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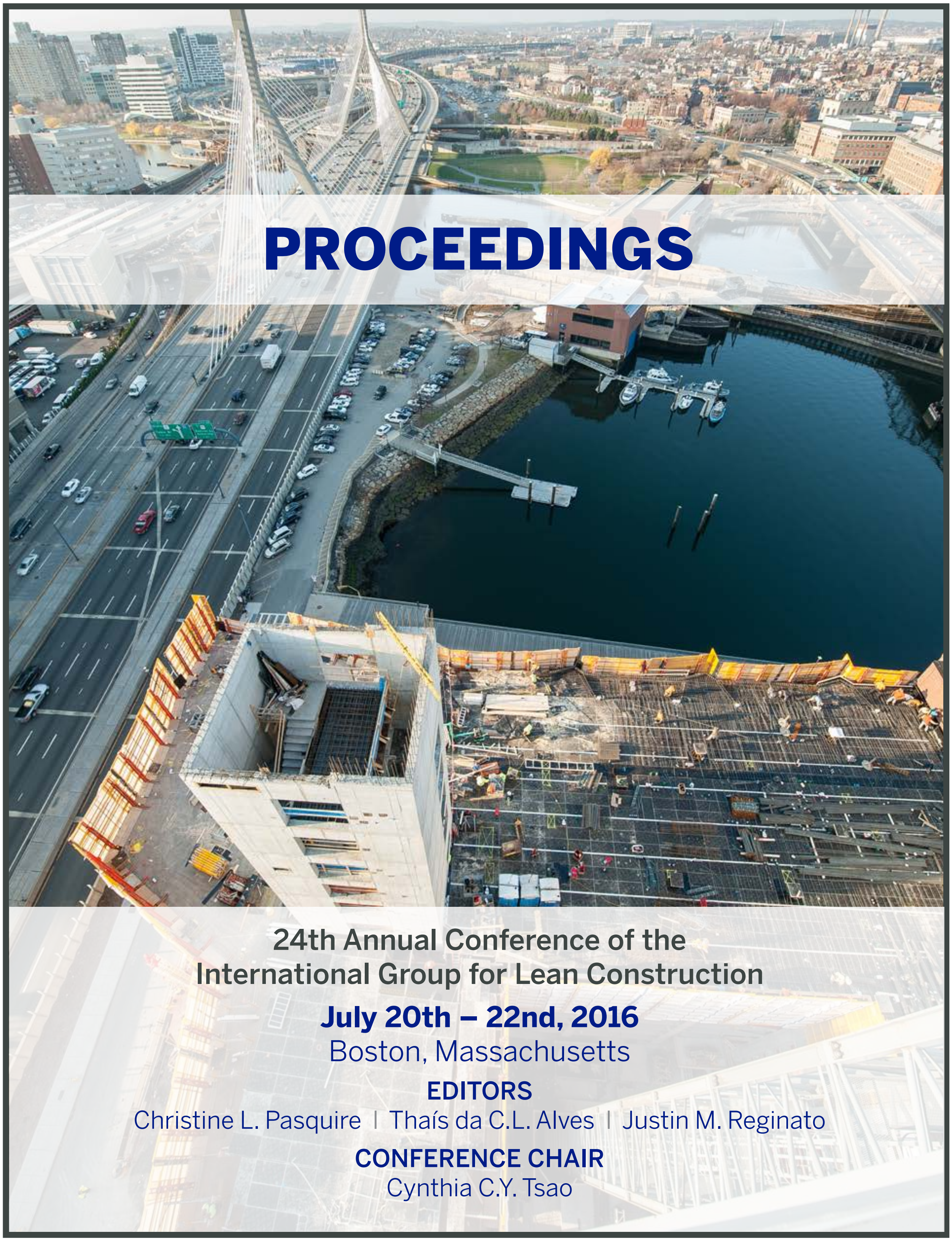

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EXPLORATION OF A LEAN-BIM PLANNING FRAMEWORK: A LAST PLANNER SYSTEM AND BIM-BASED CASE STUDY

Mauricio Toledo[1], Katherine Olivares[2], and Vicente González[3]

ABSTRACT

Current Lean Construction and Building Information Modelling (BIM) research has been focused largely on the theoretical aspects related to their integration and synergies. But little attention has been paid to the development of BIM-Lean practical methods to manage projects and provide evidence of the opportunities for performance enhancement. In this paper, we attempt to bridge this gap by proposing a Lean-BIM planning framework by integrating the Last Planner System and BIM.

The development of the proof of concept of the BIM-Lean planning framework was undertaken by comparing two case studies: one using only LPS and the other using LPS and BIM. We followed construction activities related to rough work in two comparable building projects as part of the field office staff. We gathered project data and analysed and compared planning procedures in both projects. Data collected included: weekly and lookahead planning meetings analyses; design requests for information (RFI); and LPS metrics. We then used flowcharts to document both planning processes and the improved planning proposal, and also, integrated the different planning levels. Results show that the coordinated use of LPS and BIM generates an increase in PPC, a decrease in reasons for non-compliance, a shortening of the meeting durations, and a decrease in the total number of design RFIs. The improved planning proposal combines LPS+BIM and facilitates the interaction of a larger and diverse number of project stakeholders around BIM manipulation in planning meetings. Project meetings become more effective and the communication of project planning improves as a result.

KEYWORDS

lean-BIM, last planner system, RFI

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INTRODUCTION

Information technologies, such as BIM (Building Information Modeling) (Eastman et al., 2008) help stakeholders to better deliver construction projects. For instance, 4D modeling (animation of the construction process achieved by combining the project´s 3D geometry with the planned construction sequence) help the project participants to better understand and communicate the construction plan (McKinney and Fischer, 1998; Kuo et al., 2011). BIM models display design and construction information and hence, help to improve the interaction and collaboration among the project participants (Koo and Fischer, 2000).

The "Last Planner System" (LPS™) is a production control system based on Lean Production. The LPS's goal is to increase performance as a result of improved reliability of planning and reduced variability of workflow. LPS™ acts over four project planning levels. The Master plan produces the initial project budget and schedule, and provides a coordinating map that 'pushes' completions and deliveries onto the project. The Phase schedule produces more detailed and manageable plans from master plans with high complexity level. The Lookahead plan focuses on controlling the flow of work through the production system, detailing and adjusting budgets and schedules 'pulling' resources into play. Commitment planning (short-term period) determines the activities and scheduled work that will be done onsite (operational level) according to the status of resources and prerequisites (Ballard and Howell, 2003; Ballard, 2000).

The ability of a crew to reliably perform work depends on the stability of the workflow. A stable workflow depends on construction preconditions such as resources and prerequisites that should be available whenever they are needed (Koskela, 2000).

LPS™ uses the percentage of plan completed (PPC) as a planning reliability index. The analysis of reasons for non-compliance (RNC) is performed to understand why planned work was not completed. The goal of this analysis is to discover the root causes and rectify the problem. This data provides a basis for improving PPC (Ballard, 2000).

Literature provides some stepping stones for the integration between LPS and BIM. Recent work has proven that the LPS™ can be used in combination with 4D models (a BIM-Lean approach) to improve the understanding of the project progress, and to prepare and provide more useful handouts to the planning meetings' participants (Mora et al., 2009; Khanzode, 2010; Sacks et al., 2011; González, 2012; Toledo et al., 2014). Sriprasert & Dawood (2003) proposed a virtual tool to help visualize physical constraints and the project progress. Bhatla and Leite (2012) proposed a theoretical integration framework of BIM and LPS. However, these contributions do not directly address the challenges of implementing such an integrated approach. They rather discuss an alternative that worked or do not provide any evidence proving that their proposal work in practice (e.g. Bhatla and Leite, 2012). The motivation behind this research is to develop a framework to better use BIM models together with LPS, in order to improve the project planning performance. Also, this paper aims to provide robust empirical evidence for the potential use and implementation of a BIM/LPS framework.

To do so, we compare in this research two similar projects that use LPS for planning. Furthermore, we used BIM in one of them to support the project delivery. We first show the impact of using BIM to assist the use of LPS (Lean-BIM) on the improvement of commonly used lean project performance indexes: percentage of plan completed (PPC), reasons for non-compliance (RNC) and request for information (RFI). We then used flowcharts to document both planning processes and the improved planning proposal. Flowcharts created include master planning, lookahead and weekly schedules, and the way they integrate with each other.

RESEARCH METHOD

We first gather weekly planning data during rough work from both projects. Aspects tracked included planning meetings dynamics –such as meeting durations, participants and their project roles-; LPS indexes –such as percentage of plan completed (PPC) and reasons for non-compliance (RNC)-; and design requests for information (RFI). We analysed the project information and compared the performance of both projects.

We made a diagnosis of existent problems and prepared an improved proposal for project planning using LPS and BIM that were documented using flowcharts for each planning phase (master plan, lookahead and weekly plan).

DESCRIPTION OF CASE STUDIES

We present two comparable case studies in this section. One uses LPS and the other uses LPS and BIM. Following, we show their similarities and differences.

CASE 1: INACAP RANCAGUA PHASE 1

This project consists of two higher education buildings located in Rancagua, Chile. The four floor reinforced concrete buildings consider classrooms, labs, administrative offices, an auditorium, and a library. Total gross area is 11,500 m2 and the rough work phase original duration was 9 months.

Project planning and control was done using LPS and a Master Plan was created at the beginning of the project. There is also a weekly lookahead planning meeting to review the Master Plan activities and plan the work for the next 4 weeks (4 week lookahead planning). In this meeting all restrictions, the responsible to release them and the deadlines are committed in order to execute the project according to plan. There is also a weekly planning meeting, where the current week activities are scheduled according to the lookahead plan. At this weekly meeting, project compliance is monitored and LPS performance indexes are recorded and shared (PPC and RNC). During the project execution, the General Contractor submits RFIs to the owner´s representative. Most of them are related to missing drawings and drawing details and specs, geometric interferences and project information validation (due to contradictions or lack of clarity). Latency for RFIs varies widely and was also tracked.

We participated in about 35 lookahead and weekly planning meetings. We recorded the date, start and finish time, participants (and their project roles) and we had access to the meeting minutes. During the lookahead meetings we reviewed the lookahead constrains in tabular form and determined the planning reliability for each last planner. Each week we tracked and shared this planning performance index. During the weekly planning meetings every last planner shared their PPC and next week plan, and RNC were recorded. After the meeting, PPC, weekly plans and RNC were shared in tabular form which was included in next week's presentation.

RFIs were received and channeled through a member of the onsite technical office to the owner representative. They were received as they arose. They were formalized in a paper form followed by an email to the owner representative. We reviewed and classified them, and focused our attention on the most common ones that deals with geometric interferences and project information validation.

We developed four flowcharts to formalize the weekly and lookahead planning cycles (2) and one each to document the dynamics within each meeting (2).

CASE 2: INACAP RANCAGUA PHASE 2

This project consists of one higher education building located at the same site of the previous case in Rancagua, Chile. The reinforced concrete building has two floors and one underground level that include teaching workshops, some classrooms, and a cafeteria. Total gross area is 7,500 m2 and the rough work phase original duration was 5 months and 3 weeks.

Besides the project planning described for the first case, in this project the owner provided a BIM model (Autodesk Revit) which was used in the weekly meetings to show the project details and the scheduled and completed activities. Screen captures for each activity were shared on a meeting presentation, where each day's work was shown with different colors. The owner´s architect performs clash detection and documents RFIs with it. Direct manipulation of the BIM model at the meetings is done at the participants request for details. Lookahead planning meetings and RFIs management took place the same way as described before.

We participated in about 22 lookahead and weekly planning meetings during the rough work phase, which were carried out similarly to the first case study. Main differences can be summarized as follow: (i) besides PPC and RNC tracking, for each RNC a corrective measure was suggested; (ii) an analysis of all topics not covered in previous meeting minutes was added and safety, human resources and material warehouse reports were briefly discussed; (iii) during weekly planning meetings a presentation that included BIM screen captures was shared; (iv) RFIs were still managed as they arose, but during the weekly planning meetings their status was checked and some questions were cleared using the BIM model.

As we did with the first case study, we developed flowcharts to document weekly planning cycles (lookahead planning remains the same, so no map is added) and the dynamics within the meeting. The resulting process maps highlight the changes between both case studies.

RESULTS AND COMPARISON OF CASE STUDIES

We show the main results from the case studies and compared them. Project data for lookahead planning meetings, weekly planning meetings, and RFIs is presented.

LOOKAHEAD PLANNING MEETINGS

For Case 1, project participants spent on average 23.25 men-hours in lookahead planning meetings and the average attendance was 9 professionals representing 5 different project roles. The average duration of the lookahead planning meetings was 2:35 hrs. Planning reliability for all last planners was 66% (measured as % of constrains released as scheduled).

For Case 2, project participants spent on average 19.60 men-hours in lookahead planning meetings and the average attendance was 9 professionals representing 5 different project roles. The average duration of the lookahead planning meetings was slightly shorter than in Case 1 at 2:27 hrs. Planning reliability stood virtually the same at 65%.

WEEKLY PLANNING MEETINGS

For Case 1, projects participants spent on average 18.66 men-hours in weekly planning meetings. 15 professionals representing 5 different project roles regularly took part in the meetings. Others were invited but opted out. The average duration of the weekly planning meetings was 1:52 hrs.

PPC goal for the project was 75.0% and a 76.7% was achieved, with an average variability of 10.1% respect to the average (see Figure 1). Table 1 shows that 89 RNC were recorded for Case 1, with an average of almost 10 RNC/month.

