P. A. E., & Farr, E. R. . (2013). Evolution of nontraditional methods of construction: 21st century pragmatic viewpoint. Journal of Archetectural Engineering, 19(2), 119–133.
Pasquire, C. , Gibb, A. & Blismas, N. 2005, 'What Should You Really Measure if You Want to Compare Prefabrication With Traditional Construction?' In:, 13th Annual Conference of the International Group for Lean Construction. Sydney, Australia, 19-21 Jul 2005. pp 481-491
Schöttle,A. and Arroyo, p. (2017). 'Comparison of weighting-rating-calculating, best value, and choosing by advantages for bidder selection'.J. Constr. Eng. Manag., 143 (8) , Article 05017015
Suhr, J. (1999). 'The Choosing by Advantages Decision Making System'. p. 293

Chauhan, K., Peltokorpi, A., Lavikka, R., and Seppänen, O. (2019). “Deciding Between Prefabrication and on-site Construction: A Choosing-by-Advantage.” In: *Proc. 27th Annual Conference of the International. Group for Lean Construction (IGLC), Pasquire C. and Hamzeh F.R. (ed.),* Dublin, Ireland, pp. 749–760. DOI: https://doi.org/10.24928/2019/0158. Available at: <www.iglc.net>.