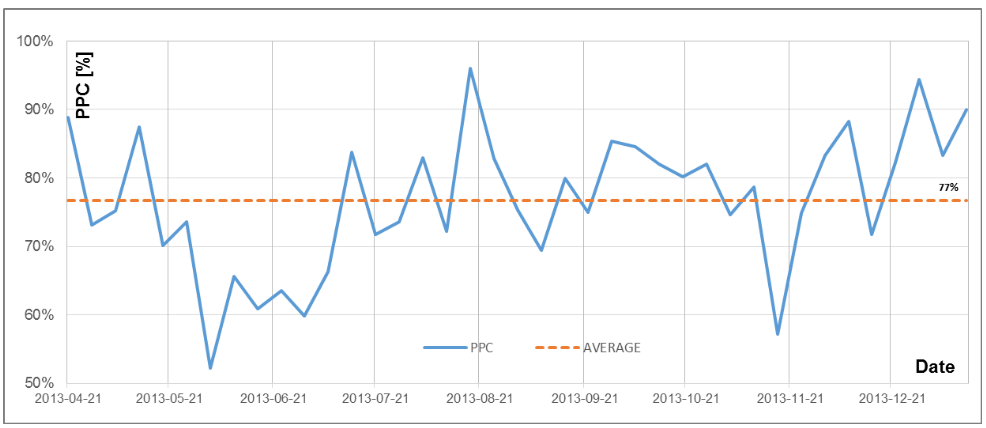

Figure 1: Percentage of Plan Completed - Case 1. Recorded at weekly planning meetings.

Table 1: Reasons for non-compliance - Case 1. Tracked at weekly planning meetings.

Reasons for non-compliance (RNC)	# RNC	Avg # RNC/month
Too many activities assigned to subcontractor	6	0.7
Activity performance overestimation	38	4.2
Wrong planning	35	3.9
Others (planning problems)	10	1.1
TOTAL	**89**	**9.9**

For Case 2, projects participants spent on average 18.54 men-hours in weekly planning meetings. 16 professionals representing 9 different project roles regularly took part in the meetings. The average duration of the weekly planning meetings was 1:30 hrs.

Therefore, at about the same cost (similar men-hours), a larger number of participants and project roles participated in shorter weekly meetings backed by BIM models.

Average PPC was 85.0% (above the goal and significantly better than in Case 1). The average variability was reduced to 4.6% respect to the average (see Figure 2). Table 2 shows that 55 RNC were recorded for Case 2, with an average of 10 RNC/month (no change from Case 1). We can also note from Tables 1 and 2 that most RNC related to planning decreased in Case 2 (performance overestimation or wrong planning).

On top of the performance improvement on LPS indexes and RFI management when we compared Case 1 and 2, we can point out that the use of BIM had a positive impact on last planners during the weekly planning meetings for Case 2. In Case 1, weekly plan was shared in tabular form without much interaction among project participants, while in Case 2, when BIM was used, last planners asked questions and participated in the meeting. The process improvement meant an increase in meeting participation, particularly when defining the work plan and scheduling of concurrent activities (hard to detect in tabular form). The interaction was focalized and even meant a shortening of project meetings from 1:52 to 1:30 hrs. for Case 2. Case 2 learnt lessons reached beyond the project success and were taken by the last planners to their next projects. They requested LPS+BIM integration to their project managers (some of whom were not even familiar with their joint use).

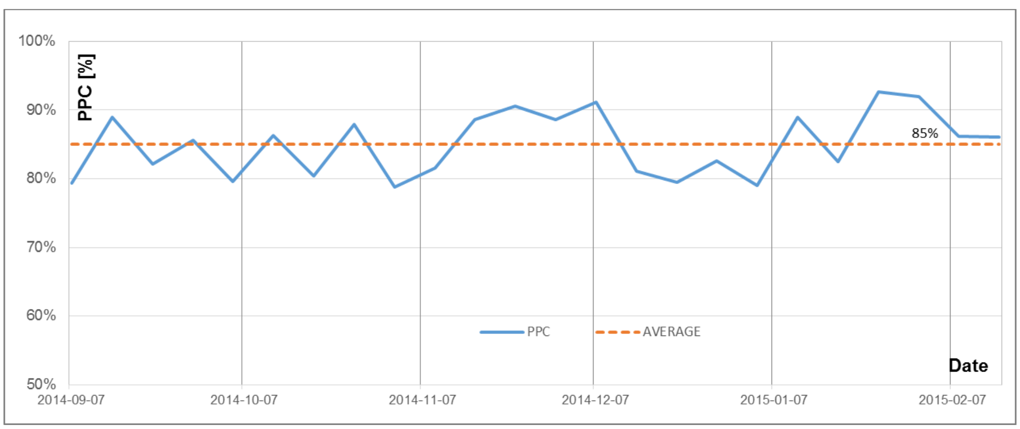

Figure 2: Percentage of Plan Completed - Case 2. Recorded at weekly planning meetings.

Table 2: Reasons for non-compliance - Case 2. Tracked at weekly planning meetings.

Reasons for non-compliance (RNC)	# RNC	Avg # RNC/month
Too many activities assigned to subcontractor	21	3.8
Activity performance overestimation	12	2.2
Wrong planning	17	3.1
Others (planning problems)	5	0.9
TOTAL	**55**	**10.0**

RFIs

For Case 1, a total of 104 RFI were managed during the project rough work. 2.89 RFI/month were issued regarding project geometric interferences, while 2.11 RFI/month were issued about project information validation.

For Case 2, a total of 45 RFI were managed during the project rough work. 1.04 RFI/month were issued regarding project geometric interferences, while 1.04 RFI/month were issued about project information validation. The absolute number of RFI was drastically reduced from 104 to 45 (from 12 to less than 8 RFI/month) in Case 2. Project geometric interferences were reduced from 2.89 to 1.04 RFI/month due to BIM use.

DIAGNOSIS OF PROBLEMS AND LEAN-BIM FRAMEWORK

Though there is a performance enhancement from Case 1 to Case 2, there is still room for improvement. The main problems identified are:

i. BIM model is not shared with all project stakeholders.
ii. There is little sharing and reinforcement of information reviewed and discussed within the lookahead and weekly planning meetings.
iii. Meeting participants came unprepared to lookahead planning meetings which meant long meetings.
iv. RFI related information was not readily available to lookahead planning meeting participants, so a piece of information was missing.
v. There is no explicit connection between lookahead planning meetings and weekly planning meetings.
vi. Though a larger number of participants were invited to the weekly planning meetings, their attendance was not mandatory (and some opted out). However, they could be missing when decision making was necessary for the work plan.
vii. Weekly planning meetings included an agenda with topics unrelated to the weekly work plan development.

Based on the project performance improvements observed from Case 1 to Case 2 and the problems just listed, we identified the following features that our framework should include:

- The final Master Plan and the corresponding 4D model should be shown to the entire project team.
- On site informative bulletin boards have to be available to display all information about lookahead and weekly planning meetings. They should be updated weekly.
- Every participant of the lookahead planning meeting should analyse the lookahead activities before the meeting.
- RFI will be part of the lookahead planning meetings in order to consider design constrains and communicate solutions and commitments to weekly planning meetings. The constrains status should be sent by email to last planners.
- Subcontractors' last planner related to critical activities must take part in weekly planning meetings.
- Safety and human resources reports will not be part of the weekly planning meetings (kept out the agenda) to focus the discussion on the work plan.
- A set of interrelated process maps will facilitate the adoption of the proposed framework.

Figures 3, 4 and 5 explain how the proposed framework works.

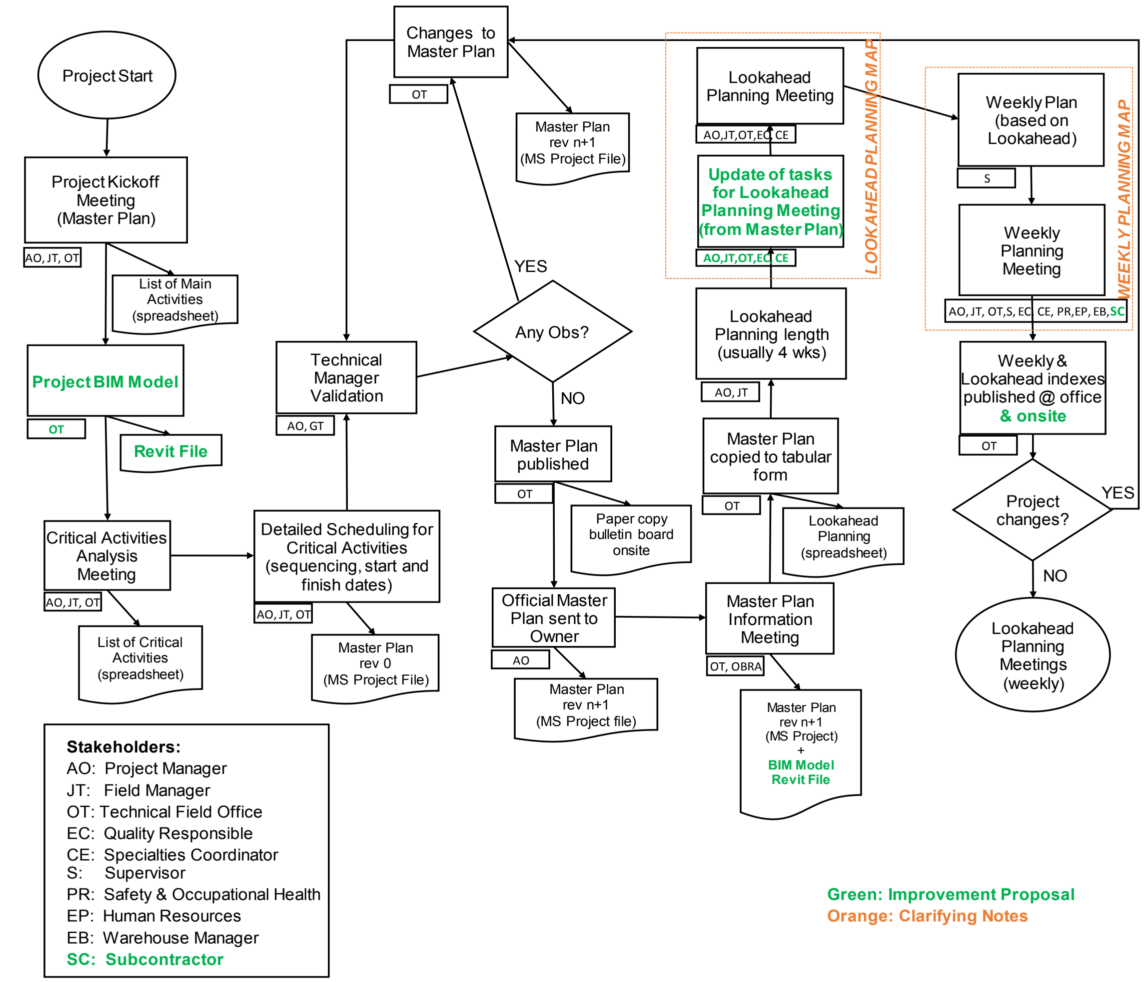

Figure 3: Improved proposal for BIM-LEAN framework.

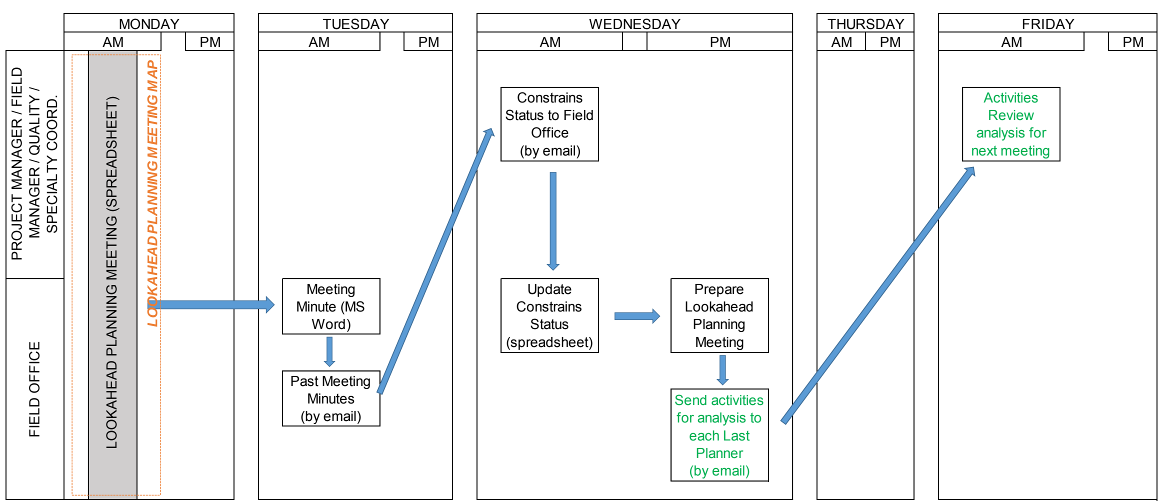

Figure 4: Improved proposal for lookahead planning.

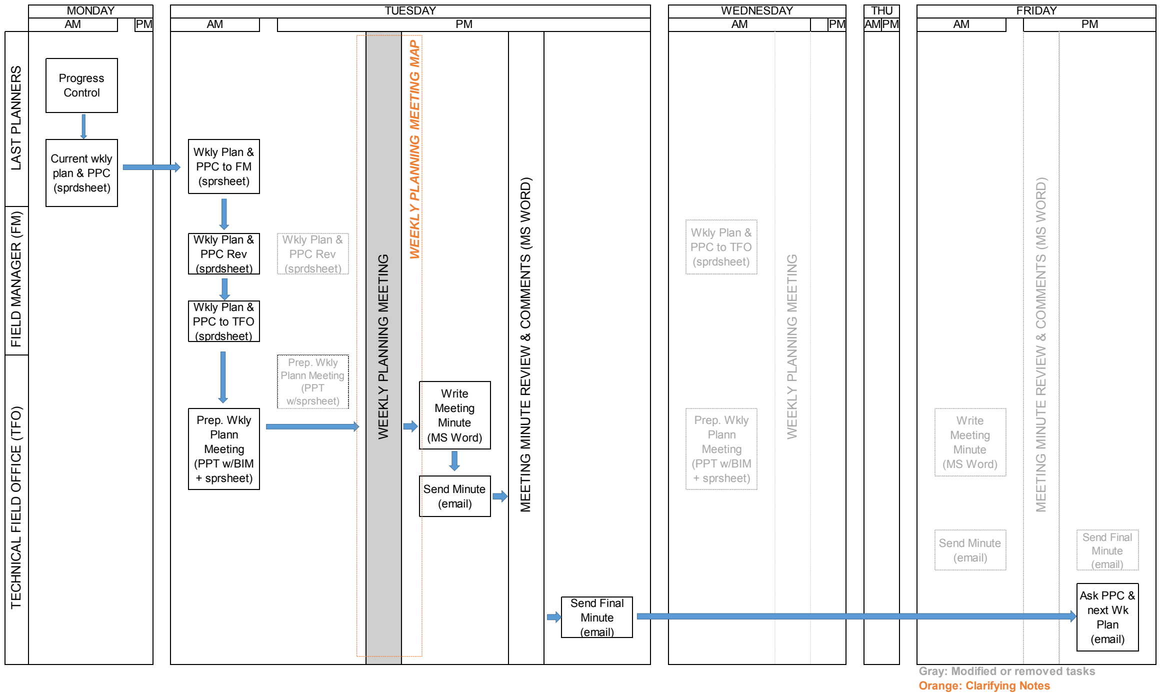

Figure 5: Improved proposal for weekly planning.

CONCLUSIONS

Lookahead planning meetings suffered virtually no changes (in duration and last planners' reliability). We should note that BIM models were not used for lookahead planning.

Regarding weekly planning meetings, LPS+BIM enabled an increase of participants (from 15 to 16), representing a larger number of project roles (from 5 to 9) by reducing the meeting duration from 1:52 to 1:30 hrs. while maintaining the total number of men-hours spent on this type of meeting (a little over 18,5 hrs/week). Therefore, at the same cost (men-hours) a better project understanding is reached when using LPS+BIM.

PPC improved from 76.7% to 85.0% and PPC variability decreased from 10.1% to 4.6% for LPS+BIM. Therefore, planning reliability improved. We can also note that most RNCs related to planning decreased in Case 2 (performance overestimation or wrong planning).

Regarding RFI management, we observed a big improvement when using LPS+BIM. Absolute number of RFI decreased from 104 to 45 (from 12 to less than 8 RFI/month). Project geometric interferences were reduced from 2.89 to 1.04 RFI/month due to BIM use, because they were earlier detected in weekly project meetings and solved with the aid of the BIM models (no need to create a RFI).

Lessons learnt from both cases were incorporated in the Lean-BIM framework described through a set of interrelated flowcharts.

Our findings are grounded on the reinforced concrete building construction case studies presented during the rough work phase. Further work is needed to generalize the results to the finishing phase, and/or other building types. Both projects were executed by the same general constructor and same project team, so a learning curve effect should not be discarded when explaining the performance differences among both case studies.

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BUILDING INFORMATION MODELING: A REPORT FROM THE FIELD

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ABSTRACT

Since its inception in the early 2000s, Building Information Modeling (BIM) has evolved from an emerging innovation to an integral part of the construction industry. Though the benefits of BIM during the preconstruction and coordination phases have been thoroughly researched and documented, investigation into the present status of BIM implementation at the construction phase has remained primarily theoretical. This article aims to record the current state of field level BIM use by General Contractors in order to gain insight on how BIM is being implemented at the construction site today. The data used for analysis was collected via a nationwide survey distributed to several internationally known General Contractors. Through this research, the goal is not only to understand the ways through which field level employees are using BIM on their projects, but also to determine the underlying structures of the field implementation processes, the employees' comfort navigating the technology, the perception of BIM's reliability, and the impact of Lean Construction on project sites through use of the BIM. From this article's findings, it is the authors' hope that companies can leverage the information to stimulate training, revise inefficient BIM implementation structures, and further the integration of BIM and Lean at the field level.

KEYWORDS

Building Information Modelling, Collaboration, Continuous Improvement, Value

INTRODUCTION

Over the past 25 years, the use of BIM in the AEC industry has evolved from a technological novelty, to an integral part of the present day building and design process (van Nederveen and Tolman, 1992). During this same time period, research into the use and value of BIM in construction has steadily increased, providing insight into the implementation of the technology in a wide variety of building stages and conditions. This increase in research has helped to define the quantifiable benefits of BIM as well as

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theorize additional ways BIM may be used beyond design development and coordination. Though large strides have been made in understanding BIM's impact on the AEC field, current research into the present state of BIM usage at the operational level is lacking. Through this paper, the authors seek to understand both the current use of BIM and the current intersections of BIM and Lean at the field operational level on a national scale in order to help further industry understanding in those areas.

LITERATURE REVIEW

In the study "The Perceived Value of BIM", Becerik-Gerber and Rice (2010) found that less than half of AEC companies surveyed used BIM on their projects in any capacity. Of the companies taking advantage of the technology, benefits were noted in project profitability, decreased project costs, reduced project duration and increased quality and accuracy of construction documents. It was noted by survey participants, however, that "in order to effectively study the value of BIM and for significant returns on investment to be noticed, a time frame of 5 to 8 years is needed"

Since that time, academics and industry professionals have further explored the presence of BIM in construction. Sacks et al. (2010a) researched connections between BIM and Lean Construction, hypothesizing ways that BIM could further be used to affect change in the AEC realm. Dave et al. (2011) and Sacks et al. (2010b) piloted BIM programs (Visilean and KanBIM respectively) and both integrated Lean concepts within the BIM environment to support the management of construction operations. Bhatla and Leite (2012) suggested a framework to integrate BIM and the Last Planner System®,(LPS) which promotes the use of multiple Lean concepts to protect production tasks from uncertainty and stabilize the flow of tasks on site. On a similar note, Harris and Alves (2013) have discussed how BIM could be used on site to promote transparency, enhance communication between parties, and prevent wasteful activities. More recently, Lin and Golparvar-Fard (2016) have integrated 4D BIM with the capture of site images to manage construction activities in real time, and provided an unprecedented level of visualization of tasks indicated in multiple levels of the LPS.

Though these studies were ground-breaking in their investigation into BIM's relation to the construction process, little information was found which could serve to elucidate and quantify the degree to which BIM is being used on construction sites today and why its full potential has not yet been achieved. Practitioners and academics understand that BIM has yet to be fully used to manage field operations and synergistically promote Lean principles. As such, this study was performed in order to help bring clarity to the current status of field BIM implementation and indicate potential areas that need to be addressed if the industry is to achieve the numerous synergies identified by Sacks et al. (2010a).

METHODOLOGY

The survey questions and format were assembled over several iterations between October 2015 and December 2015. Following completion of the survey, it was recreated electronically for ease of testing and distribution, reviewed with industry professionals for content value, and distributed to a test group of individuals for confirmation of response timing and technical soundness. SurveyMonkey was used to create and distribute the survey.

Next, three internationally recognized general contractors were approached for inclusion in the study. All three companies were provided with identical surveys via separate, company specific survey links. An upper level management figure was presented with their company's specific survey link as well as verbiage describing the study. The link and verbiage were then disseminated to field employees via distribution email lists for response. Over the survey period of December 2015 to February 2016, a total of 149 survey responses were received.

The survey was composed of four major sections covering the respondent's personal demographics and BIM use. The first section asked general questions regarding the participant's location, role, construction experience, in addition to current project type and size. The second section asked respondents to detail their current use of BIM in the field via answers to multiple choice and fill in questions. The third section covered the respondent's access to tools and training for BIM. The last section asked the respondents questions regarding their opinion on the current value of BIM in field operations.

SURVEY RESULTS

This section discusses the results of the survey and puts them in context by comparing the results obtained from this study to previous studies when these are available for the same items analyzed in this study. The section starts with a discussion about the demographics and moves on to analyze BIM usage by different professionals with different roles and in projects with varied sizes, and the use of BIM-related tools.

RESPONDENT DEMOGRAPHICS

A total of 149 completed survey responses were received over the course of a two-month collection period. Of the three international general contracting firms approached to participate, the majority of the responses were received from one of the three GCs. Though it is possible that the lack of company diversity in the received responses impacted the representative nature of the data, the authors believe that the geographical spread of the data may limit the influence that localized corporate leadership choices could potentially have on the use of BIM in the field. The demographics of the survey can be summarized in the data presented below:

- 88% of respondents were located in Southern California, San Francisco, CA, Washington DC, Phoenix, AZ or Dallas, TX.
- The most frequent responders were Project Managers (48.3%); though Superintendents (22.1%), Project Engineers (19.5%), and BIM Coordinators (4.7%) were also represented.
- Approximately 1/3 of the respondents (37%) were still fairly early in their careers (0-10 years of industry experience). The remaining 2/3 of the respondents (63%) had been a part of the construction industry for 10 or more years.

- 16.1% of respondents were currently working on projects between 0-10MM, 62.4% on projects between 10-100MM, and 21.5% working on projects with values over 100MM.
- Most currently accepted delivery methods were represented in the sample, with 65.8% of the respondent's projects having a CM, GC, or DB delivery method

BIM USAGE IN FIELD OPERATIONS

When asked about individual usage of BIM, over 1/3 (37.6%) of the respondents reported that they did not personally use BIM on their current project. Of those that used BIM, the most common response (25.5%) was that BIM was used at least once per week. Comparing the proportion of people who used BIM between once a day and once per week, to those that did not use BIM at all, the amount of respondents were close in percentage (38.3% and 37.6%, respectively). As these responses are on either end of the BIM usage spectrum, this could indicate a dichotomy in the use of BIM on jobsites, with certain roles more frequently using BIM due to need or task delegation, while others of different roles may rarely open the model, if at all. This may also mirror a dichotomy in the application of Lean construction principles. The 37.6% of respondents not using BIM, will not have the opportunity to experience enhanced visualization and higher levels of transparency, at the field level, while those using BIM once or more per week will likely capitalize on these added benefits and enjoy better communication, shorter cycle times to identify and resolve problems, and fewer unnecessary steps to complete tasks. Though previous research did not cover the use of BIM at the field operations level in depth, a survey distributed and analysed in Becerik-Gerber et al (2010) report indicated a similar duality for their respondents with 38.9% of firms using BIM for 80-100% of their projects, and 30.0% using BIM for 0-20% of their projects.

Following the review of the individual uses of BIM, the effect of job role on personal BIM usage was explored. Figure 1 shows that BIM Coordinators used the BIM the most often of the job roles, with 85.7% of BIM coordinators using BIM daily. Superintendents, on the other hand, had the highest instances of BIM not being used, with 51.5% of superintendents not personally using BIM on their current projects. Project engineers showed a fairly even split between BIM being used daily (20.7%) and rarely (27.6%), while the majority of PMs appeared to be either not using BIM at all (38.9%) or using it once per week (27.8%).

These findings seem to indicate the use of BIM and thereby the increase of potential positive BIM-Lean construction interactions, currently vary by project role. BIM Coordinators are required to use BIM on a daily basis to perform their work, while Superintendents and Project Managers, arguably two of the most important roles running a project, are not benefiting from the potential that BIM has when it comes to supporting production planning and control, simulation of activities during preconstruction meetings, and visualization to clear constraints and clarifications about systems. Moreover, this finding might also indicate that the responsibility for onsite BIM tasks do not fall on the entire team. This conclusion is further supported when reviewing survey responses regarding the inclusion of an onsite staff member who is tasked with BIM. Over half of the respondents (55.6%) indicated that there was a dedicated staff member for BIM tasks on their project. If so much of the responsibilities for using the BIM falls onto one single individual in so many projects, leveraging the synergies between BIM and Lean on site, is limited to how much this individual understand how BIM can lead to increased value delivered to clients (on site and the end users), better flow, and reduced waste.

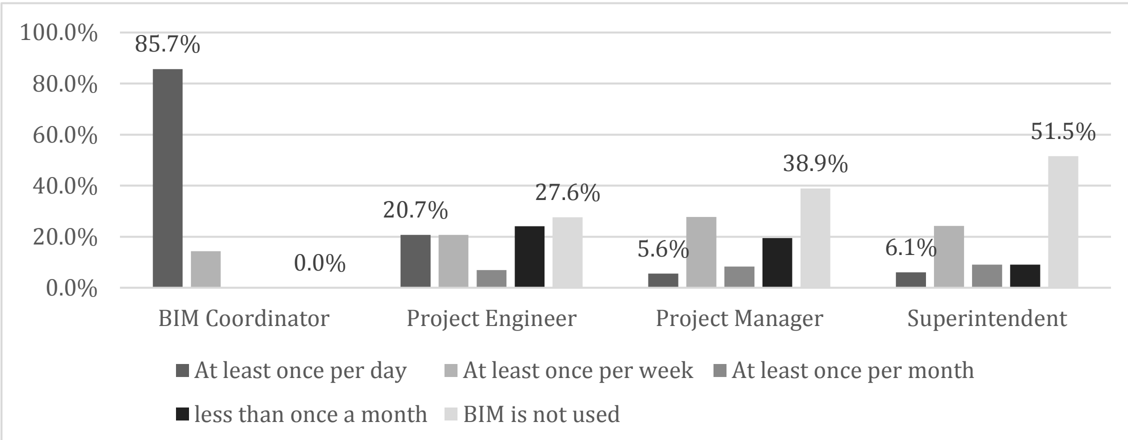

Figure 1: BIM Usage by Job Role

Respondents were next asked the ways through which BIM was used at their project site. The results of that question have been captured in Table 1.

Table 1: BIM Use by Task and Relative Location of Task Performance

	Percentage of BIM users who used BIM to assist with:	Percentage of BIM tasks performed onsite	Percentage of BIM tasks performed remotely	Percentage of BIM tasks performed both onsite and remotely
Clash Detection?	83.9%	34.6%	43.6%	21.8%
4D Scheduling?	10.8%	30.0%	40.0%	30.0%
Safety?	19.4%	72.2%	11.1%	16.7%
QA/QC?	28.0%	80.8%	3.8%	15.4%
Logistics Management?	20.4%	63.2%	21.1%	15.8%
Field Coordination?	61.3%	70.2%	12.3%	17.5%
Activity/Task Management?	16.1%	60.0%	13.3%	26.7%
Visualizing/Explaining Issues?	45.2%	64.3%	7.1%	28.6%
Commissioning?	3.2%	66.7%	33.3%	0.0%
Materials Management?	4.3%	50.0%	0.0%	50.0%
Closeout/Turnover?	17.2%	43.8%	25.0%	31.3%
Virtual Mock-ups?	17.2%	56.3%	25.0%	18.8%
Punch List?	16.1%	73.3%	13.3%	13.3%
Inspection Support?	4.3%	100.0%	0.0%	0.0%
Other BIM Field Use?	7.5%	57.1%	28.6%	14.3%

By reviewing Table 1, it can be determined that the majority of respondents used BIM for Clash Detection (83.9%), Field Coordination (61.3%), Visualizing Issues (45.2%), QA/QC (28.0%). For nearly all tasks reported, the data showed that the percentage of BIM tasks performed onsite was higher than those performed offsite or from dual locations. This is actually encouraging as those using BIM can take advantage of the "go and see for yourself" principle to match the model with site work as well as incorporate real time field knowledge into the models. The tasks performed mostly offsite were Clash Detection and 4D Scheduling. These findings seem logical as these two BIM tasks are incredibly time consuming and often require the assistance of a dedicated person. Often time these responsibilities are performed at a remote main office location by a support staff member separate from the onsite project team. When reviewing these BIM task results in conjunction with the BIM and Lean interactions identified by Sacks et al (2010), several areas of alignment were found between performed BIM tasks and positive LC interactions. Clash detection helped users to "reduce variability", "reduce cycle time" and "design the production system for flow and value" (Sacks et al, 2010). Field coordination and visualizing issues helped users "reduce variability", "reduce cycle time", and "use visual management" though increased communication and visualization (Sacks et al, 2010). Lastly, QA/QC BIM tasks allowed users to "reduce cycle time", "reduce variability", "verify and validate" and "go and see for yourself" (Oskouie et al, 2012).

Regarding the comfort level using BIM in the field, the most frequent response was that BIM users could open and navigate the model slowly, with issues (32.6%). It is interesting to note, however, that though approximately 2/5 of the respondents who used BIM were comfortable in the model, an additional 1/5 of users indicated that they did not know how to either open or pilot the BIM model. That's a full 19.6% of users who are currently unable to use BIM technology or benefit from Lean Construction capabilities inherent in the system.

INCORPORATION OF BIM TOOLS AND TRAINING AT THE FIELD LEVEL

When surveying the availability of BIM tools on the jobsite, it was found that the majority of respondents had access to a desktop/laptop computer (89.2%) and/or tablet (87.1%) hardware and BIM 360 (67.7%) software. When analyzing the respondent's available BIM tools in conjunction with the BIM tasks performed onsite, some connections can be made between the findings. The tasks with the highest percentages of performance onsite were inspection support (100%), QA/QC (80.8%), Punchlist (73.3%), and Safety (72.2%). The BIM 360 tool helped to provide a gateway to both the project team member's onsite BIM use and increased positive interactions with Lean Construction. Through BIM 360, teams were encouraged to "go and see for yourself" to complete safety checklists, were given an enhanced ability to "validate and verify" through QA/QC inspections, and "used visual management" to help trade contractors successfully complete work items with a visual punch list.

Regarding training on the use of BIM, 11.5% of respondents received a large amount of BIM training with the remaining 88.5% receiving either some or no training in the use of BIM. When taken in context with the responses to the users' comfort level using BIM (40% proficiency in navigating BIM), these numbers are understandable. Since BIM training appears to be lacking for the survey respondents, this absence of further training could explain the approximately 60% respondents who indicated issues opening and navigating the BIM. Additional survey questions confirmed that the majority of respondents (71.6%) believed that additional BIM training would be very beneficial to them in their current roles. A further 39.0% were neutral to additional training with only 2.4% believing that additional BIM training would be not at all beneficial. This mirrors many of the interview responses received. Nearly all interviewees indicated the need for additional training in order to support furthering the implementation efforts with BIM in the field. To capitalize on these trainings, inclusion of the benefits of Lean Construction in BIM operations should also be explored with the training attendees.

PERCEIVED VALUE OF BIM

Figure 2 shows the impact that job role has on the likelihood that survey respondents will find BIM to be a reliable source of information.

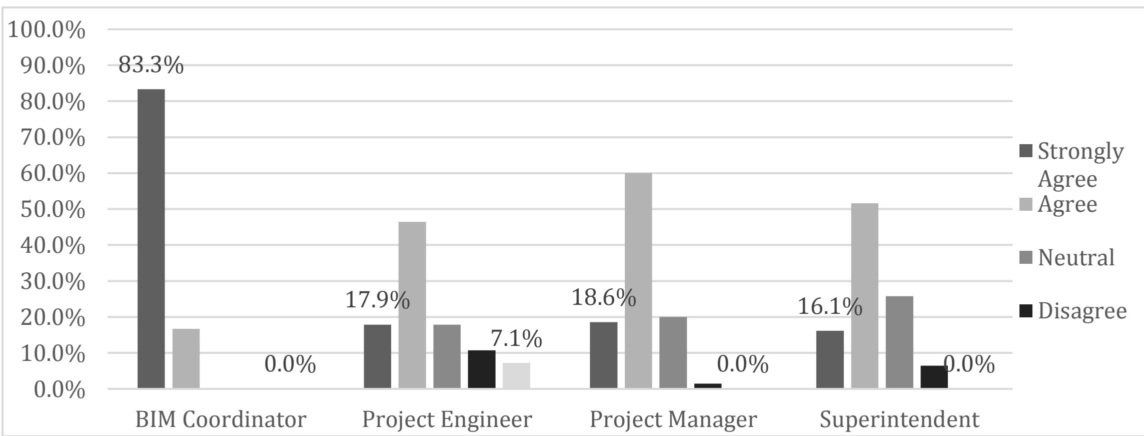

Figure 2: Perceived Reliability of BIM by Project Role

From Figure 2 it can be concluded that BIM Coordinators are the most likely to believe that the BIM is a reliable source of information, with 83.3% of BIM Coordinators strongly agreeing. This seems logical as BIM coordinators work in the BIM environment daily. Potentially skewing their perception, however, may be the fact that as BIM coordinators are mainly located outside of the project site, they may not recognize the issues with BIM that occur in the field, such as the model not keeping up to date with project changes or trade partners missing from the BIM coordination effort that have critical coordination scope.

Project Engineers (PE) are the least likely to find the BIM model as a reliable source of information, with 7.1% of Project Engineers strongly disagreeing. This result is particularly interesting because, per the personal BIM use results, PEs are the second most likely to spend the most amount of time in the BIM model. Due to their familiarity with the model as well as their responsibility for updating the plans/specs with construction document changes, PEs may not see the BIM as a reliable source of information because they are aware when the model is not up to date with the most current information. Instead of being updated by the trades as information is received, the BIM often time reaches the fully pre-construction coordinated phase then lays fallow until they are updated as as-builts for closeout. Superintendents follow project engineers in their likelihood to believe the BIM model is not reliable, with 6.5% of superintendents disagreeing that BIM is a reliable source of information. These findings are particularly troublesome to ramp up the use of BIM to support field operations because these are specific job roles that develop their tasks on site. This shows a great gap that needs to be bridged to promote the use of BIM to support field operations and promote the visual management of the project.

Figure 3 shows the impact that job role has on the likelihood that respondent found BIM to be valuable to field operations beyond use with clash detection. From this graph it can be determined that BIM Coordinators are the most likely to believe that BIM has value outside of clash detection with 100% responding “Yes”, while Project Managers are least likely to believe that BIM has value outside of clash detection with 7.1% responding “No”. These findings make sense when taking into account the findings from above regarding the different job roles understanding of the capabilities that BIM possesses beyond clash detection. Interestingly from these findings, though Project Engineers are more likely than other roles to believe that the information in the BIM is not reliable (Figure 2), they are the second most likely to believe that BIM is valuable outside of clash detection with 82.1% responding “Yes”. This could indicate that though PEs are aware of the current shortcomings of BIM for use of the field, they may believe that with corrections to the BIM task structure, BIM could have further value/use at the jobsite level.

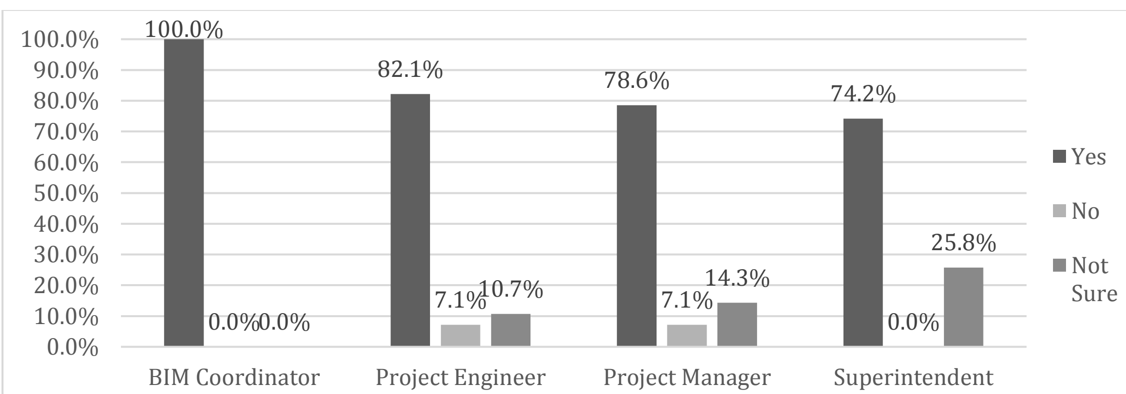

Figure 3: Perceived Value of BIM by Project Role

Similar to Figure 3, Figure 4 investigated the impact of time spent in BIM to the likelihood of finding the BIM valuable beyond clash detection. From the graph it was found that respondents who use BIM at least once per day were most likely to believe that BIM was valuable beyond clash detection, with 100% responding “Yes”, and respondents who did not use BIM were most likely to either believe that BIM was not valuable beyond clash detection (7.8%) or not be sure of whether BIM held additional value (27.5%). Generally, it was seen that as the amount of time in the model increased, the perceived value of BIM beyond clash detection increased.

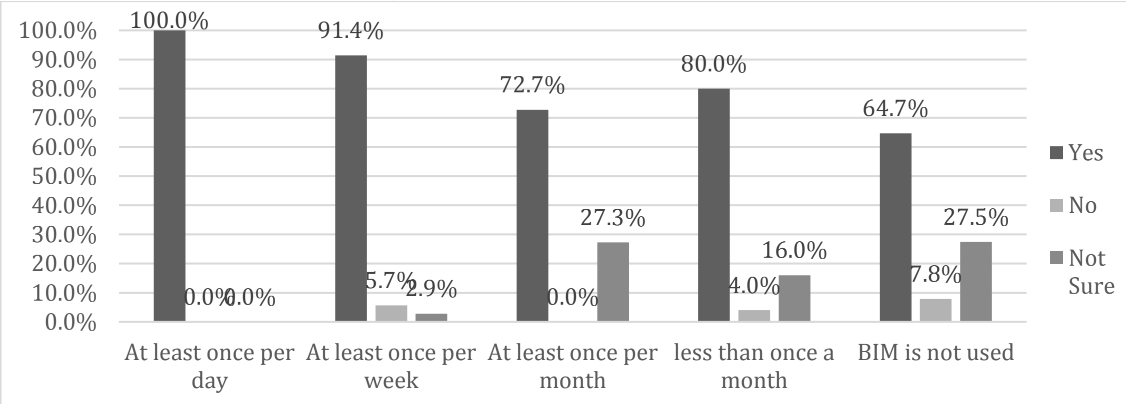

Figure 4: Perceived Reliability of BIM by BIM Usage

Looking at the findings on users' perception of the reliability and value of BIM, it can be inferred that a positive change in the perceptions of BIM could potentially lead to an increase in the use of or willingness to explore BIM. Given the interconnectedness of BIM and Lean, this potential increase in BIM would likely allow for increased instances of Lean Construction interactions.

CONCLUSIONS

From analysis of the survey results it was found that the use of BIM in the field is still not where it should be in order to reap the potential benefits of construction stage BIM usage, and consequently those related to BIM-Lean synergies. Potential interactions between BIM and Lean that can be leveraged at the field level have yet to materialize given that the use of BIM and its related tools, as well as the confidence practitioners have on these tools have to improve. Despite all of BIM's documented benefits, including but not limited to increased levels of visualization and collaboration, field personnel will not fully embrace the technology unless they perceive it as reliable. Data revealed that BIM coordinators are the ones who trust BIM the most, perhaps because they are the ones creating and manipulating the models. Further investigation of why reliability levels vary across job roles is needed. BIM coordinators appear to have a strong role if the synergies between BIM and Lean are to materialize. Findings indicated that over half of the respondents reported that their projects have a dedicated person to work with the BIM. This individual might be the gatekeeper who will be able to unlock enormous benefits indicated by Sacks et al. (2010a) regarding improving flow, increasing/generating value, developing partners and solving problems. Moreover, the low levels of use and confidence displayed by Project Engineers (PEs) also point to an important job function that might have been underutilized as far as BIM use goes. While BIM Coordinators are BIM savvy and might or might not be on site, PEs need to be on site and would greatly benefit from BIM to perform their daily tasks and support leaner field operations.

The results also showed that use of and reactions to the BIM may be influenced by several factors including job role, project size, time spent in the model, and available

BIM tools. Most participants were aware that they were not using BIM to the max of its capabilities and indicated that additional training would likely help close this gap in technology familiarity. Through targeted training of project team members, it is likely that implementation of BIM at the jobsite level would increase. Project Managers, Superintendents, and Project Engineers all displayed different levels of comfort and confidence in the model. It is suggested that training programs be designed to show specific benefits BIM can bring to each of these roles in a project in addition to the overarching capabilities and benefits it can bring to the project as a whole.

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EXPERIENCES FROM THE USE OF BIM-STATIONS

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ABSTRACT

BIM has gone from being a design-tool to being an important part of the production process. BIM-stations make 3D-models available for everyone, including all the workers on-site.

This paper 1) reports on experiences from the use of BIM-stations on site and 2) suggests certain improvements to increase the benefit of the BIM-stations. Following a case study approach, it examines the production phase of a building project in Norway.

Initially, a survey among 50 workers on-site was carried out. Both carpenters, plumbers and electricians conducted the survey. This was followed by semi-structured in-depth interviews with six key actors. Among the interviewees was the project manager, the BIM-coordinator on the project, and managers from the project owner’s organization.

The research revealed that workers experience saving time with BIM-stations. They report higher productivity due to having the necessary information available at all time. The highest productivity increase appeared for the MEP workers.

This study was carried out over a relatively short period, with limited access to measurements of cost and savings from the use of BIM-stations. Nonetheless, the findings are still very positive and can guide future implementation of BIM-stations in the production phase.

KEYWORDS:

Building information modelling, BIM on site, BIM-stations, visualization, on-site communication

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INTRODUCTION

The use of 3D-models as a building modelling tool has been in constant development since it was introduced in the late 1970s and early 1980s. Computer Aided Design (CAD) started out as a design tool primarily for mechanics, electronics and aerospace (Eastman et al. 2011). The systems were expensive and overwhelmed the available computing power. As the development went on, new digital tools for all industries were introduced. In the building industry, the Building Information Modelling (BIM) appeared.

BIM is a three-dimensional CAD-technology, widely used in the design phase of all kinds of projects. It is even a requirement from some project owners. BIM has the potential to reduce the number of errors and omissions, as well as improving collaboration in projects, and eventually increasing productivity and reducing costs (Cant 2014).

Even if BIM typically has been seen as a tool for only the design phase, the technology equally represents a great potential in the construction phase. Some of the areas of use in this phase are visualization, calculation, planning and clash detection. Although these are uses for BIM in the production phase, the BIM is usually reserved for managers at the construction office. BIM is significantly less used on the construction site, where paper drawings still dominate. A current trend in construction is that projects are getting more complex and require detailed drawings. Van Berlo and Natrop (2015) question if the information presented by the drawings really constitute the information needed on the construction site. They even claim that most drawings are not specific enough for specialized tasks. With BIM, much more information is available.

To develop the use of BIM in the production further, it consequently seems desirable to move BIM from the office to the construction site, where the physical work is actually carried out. Such an introduction of BIM to the workplace enable information to be available when and wherever it is needed.

In this paper, we examine a case from the Norwegian construction industry. The case project is an ongoing project, notably the building of a new university building in Trondheim, Norway. The project was initiated by the Norwegian Directorate of Public Construction and Property, Statsbygg, as building owner.

In this project the main contractor, Betonmast, has introduced so-called BIM-stations on site. A BIM-station is a computer with a large screen placed on the construction site, where the workers can access the information they need. Here they can find the 3D-model, the web hosting service with all the drawings and other useful information previously reserved for the management.

The main contractor is using BIM-stations for the first time on this project. In addition, only a limited number of contractors and clients have previous experience with use of BIM-stations. Since research on the topic seems limited, but the potential to achieve higher productivity in the production process seems great, we wanted to:

1) report on experiences from the use of BIM-stations on site and

2) suggest improvements to increase the benefit of the BIM-stations

This paper proceeds as follows; first, we review recent research on the use of BIM on construction sites. Second, we present our research method. Next, we present and discuss our findings on the use of BIM-stations in the case study. Finally, some concluding remarks follow.

RESEARCH METODS

The literature part of the study followed the steps specified by Blumberg et al. (2011), notably 1) the building of an information pool, 2) the application of a filter to reduce pool size, 3) a rough assessment of sources to further reduce pool size, 4) an analysis of the literature in the pool and 5) the refinement of filters or stop search when theoretical saturation is reached. This provided the theoretical framework as the basis for the research of this paper.

To gain knowledge about the utilization of the BIM-stations, what effects they might have and to find possible improvements, a case study was carried out. According to Yin (2014), a case study is most relevant if the questions one seek to explain is about "how" or "why" some phenomenon works. The same goes for questions that require an "in-depth" description. This made a case study the preferred choice for the research method.

There are two reasons why the new university building was chosen as case. First, the two first authors of the paper had part-time jobs on this project during the research period of 4 months. One of the responsibilities was to keep the BIM-stations running. This enabled observations and conversations with the workers during the research period. These observations and conversations provided the foundation for the research questions, and not at least for the questions in the interview guide and the survey. The authors have strived, however, to avoid that the impression from the observations and conversations impacted too strongly on both analysis and discussion. Second, this is a complex university building project, consisting of both new buildings and rehabilitation, with an area of approximately 16.000 m^2. Because of a very short construction period, the main contractor concentrated on achieving high productivity. To make this possible, the contractor introduced lean principles as takt-time planning and visual management. BIM-stations can be seen as a way of facilitating lean principles, as described by Vestermo et al. (2016).

The case study is based on document studies, in-depth interviews with 5 key actors with expertise and knowledge on the topic and a survey. The authors carried out the document study in order to acquire knowledge with background information of the project and the BIM-stations. The project managers from both building owner, main contractor and technical subcontractor, as well as the BIM-specialist on the project and head of the contractor's BIM department were interviewed. In general, the interviewees were chosen among those considered as having the best knowledge about the background for using BIM-stations.

The quantitative data in this paper results from a survey among 48 construction workers. Of these, 24 were carpenters, 12 electricians and 12 plumbers. The purpose of the survey was to map the use of the BIM-stations in addition to user's attitude and behaviour. The questions were a combination of multiple choice and free text answers. Multiple choice gave the ability to compare the answers and obtain a statistical representation.

The limited scope of the study does not permit for generalising the results. However, as Flyvbjerg (2006) points out, even a small number of interviewees can constitute a powerful source of information to generate new knowledge.

THEORETICAL FRAMEWORK

THE USE OF BIM AND INFORMATION CHANNELS ON CONSTRUCTION SITES

Studies have shown that the information on construction site seems to be inadequate. Hewage and Ruwanpura (2006) carried out research on this in Canada in 2003, with field observations, interviews and surveys. Findings indicate that the workers wanted an opportunity to view 3D and 4D (3D with timeline) drawings, technical information, safety information, weather updates, and other information related to the outcomes of the project. Many workers also described a lack of clarity surrounding the instructions and the technical details. Nearly all the interviewed foremen reported difficulties in accessing the real-time information from the head-offices. Foremen spent about 15 % of their working time walking between the site office and the working area. Almost all the workers expressed that they were not aware of how the final product should be.

These results were presented 10 years ago, but it seems like it is only over recent years that something has been done about it. There have been many attempts to obtain more information to the construction site, with devices like tablets and computer-kiosks. Ruwanpura et al. (2012) concluded that there was need for an information kiosk that could show updated information. Accordingly, they developed the so-called i-Booth. This was an on-site communication framework, designed to give the site-workers material management, work demonstrations and updated drawings. The i-Booth had positive results in productivity, efficiency and worker satisfaction.

The use of tablets is another way of getting information to the construction site. Davies and Harty (2013) studied the implementation process of "SiteBIM" in a case study of a large hospital project in the UK. Mobile tablets were used to access the project's BIM model. The model was automatically updated when the tablet was connected to the network at the construction site. Tablets on site combined with an in-house document management showed positive results, like waste reduction and a lower than usual cost growth for service installations.

Atkinson (1998) states that bad communication is one of the main reasons why errors occur during the construction phase. Harstad et al. (2015) researched how tablets can improve communication on the construction site. This research showed that tablets could provide an easy access to up-to-date drawings and BIM on the construction site. It was found that tablets make it less time-consuming to obtain necessary information. The research showed, however, that some workers have little or no motivation to use new tools on the construction site. Furthermore, Harstad et al. (2015) emphasize the importance of adequate supervision, training and change in culture when new tools are introduced at the construction site.

The construction industry has been known to have some resistance in using new technologies (Brodie and Perry 2001). The resistance to IT is especially evident on building sites (Scott et al. 1994). The study of Hewage et al. (2008) showed that the older and more experienced workers tended to be the most resistant. This also proved to be the case in the research of Harstad et al. (2015).

Several researchers have pointed out the importance of training to utilize BIM in construction. Hardin (2011) maintained, for instance, that; “You wouldn’t hand a man a tool without training him how to use it […] the same rule applies to BIM”. So when another contractor in Norway, Skanska, developed their prototype of what they called a “BIM computer kiosk” in 2014, they focused on training sessions (Bråthen and Moum 2015). A training program was developed by Skanska’s BIM coordinator to give the workers a sufficient basis of knowledge on how to use the BIM-model in their daily work. They carried out the training at the construction site, gathered around the BIM computer kiosk. One session could include approximately five workers and last about one hour. The workers could ask questions and everyone got to navigate in the model during the sessions. The result was a highly used computer kiosk, with documented positive results, especially for the workers on electricity and ventilation (Bråthen and Moum 2015).

Different approaches to BIM on site have been tried, and it is hard to say if one is better than the other. The i-booth, computer kiosks and tablets are all examples of ways of getting more information to the construction site. With BIM on site, the information also includes a valuable opportunity to visualize the building in 3D. The use of BIM on site is new to most, and an implementation may involve cultural change and time for training to get benefits greater than the costs. Although BIM might not be suited for all building projects at present, some building owners demand that certain buildings are designed with BIM.

Based on this review we can see that there is still a limited amount of research on the use of BIM on-site, and that further efforts are needed to bridge this gap in knowledge.

FINDINGS AND DISCUSSION

Set-up of the BIM-stations

A BIM-station can best be characterized as an on-site information tool, typically as a computer connected to a TV-screen. On the examined project, the BIM-coordinator had to design how the BIM-stations should be set up from scratch. A 40-inch TV-screen was placed inside a freight-case on wheels together with a powerful computer and cooling devices. Six of these home-made BIM-stations were placed on site, one on each floor of the building, available for everyone.

The BIM-stations provided the site-workers with constant access to an up-to-date BIM and all the drawings from the web hosting service. Apart from the design, the BIM-stations were a lot like Skanska’s “BIM computer kiosks”. Both allow site workers to visualize the planned project on a big screen and use the 3D-model to plan their work. Additionally, the workers can go to the BIM-stations to get information about delivery times to the site, HSE-information, weather forecasts and updated rig plans.

The use of BIM-stations was a wish of the building owner. They had positive experiences from previous projects, and believed that this could improve the project. The main contractor, Betonmast, wanted to follow their competitor’s technological development, and decided in collaboration with the project owner to invest in BIM-stations on this project. An implementation of BIM-stations entails a certain amount of costs and effort. The project owner covered the costs, while Betonmast developed the BIM-kiosks and the technical subcontractor was in charge of the internet connection.

EXPERIENCES FROM THE USE OF BIM-STATIONS

Limited Use and Lack of Training

Firstly, the BIM-stations were found to be used less than desired. The qualitative data collected from the survey showed that the use has generally been poor. When asked if they use the BIM-stations, 79% of the MEP workers said that they use them, compared to only 12,5% of the carpenters. Within the MEP workers we find electricians and plumbers, reporting almost the exact same use. The limited use was confirmed through all of the interviews in the case study. Both the survey and the interviews reveal that most believe that the limited use is due to a lack of training. Survey respondents and interviewees alike pointed out training as an important part of the implementation of BIM-station in the production phase. The training was found to be inadequate when approximately 90 % stated that they had not received any training. Most workers also stated that this was their very first project with BIM-stations. Very few had tried anything like this before. A few had gotten some general information about the BIM-stations on the project, but only foremen had gotten proper training.

The managers claimed to be aware of the lack of training, but explained that resources for proper training had not been prioritized. As a consequence of the survey, the workers got a one-to-one training session by the BIM-stations. Although some workers claimed to be in too much of a hurry, most workers were positive to the training, and even stated that they used the BIM-stations more after this. The low priority of BIM-stations was also found through the document studies. Meeting minutes from the last 1.5 years were studied, looking for BIM-station-related cases. The result showed that BIM-station was mentioned in the starting phase, but never mentioned after the first one was mounted. In addition, the mounting was postponed a number of times before it was completed.

Difference in Use between MEP Workers and Carpenters

The second main finding was the large difference in use between MEP workers and carpenters. By talking to some of the carpenters, we got quotes like; "Why should we use the BIM? We get more useful information from the paper drawings." This is probably true in some cases. An example is the level of details in the walls, where information about different layers and insulation often is excluded from the BIM-model to save time and computer capacity.

As shown in table 1, the use within two weeks varied a lot, and confirms the previous results. Most carpenters did not touch the BIM-station within the last two weeks before the survey, but for the MEP workers, the use seems to be evenly distributed. Almost 50% of the MEP workers state that they had used the BIM-stations four times or more over the last two weeks. As opposed, almost 90% of the carpenters stated that they had not used BIM-stations at all in the same period.

Table 1: The use of BIM-stations within two weeks

	How many times the BIM stations were used within two weeks				
	Never	Once	Two to three times	Four to ten times	Over ten times
MEP workers	21%	21%	13%	21%	25%
Carpenters	88%	8%	4%	0%	0%

Previous research has shown that older and more experienced workers tend to be the most resistant to new technology. This has been the case on this project as well. Some of the younger workers had experience with BIM-technology, and were the most positive to training sessions. To quote one of the older workers; "I have never used and I'm never going to use the BIM-stations. I don't even use a computer at home. I have 12-year old son for those kinds of things".

What the BIM-stations are used for

The interviews and surveys revealed what the BIM-stations on the project are used for. It was apparent that the 3D-model is the most used feature. Users report that they use the 3D-model to help visualize tasks, and to see how the finished building will be. By using the web hosting service at the BIM-station, the workers can get access to all of the drawings for the project. This is the function that is the second most used. All the drawings on the BIM-station is up-to-date, which can be needed by everyone on site. Many workers, especially the MEP workers, state that they save time having access to the drawings on site. Without the BIM-stations, workers have to walk all the way to the construction office to obtain the same information. Saving time this way is one of the main purposes of using BIM-stations on site, but it didn't always work as planned. On this project, we experienced that workers walked to the office to ask someone to show them things in the 3D-model. When this happens, the biggest advantage of a BIM-station, notably the location on-site, is lost. Once again, the lack of training becomes apparent. The workers know that there is information in the BIM-stations on site, but go to the office anyway because they can't find it themselves. The positive thing about this is that many workers now want to use the new tools. When someone see the benefits, the word is spread. Eventually, the positive attitude can spread throughout the construction industry, and tools like BIM-stations can be used even more. Rig plans and weather forecasts are also features that are available at the BIM-stations, but these seem to be less used. The interviewees claim that too much information available on-site may reduce the effect, when users take longer to find what they need.

Improved Communication with BIM-stations

The interviews and survey showed both that workers and managers alike think BIM-stations can improve the communication on the construction site as well. Both communication between different companies regarding interfaces and communication within the companies is reported to have been improved on this project. In addition, 3D-models at the BIM-stations can be a way of bridging the communication gap between subcontractors caused by their different native languages. Other ways of using BIM-station to communicate exist as well. At this project, the screensavers on the BIM-stations had HSE-messages and –pictures. The interviewees state that it is hard to know if this had any positive effect, but it definitely did not hurt.

Positive Effects of BIM-stations

As for the positive effects of BIM-stations on the project, the opinions were divided. Some of the carpenters considered the BIM-stations an unnecessary cost, with no positive effects what so ever. That was yet not the general opinion. A large percentage of workers experienced saving time with BIM-stations. They reported higher productivity due to having the necessary information available at all time. The overall impression from both survey and interviews is a unanimity that the MEP workers have the greatest benefit of the BIM-stations. This is also reflected in the answers of the last question the workers were asked. We wanted to know if BIM-stations are something the workers would like to have access to at their next projects. 96% of the MEP workers wanted this, while the result from the carpenters was 50-50.

SUGGESTED IMPROVEMENTS TO INCREASE THE BENEFIT

Figure 1 shows what the workers suggested as improvements to increase the benefit of the BIM-stations. It was clear that proper training was something the workers wanted. When asked what had to be done to achieve greater use, most workers called for training sessions. Both workers and managers see this as the most important improvement that has to be done in order to exploit the BIM-stations' potential.

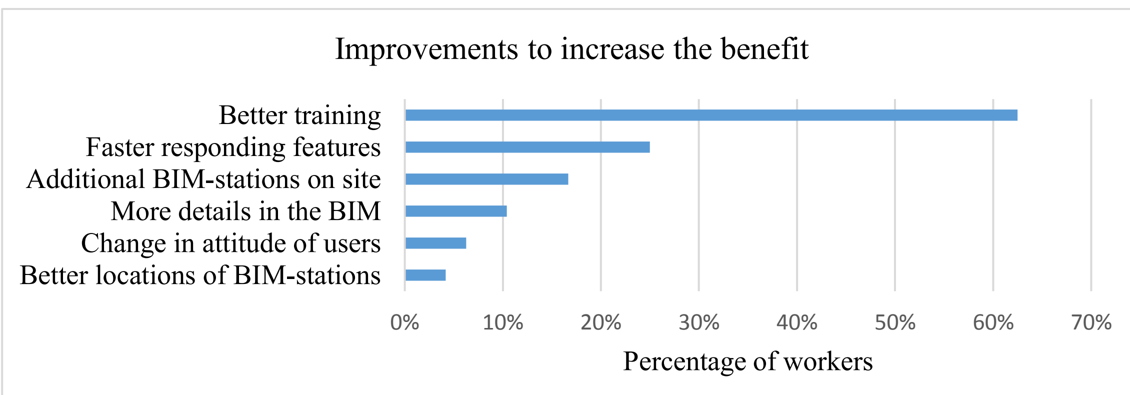

Figure 1: Improvements to increase the benefit, based on survey

Not all the workers were happy about the level of details in the BIM-model. It appears from the survey that the level of details is a limitation for the use of BIM-stations, especially for the carpenters. To increase the benefit of BIM-stations for carpenters, details as layers and insulation in walls should be added. For the MEP workers, the BIM-stations proved much more useful. The 3D-model made it much easier to visualize their tasks. However, all fields point out the ability to visualize the building as a big advantage of the BIM-stations.

The number of BIM-stations at the construction site was another thing some of the workers were unhappy about. The project was large, with about 15.000m^2 of new buildings. A few workers therefore stated additional BIM-stations as important to exploit the BIM-stations' potential. Better locations could according to the workers also increase the benefit.

A BIM that responds faster than today is another way of increasing the benefit of the BIM-stations. Some of the workers stated that they had stopped using the BIM-stations because downloading drawings took too much time.

The observational studies identified some challenges with the use of BIM-stations. Some of the workers had little or none respect for the BIM-stations on site, and did not seem to care that others might need them. Like a few of the workers admit, it seems like a campaign to improve worker's attitude could improve the benefit of the BIM-stations. The BIM-stations were often found unplugged and stored in a corner, or under a pile of junk and clatter. This led to another problem, the downtime. Moving and reconnecting the BIM-stations was found to take a lot more time than expected. Improving the prototype to a more mobile station would make this easier, result in less downtime and increase the benefit.

CONCLUSION

By presenting experiences from the use of BIM-stations, this paper supplements existing literature on the topic. BIM-stations give the workers access to the project information on site. The 3D-model helps visualize the project, and the web hosting service provides easy access to up-to-date drawings on the construction site. This can eventually lead to higher productivity in the production process. It has been found that MEP workers benefit the most from the BIM-stations. They use the 3D-model to visualize, plan their tasks and solve any problems that may arise. Carpenters also benefit from the BIM-stations, mostly by saving time getting the necessary drawings, but they were not using the BIM-stations as much as desired.

The costs of implementing BIM-stations are usually covered by the building owner. This was also the case in this project, where the building owner covered all costs. The contractors benefitted from the BIM-stations without responsibility for the cost, so they were happy. For future projects, the authors recommend the client to ask the question about what to achieve with the BIM-stations before implementation. That can help when deciding the functionality. In the investigated case, it seemed like the client decided to use BIM-stations without considering what they wanted to achieve.

As for improvements, proper training is found to be crucial. On this project there has been too little training in order to exploit the BIM-stations' potential. Many workers also pointed out that the BIM-model could be improved, with more details and faster responds. Additional BIM-stations on better locations is another thing the workers pointed out as possible improvements. These small changes, in addition to a change in some workers' attitude to new technology, could be great improvements in order to increase the benefit of BIM-stations on site. We consider the need for a cultural change in mind-set to be something that will take some time, but come more or less automatically when the project participants on site get used to continuous access to the BIM through i-booth, computer kiosk or tablets. However, there is still need for research on the use of

BIM-stations in order to exploit the full potential. BIM-stations are a relatively new tool to access information at the construction site. The numbers of cases studied are few, which makes the findings unsuitable as a basis for statistical generalization. More research is needed to be able to conclude what workers on a construction site can use BIM for and what value it can give the construction process. With future research on the effects of BIM-stations on construction sites, BIM-stations can develop further, and become even better.

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BIM-STATIONS: WHAT IT IS AND HOW IT CAN BE USED TO IMPLEMENT LEAN PRINCIPLES

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ABSTRACT

Companies are starting to use BIM and Lean processes simultaneously to create predictable workflows. Contractors are taking BIM from the office and making it an on-site tool in the production phase. This is a relatively new approach to on-site production control, and there seems to be a lack of research regarding BIM-stations on-site. This paper explores 1) what a BIM-station is and 2) how it can be used to implement lean principles. The research is based on an extensive literature review and 10 general in-depth interviews of personnel from different management levels within five contractors.

According to the research carried out, a BIM-station can best be characterized as an on-site information-tool. The BIM-station is set up so the project participants can use it for an easy and constant access to an up-to-date BIM-model and drawings. Using a matrix that links BIM-station functions with lean construction principles, 12 interactions have been identified.

So far, very few projects have used BIM-stations, limiting the number of easily available cases. However, the analysis is presented so that it may be used to create a better understanding for companies wanting to implement BIM-stations and/or lean.

KEYWORDS

Building information modeling, BIM-station, BIM on site, Lean principles, Implementation

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INTRODUCTION

To create predictable workflows, companies are starting to use lean processes and Building Information Model (BIM) simultaneously. This can provide better reliability of scheduling and deliver the most value from the client's perspective while consuming the fewest resources (Dodge Data & Analytics 2015).

BIM is a digital representation of a building's physical and functional characteristics. The information in BIM is what differentiates it from being just a 3D model. BIM is a resource for information about a building, and can be basis for decisions during the building's lifecycle. Digitalization of data in this way automates the coordination of changes to the model, and those involved can extract the information they need immediately after a change to the model.

According to Womack and Jones (1996), lean thinking can be summarized in five principles, notably value, value stream, flow, pull and perfection. Of these, they claim that value is the critical starting point. They consider value defined by the customer, and explain it as a good or a service that meets the customer's needs at a specific price at a specific time. The answer to what creates value is complex (Drevland and Lohne 2015). It will be a result of the conversation between the ends, means, and constraints of the client (Ballard 2008). In the opinion of the authors of this paper BIM could possibly be a good tool to increase the value of information between project participants and ensure a better understanding of the client needs throughout the whole building process.

Many firms are starting to use BIM as a lean tool through production planning and control. Bhatla and Leite (2012) established a framework for incorporating BIM functionalities like 4D scheduling and clash detection into the Last planner system™. Another way of improving the production planning is by increasing the detail for planning using BIM. Sacks et al. (2009) did this by developing a tool called "KanBIM". This represents the implementation of a lean pull system using BIM. The system helps to achieve stability in the workflow and to minimize waste of labour time in construction (Sacks et al. 2013). By giving the workers on site access to the BIM-model, they can visualize the final product and the potential of positive impacts is great.

BIM and Lean Construction have both been researched extensively the recent years. Different lean construction researchers claim that the use of BIM technology in construction can reduce inefficiencies and rework (Arayici et al. 2011; Sacks et al. 2010; Sacks et al. 2009). However, there has been little research linking these two (Sacks et al. 2010). One of the key principles of lean construction is continuous process improvement. By linking lean construction with BIM-stations, new work processes can emerge and create an even more efficient construction industry. Consequently, this paper addresses:

1) what a BIM-station is and

2) how it can be used to implement lean principles.

Firstly, we will present our research methods. Secondly, we review recent research on the use of BIM on site. Then we will list BIM-station characteristics and lean principles. Finally, we will link these together and analyse the interactions.

RESEARCH METHODS

The main body of the research is based on a literature review and general in-depth interviews with key actors from five contractor organizations. The review focused on the use of BIM in the construction phase, and how it is related to the principles of lean. The literature study followed the steps specified by Blumberg et al. (2011) with; 1) the building of an information pool, 2) the application of a filter to reduce pool size, 3) a rough assessment of sources to further reduce pool size, 4) an analysis of the literature in the pool and 5) the refinement of filters or stop search when theoretical saturation is reached.

To gain experience in several areas, key actors from five of the leading contractors in Norway were interviewed. These contractors have to a varying degree adopted BIM-stations in their projects. Ten general in-depth interviews with people considered to be among the most experienced on BIM within these contractor organizations were conducted. These included seven BIM-specialists and three project managers. The interviews were carried out in line with the recommendations of Yin (2014).

In addition, the first two first authors of the paper had part-time jobs on a building project with BIM-stations during the research period. One of the responsibilities was to keep the BIM-stations running. This gave the ability to do observations and have conversations with the workers during the research period.

THEORETICAL FRAMEWORK

THE USE OF BIM ON SITE

Over the last years there has been developed different methods to bring BIM to the workers on site, enabling access to the model wherever they are. The different tools that are being used can be divided into three categories. 1) Computer terminals on site (hereafter called BIM-station), 2) mobile devices and 3) specialized environments (e.g., BIM-caves). With BIM on site, it is possible to find and solve problems early. This is a relatively new approach to on-site production control for contractors. Van Berlo and Natrop (2015) state that paper drawings typically dominate information on the workplace. Furthermore, they claim that BIM on site can realise a great potential in the construction phase and that construction workers get the benefit of visualizing when communicating with BIM on site.

Hewage and Ruwanpura (2006) found through their research that there was a need for a mobile, real-time information source on site. Workers wanted an opportunity to view 3D and 4D (3D with timeline) drawings, technical information, safety information, weather updates, and other information related to the project. Following this research, Ruwanpura et al. (2012) developed an information booth to give the workers on site access to material management, work demonstrations and updated drawings. This led to positive result in productivity, efficiency and worker satisfaction.

Davies and Harty (2013) found that there is limited research on how BIM has been used on site. They studied the implementation process of "SiteBIM" in a case study of a large hospital project in the UK. Mobile tablets were used to access the project's BIM model. Tablets on site combined with in-house document management systems resulted in positive effects, like waste reduction and a lower than usual cost growth for service installations. Harstad et al. (2015) has also documented positive effects from their research on tablets at the construction site. In sum, tablets provide easy access to information, are easy to carry around, and can increase the understanding of the project while creating a new line of communication.

The contractor Skanska developed in 2014 a prototype of what they called a “BIM computer kiosk” (Bråthen and Moum 2015). They placed a computer connected to a 50-inch TV-screen on each floor of the building. These computer kiosks allowed workers to access the 3D-model on site. The equipment was placed inside a protective wooden cabinet with internet connection (Bråthen and Moum 2015). BIM kiosks were widely used and resulted in better productivity, especially for MEP workers.

Van Berlo and Natrop (2015) analysed a concept using BIM to generate drawings adapted to the task of workers on site. The idea behind this was to “[...] provide site workers with all the information they need for the task, but nothing more”. They found that this approach created a very good communication tool between the site office management and construction workers. According to Chen and Kamara (2008) the most effective way for workers to acquire information on site is to collect or capture information at the point where they are, when they need it.

BIM can result in a leaner construction process with a greater degree of utilization of prefabrication, improved workflow stability, reduced inventories and enhanced teamwork (Alarcon et al. 2013). When BIM is implemented in the design phase, there could be some challenges to carry it forward to the construction phase. Some of the most common barriers are: software and hardware issues, cultural barriers, contractual and legal aspect, lack of commitment, lack of training and lack of client request (Alarcon et al. 2013). Compared to the positive aspects with implementing BIM in the construction phase, however, the challenges must be said to be of relatively limited nature.

Different approaches to BIM on site have been tried, and it is hard to say if one is better than the other. The i-booth, computer kiosks and tablets are all examples of ways of getting more information to the construction site. These are also ways to introduce lean principles to construction projects. With BIM on-site, the workers have the benefits of better understanding of the planned building. This is due to possibilities for visualization and a greater level of collaboration between the site workers.

LEAN PRINCIPLES

In the following, we present seven lean construction principles that can interact with BIM-station characteristics. The principles are adapted from Sacks et al. (2010). These researchers came up with 56 hypotheses that link BIM and lean construction. According to the article, BIM can reduce variability in both product, process, cycle time and flexibility. The 56 issues identified were intended to guide and stimulate further research. Not all principles from the research of Sacks et al. (2010) are relevant to BIM-stations. The principles that are chosen for this research are listed in bold with a following explanation:

Go and see for yourself is a "going to gemba" principle. This is a principle of Japanese business strategy, which means "go to the real place." The gemba is where the action is and where the facts may be found (Imai 1997). The principle says that to really understand the situation, one must go to gemba (Liker 2003). **Standardization** of work process reduces variability and facilitates continuous improvement (Womack and Jones 2003). **Visual Management** is an orientation towards visual control in production, quality and workplace organization (Greif 1991). The goal is that visualisation should be immediately recognizable by anybody. This is one of the original "just-in-time" ideas (Koskela 1992). **Reducing variability** reduces the volume of non-value adding activities (Koskela 1992). **Reducing cycle time** reduces the time it takes to perform a process through elimination of non-value adding activities and variability reduction (Koskela 1992). **Cultivate an extended network of partners -** An extended network of partners should be built, challenged, and helped to improve (Sacks et al. 2010). This can lead to better collaboration across disciplines in construction projects. **Decide by consensus, consider all options -** By increasing the number of people who influence a decision, one can expand the knowledge base for the decision to be taken. One can get more suggestions and opinions, thereby increasing the likelihood that the best decision is taken. This principle comes from practice at Toyota (Liker 2003).

Based on this review we can see that there is a limited amount of research regarding BIM on site and its effect on implementation of lean principles. Furthermore, there is a need for more research that can guide management when implementing lean principles along with BIM-stations.

FINDINGS AND DISCUSSION

According to the research carried out, a BIM-station can best be characterized as an on-site information tool. It is typically a computer connected to a TV-screen that the workers can use to easily visualize and determine how practical problems at the construction site can be solved. The BIM-station is set up so the project participants can use it for an easy and constant access to an up-to-date BIM-model and drawings. It is a meeting place for collaboration internally and between different disciplines, contributing to problem solving. Contractors also use the BIM-station as an information channel to show delivery schedule, HSE-information, weather forecasts and updated rig plans.

The aim with the BIM-station is to increase the availability of information. Building projects are becoming more complex and harder to build. Workers, particularly in technical disciplines may have difficulty to imagine how the final products should be with only 2D drawings. With the BIM-station, contractors and suppliers could extract the information they need to achieve the intended result. The BIM-station also contributes to a better cooperation between the workers, partly because it can bridge a gap caused by their different native languages. They can use the BIM-model in face-to-face collaboration. By using BIM-stations, workers can easily visualize and determine how practical problems at the construction site can be solved.

A large percentage of workers we talked with experienced saving time with the BIM-stations. They reported higher productivity due to having the necessary information available at all time. MEP workers use the 3D-model to visualize, plan their tasks and solve any problems that may arise. Carpenters are also found to benefit the BIM-stations, mostly by saving time getting the necessary drawings. The overall impression from the workers is that the MEP workers have the greatest benefit of the BIM-stations. However, some workers find it inconvenient to have access to the BIM-model on only these specific locations. Some of them report that they rather would want to use computer tablets, and that this may be a more practical tool than the BIM-stations. The BIM-specialists interviewed claimed, however, that the tablet software for BIM is not good enough yet. In addition, tablets are fragile in rough environments like a construction site. During the research period there was also carried out a case study. Look at the research of Murvold et al. (2016) for all experiences from the use of BIM-stations on this project.

BIM-STATION CHARACTERISTICS

In the following section, we present and explain the content of table 1, which presents the most important BIM-station characteristics we found through both the literature review and the interviews.

Table 1: BIM-Station Characteristics (not ranked after importance)

BIM-Station Characteristics
Visualization of form. A BIM-station contains BIM program with 3D model for visualization of the final product. It makes the 3D model accessible for the workers on site to visualize the building design.
Visualization of process status. To see clearly the process status, the BIM-station can be used to visualize progress compared with the planned progress. For example, visualization of a three-week plan.
Automatic generation of lists. Workers can enter a room in the BIM and automatically get generated a list of materials needed for this room. This list can then be used to deliver this equipment directly to the room.
Online access to documents. An object in the 3D model can work as a hyperlink to databases. By clicking on the object, a list with links to choose from will appear. There you can get information about floor plans, details, room form, safety sheets and other useful documents. Another alternative is a web page as a background on the BIM-station. On this web page, you will find the same information as on the hyperlink-objects in the 3D model.
Easy maintenance and updating of information. The 3D model updates automatically at the BIM-station. It will be updated whenever it is needed through Dropbox or a script directly linked to the web hosting service.
Easy updating of drawings and documents. When updated technical drawings along with other documents is added to the web hosting service, it will be available for download directly from the BIM-station.
Two-way communication. BIM station can act as a meeting place for workers from one or more disciplines, where everyone can see the 3D model and discuss together as a group.
Online/Electronic Communications. Information like production basis, information about the shipments, weather, safety or other messages from the management can be sent to users through the BIM-station.
Feedback to the management. E-mails can be sent directly from the BIM station to the management. This may be reports, comments on the 3D model or other messages.

INTERACTION BETWEEN LEAN AND BIM-STATIONS

In the following, we propose 12 interactions between the BIM-station characteristics and the lean principles. These propositions are based on the literature review and the interviews. Table 2 contains the interactions we consider to be the most important (not ranked).

Table 2: Interactions between BIM-station Characteristics and Lean Principles

Interactions between BIM-station Characteristics and Lean Principles
(1) A BIM-station makes it possible for the workers to visit the construction site through a virtual reality with the use of BIM.
(2) A BIM-station make it possible for the workers to visualize changes faster as they have access to updated drawings and a 3D model on site.
(3) Using a BIM model on a BIM-station let the workers on-site get a better understanding of how the final product is going to be. The BIM-station can be used for clarification in situations where information in 2D drawings is lacking.
(4) Direct delivery of information to a BIM-station reduce waiting times and improve flow.
(5) By having a BIM-station online, the process of obtaining updated drawings to the construction site can be simplified. This could also prevent a lot of paper waste since the workers do not have to print new drawings to check for updates.
(6) Having online access to information on the BIM-station standardize the way of obtaining information. Workers can retrieve drawings directly from the BIM-model, rather than having them all pre-printed.
(7) Process visualization and online communication make it possible to use BIM-stations for status updates. A carpenter can for example send a status update when he has put up a wall, then the electrician is notified when it is ready for him.
(8) By having updated process status available on the BIM-station, it is possible to use the BIM-station to see where it is ready to start working, or how long one must wait until it is clear. This reduce latency and cycle time for activities.
(9) By automatically generating lists of needed materials from the BIM model, it is possible to save time and achieve more accuracy. A carpenter can for example generate list for a room to see exactly how much materials is needed. This leads to increased productivity and reduced variability.
(10) By utilizing the BIM-station as a meeting place for workers from one or more disciplines, everyone can give their opinions and the knowledge base for taking the decision increases. The likelihood that the best decision is taken therefore increases. By using BIM, you increase the information available to support the decisions. In this situation, the BIM station facilitates a greater level of face-to-face collaboration between site workers.
(11) BIM-stations provides the ability to report directly from the BIM-station to the management. Examples of such need for reporting can be instant feedback on error, conflicts, deviation or other things. Such direct information channels can help to ensure that more time is used for the production and achieve reduced cycle time.
(12) With hyperlinks to drawings and documents, the way of obtaining information is standardized. The variability is reduced when you have direct links to the documents you need.

In sum, it seems clear that the BIM-station contributes to a better workflow by reducing variability while it standardizes the work process. Implementing BIM-stations comes hand in hand with visual management. The BIM-station helps workers manage their own activities with production control and a better understanding of the final result. These interactions can guide management when implementing lean principles using BIM-stations. It is possible to look at BIM-stations and lean construction as isolated parts. However, to achieve a good outcome one should see them as a whole as they have a synergistic effect to each other.

In table 3, the BIM-station characteristics and the lean principles are linked together. The interactions – numbered from 1 to 12 – show how a client can use BIM-stations to implement lean principles.

Table 3: Interaction Matrix of Lean Principles and BIM-station Characteristics

	Lean principles						
BIM-station characteristics	Go and see for yourself	Standardize	Visual management	Reduce variability	Reduce cycle time	Cultivate an extended network of partners	Decide by consensus, consider all options
Visualization of form	1		3				
Visualization of process status			7				
Automatic generation of lists				9			
Online access to documents		12		12			
Maintenance and updating of information			2	4 5			
Updating of drawings and documents			2	4 5			
Two-way communication							10
Online/electronic communication		6		4	8		
Feedback to the management						11	

CONCLUSIONS

BIM and Lean are being implemented simultaneously on construction projects. The aim of this paper has been twofold: firstly, to explore what a BIM-station is and secondly to explore how it can be used to implement lean principles. According to the research carried out, a BIM-station is best characterized as an on-site information tool. It brings information out to the construction site. The workers can use it to easily visualize and determine how to solve practical problems at the construction site. It can also serve as a meeting point for internal collaboration between different disciplines, contributing to problem solving.

This study shows that there are many interesting interactions between lean construction and BIM-stations. The interactions show that BIM-stations are helping to reduce the volume of non-value adding activities. The 12 interactions are presented so that they may be used as a guide for companies wanting to implement BIM-stations and/or lean in the production phase of building projects. The use of BIM-stations in the production phase can significantly enhance the lean outcomes.

Further research should try to do more testing to validate the 12 interactions proposed, and explore if there are additional interactions that should be included in table 3. In addition to looking at BIM-stations on site, researchers should study the potential of using tablets and smartphones on site in synergy with lean construction. BIM-stations on site combined with the foremen using tablets could be a good solution for future work.

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DEPLOYING BIM IN A HEAVY CIVIL PROJECT

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ABSTRACT

This paper explores the case of a heavy civil project that implemented a comprehensive BIM execution plan. Although BIM was not required in the tender documents, the bid was won partially due to the contractor's proposal to use BIM to develop and manage the complex project. The paper presents a synopsis of the value proposition of BIM on this project and how it supported a number of Lean principles. An outline of project challenges, including design complexity, dispersed design team, and inexperience with BIM, is presented. Finally, through a research method consisting of interviews and site observations, the authors demonstrate that understanding people's work routines and establishing the right level of BIM ambitions for the project allowed the project team to successfully exploit the opportunities BIM has to offer. Using the BIM functionalities list identified by Sacks et al.'s BIM-Lean interactions matrix, the authors identify the Lean principles that the specific functionalities implemented at the project enabled. The aim of this is to support previous research suggesting that there are specific synergies between different BIM functionalities and corresponding Lean principles, as well as document how they were implemented in a heavy civil project.

KEYWORDS

Collaboration, visual management, BIM, heavy civil project

INTRODUCTION

The intent of this research is to explore how the introduction of Building Information Modeling (BIM) functionalities, in conjunction with lean principles, reduce waste and bring a positive cultural shift to an industry segment that traditionally works in two dimensions. Building Information Modeling is the use of an information-enriched 3D-model intended for multi-disciplinary design and coordination. The BIM model is used for several purposes, such as checking design quality, planning, procurement, visualizations and safety evaluation. At a project level, the BIM is a collaboration platform around which processes are built and information is shared. Sacks et al (2010,

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p.968) state that "while [BIM and Lean] are conceptually independent, there appear to be synergies between them." This case study tests that statement as both Lean and BIM methodologies were introduced to a team who was not familiar with either.

The current status quo in heavy civil construction in Norway is to use two-dimensional drawings to guide construction. Heavy civil projects are at a larger scale and generally involve expansive grading defined by GPS coordinates. Design and construction modeling programs, on the other hand, have focused on building components and detailing. However, as heavy civil projects become more complex, and modeling tools expand functionality, the use of BIM to plan these projects becomes both technically possible and necessary for coordination. On the case study presented in this paper, conveyor belts going in all sorts of angles, technically and geometrically complex buildings, and underground tunnels called for a better platform for mutual understanding between project parties.

As heavy civil projects become increasingly complex, they can also greatly benefit from the use of BIM. That said, the authors propose that the lessons learned through the joint implementation of Lean and BIM, in the heavy civil project described, can be utilized by practitioners implementing BIM in other heavy civil projects.

INTERACTIONS BETWEEN LEAN AND BIM

The discussion of the case study presented in this paper uses previous work developed on how Lean and BIM support each other. More specifically, the paper builds on the work developed by Sacks et al. (2010) who studied the potential interactions between BIM and Lean and developed a framework, in the form of a matrix, linking the two. The matrix is useful to understand why companies should care to use BIM in their projects, how the use of BIM can be leveraged by understanding which areas can benefit from its implementation, which areas have traditionally taken advantage of BIM more often, and which Lean principles have the highest number of interactions with BIM functionalities. The BIM-Lean interactions matrix has been used in previous research to analyze and exemplify instances in which BIM helped or could have helped to generate value, promote flow, and reduce waste in projects (e.g., Bhatla and Leite 2012, Harris and Alves 2013). However, examples of the interactions have not been discussed in a heavy civil project, given that these types of projects seem to be lagging in Lean implementation.
Sacks et al.'s (2010) goal was to focus on what BIM as a platform can do for the construction industry rather than focusing on any specific technology that might help achieving these functions. The BIM functionalities they identified were categorized into three main stages of the life cycle of a construction project:

Design: visualization of form, rapid generation of design alternatives, reuse of model data for predictive analyses, maintenance of information and design model integrity, and automated generation of drawings and documents.

Design and fabrication detailing: collaboration in design and construction.

Preconstruction and construction: rapid generation and evaluation of multiple alternatives, and online/electronic object-based communication.

Next, Sacks et al. (2010) identified from the Lean literature at large a number of principles that help define and explain Lean. The main principles were grouped into four categories as indicated below to show how they support areas of the Lean philosophy:

Flow process: reduce variability, reduce cycle times, reduce batch sizes, increase flexibility, select an appropriate production control approach, standardize, institute continuous improvement, use visual management, and design the production system for flow and value.

Value generation process: ensure comprehensive requirement capture, focus on concept selection, ensure requirement flow down, and verify and validate.

Problem solving: go and see for yourself, and decide by consensus, consider all options.

Developing partners: cultivate an extended network of partners.

The lean principles with the highest number of interactions, distributed over the design and construction stages, were: get quality right the first time (reduce product variability), focus on improving upstream flow variability (reduce production variability), and reduce production cycle durations. As for the BIM functionalities, with the highest number of interactions they were: aesthetic and functional evaluation, multiuser viewing of merged or separate multidiscipline models, 4D visualization of construction schedules, and online communication of product and process information. From this analysis it is clear that a number of principles and functionalities were underrepresented in practice and the literature, and there is a lot of room for improvement when it comes to taking advantage of the full potential of BIM to design and improve production systems from design through construction and maintenance.

In order to take the most advantage of BIM, Kunz and Fisher (2012) suggest that key stakeholders be invited to a kick-off meeting in which participants would define: the visualizations of the model that would be most beneficial to them, the levels of detail appropriate for the discussions and the design team, and define breakdown structures that relate cost, schedule, and other relevant information to track the project's performance. Given that powerful computers, visualization tools, and software are more affordable than ever, teams should also use multiple screens to visualize the project in meetings held throughout the life of the project (Kunz and Fisher 2012). The case presented took some of this advice during the implementation stage as discussed later in the paper.

Case Study Description and Method

The case studied was a heavy civil project in Northern Norway, with the scope of expanding an iron ore extraction facility currently increasing its production capacity from 20 to 30 million tons iron ore per year. The project was divided in packages, and the study presented in this paper refers to a specific package, consisting of a screening station, conveyor belts, a spill silo with a technical building, a weight silo, a reloader with a technical building, and a sedimentation pool. The delivery method used was design-build, with the general contractor managing both design and construction. Total project duration was 1.5 year and the cost was approximately 600 million Norwegian kroner (roughly $85M).

The owner prioritized teamwork and Lean culture among all project participants. The alignment of the project team to project goals was fundamental to implementing change on the project. Once the general contractor won the project, a BIM strategy was put in place. There was no specified requirements regarding BIM in the tender documents, but feedback received during the bid phase was that the contractor had shown remarkable understanding of the client needs and project scope through excellent BIM deliveries. This was possible because the contractor has an extensive BIM execution plan consisting of two parts: a document explaining standard requirements and procedures, and a project specific outline of model objectives, procedures, and development schedule. The BIM execution plan was largely adhered to, and the model was successfully used for all defined goals.

When this process started, there was a wide variety of design programs used, file formats, and work flows. The BIM coordinator managed the multi-disciplinary model in Solibri Model Checker, as did design and production teams for viewing the BIM model. The design teams used Autodesk Revit, Elite, Tekla Structures, Solidworks, Microstation 3D Reshaper and Autodesk Inventor to develop their designs. At first, the BIM set up seemed trivial, however, it was a challenge to completely align the team's working methods within an environment with no existing standards. Nevertheless, all design programs could produce files compatible with the model management program. This interoperability allowed the use of one program (Solibri Model Checker) for model checking and viewing, and became the unifying factor between teams.

Furthermore, the design team consisted of people situated in Norway, Germany, Sweden, Denmark, and Finland. This created several challenges in terms of both culture and accessibility. English was spoken at meetings, and the team was only co-located every three months for two full days of well-planned meetings.

The documentation used for this case was obtained by the first author who was part of the project team, and also conducted interviews with members of the team to capture their perceptions about the use of BIM and its synergistic effects with Lean. The discussion starts with the identification of the BIM functionalities that were implemented in the project and how they supported Lean principles (based on Sacks et al. 2010). Then, a discussion of results from interviews with three project team members (owner's representative, project manager, and design manager) is presented showing their perceptions regarding the benefits and challenges associated with BIM implementation.

BIM FUNCTIONALITIES AND LEAN PRINCIPLES

This section addresses the implementation of BIM at the project level and how its functionalities, as defined by Sacks et al. (2010), supported Lean principles. After the initial introduction to BIM through the bid phase, the owner was very supportive of further BIM implementation, and the BIM execution plan quickly established some functionalities that should have positive impact on normal project challenges. Below is a discussion of Lean principles that were supported by the BIM functionalities implemented at the project: reducing waste in the design process, reducing rework through better understanding of existing conditions, using visualization to communicate solutions, increased transparency in the project, and bringing BIM to the worksite (go and see).

1. Removing Waste in the Design Process

Examples in this section address BIM functionalities related to: design – visualization of form, rapid generation of design alternatives, maintenance of information and design model integrity, and automated generation of drawings and documents.

The project team collocated approximately once every three months, and immediate common understanding and collaboration at those meetings was necessary. Spending time interpreting drawings, explaining design concepts, and solving misunderstandings were forms of waste for which this team did not have time.

In this multi-lingual team, using BIM for communication between team members was essential. Where words, lists, and complicated drawings were not sufficient for understanding, the BIM became the central source of truth and understanding. Through clash detection and visual controls, design problems were identified rapidly and made transparent through the model, ensuring a visible information flow.

The team used visual status indicators of BIM objects to show how far into development they had come, enabling the design team members to see if components or systems they were dependent on could move or change dimensions, or if they were locked and should be designed around. This process removed unnecessary rework through locking down design in the correct sequence.

Quantity take-off in all design stages gave the project management better understanding of quantity implications of design changes. This allowed for quick feedback if a design had to be changed entirely instead of creating unnecessary iterations on a design that was not sufficient regardless of how much effort designers could put in trying to fix it.

The Lean principles enabled by these BIM techniques were: reduction in the variability of design output between designers, reduction in the cycle times of design and costing, and visual management of the design process.

2. Reducing Rework through Better Understanding of Existing Conditions

Examples in this section address BIM functionalities related to: design – visualization of form, rapid generation of design alternatives, reuse of model data for predictive analyses, and maintenance of information and design model integrity.

There were a number of tunnels in which old conveyor belts were being replaced, as well as additional conveyor belts being installed. These tunnels were scanned by the contractor’s survey department, giving accurate design input to ensure that components would fit when being assembled on-site.

Existing infrastructure was also scanned to be incorporated in the BIM model to ensure coordination between existing and new infrastructure. Several places in the projects were very complex, requiring precision and accuracy. Furthermore, a drone scan was performed to incorporate the current design within the next stage of the project.

The Lean principle enabled by these BIM techniques was to go and see for yourself. Recognizing that 2D as-builts was not sufficient, the team made the investment to document existing conditions to ensure project success.

3. Using Visualization to Communicate Solutions

Examples in this section address BIM functionalities related to: design – visualization of form, rapid generation of design alternatives, maintenance of information and design model integrity, and automated generation of drawings and documents; Preconstruction and Construction: rapid generation and evaluation of multiple alternatives, and online/electronic object-based communication.

Visualizations have at times been considered potentially "glossy" and not able to extract much value from BIM. However, when used correctly, visualizations can serve the purpose of showing to the client, suppliers, and teams involved during construction how the task is understood and potential solutions for it.

In the project, multiple design versions were maintained until the last responsible moment. This helped the team to clearly communicate the design intent and potential options to the client in a clear, visual way. The client had three different design options to choose from, which provided more value for the client to achieve their business goals. The owner considered the flexibility and attention to the owner's needs in the design workflow to add value to the entire design process.

The Lean principles enabled by these BIM techniques were the use of visual management and focus of concept selection. The team was able to maintain and present multiple options to the owner through the use of BIM.

4. Increased Transparency in Project Team

Examples in this section address BIM functionalities related to: preconstruction and construction – online/electronic object-based communication.

Between meetings, the model was used for design discussions. Email correspondence often contained screenshots with text and markings, and video meetings had the model on a shared screen view. In the meetings, it was common practice when someone mentioned an issue that the group would stop the discussion until the design manager had navigated to the correct place in the model before the discussion would recommence. Some technical functionalities, such as BIM Collaboration Format (BCF) reports, enabled further improvement in the information flow. A BCF is a digital report where design team members can save viewpoints in a model, add comments, and assign responsibilities.

The Lean principle enabled by these BIM techniques was continuous improvement. The team was able to incorporate and leverage this new means of visualization to significantly improve their communication.

5. Bringing BIM to the Worksite (Go and See for Yourself)

Examples in this section address BIM functionalities related to: design and fabrication detailing: collaboration in design and construction; preconstruction and construction – online/electronic object-based communication.

There was a clear ambition in the project to view BIM as platform for better incorporating design and production. The BIM model was the basis for on-site discussions with production managers about planning and safety, e.g., the rebar crew assembled all the rebar for the screening station straight from the BIM model.

Crews were equipped with tablets and had both BIM and drawings completely updated at all times. Furthermore, BIM stationary units were placed out on site with the BIM model accessible to everyone. The strongest benefit with the stationary unit was that crews could rotate models themselves for better understanding and problem solving, as well as take out quantities and measurements themselves instead of relying on a designer to have put in all the correct measurements on drawings.

The Lean principles enabled by these BIM techniques were verify and validate and go out and see for yourself. This case is an interesting twist on ‘go out and see’. Traditionally, this concept is thought of as managers going to the work place to understand issues where they happen. In this case, it illustrates the workers going to the BIM, as a form of visual management, to understand the issues.

INTERVIEWS WITH THE PROJECT TEAM MEMBERS

The first author conducted interviews with some key project participants (design manager, project manager and owner’s representative) to document their perceptions about the use of BIM at this project. Initially, the three interviewees were asked about which BIM functionalities affected their daily work at the site, and rated them on a scale of 1 through 5, with 1 indicating that BIM had no effect in the project and 5 indicating that BIM provided exceptional value to the project. These BIM functionalities were selected in an initial meeting between the project management team and the bid team for early processes. During this meeting, the goals related to BIM use were discussed. Throughout the project, these goals were adjusted to include additional goals to be pursued by the team.

Interviewees indicated a number of functionalities had an exceptional effect in their work routine (ratings between 4 and 5), especially those related to having visual representations during meetings, including the use of video clips and using the visualizations for production purposes. The ability to conduct clash detection was also viewed as having an exceptional effect on their work. The use of mobile devices (tablets and kiosks/BIM stations) and the use of BIM for planning obtained ratings between 3 and 4. Additionally, the interviewees were asked a few open questions about implementation challenges and project benefits from the use of BIM. Their responses are summarized in Table 1.

Table 1: Results from the interview about the benefits and challenges of BIM

Question 1: From your perspective, what are the 3 biggest benefits from BIM in your project?		
Owner’s Rep.	**Project Manager**	**Design Manager**
1. BIM ensured mutual understanding even though different nationalities and languages were present in	1. Understanding what has been designed. 2. Better compliance towards existing infrastructure.	1. Quick clarifications in meetings of where we are and what we are talking about. 2. Scanning of existing

meetings. **2. We don't speak different languages, we speak BIM.** **3. Visualisations increase ability to demonstrate understanding.**	3. Mutual understanding regardless of spoken language.	infrastructure is very important. 3. Using the model for your own understanding of the project, planning and forward thinking.
Question 2: What have been the 3 biggest challenges while implementing BIM?		
Owner's Rep	**Project Manager**	**Design Manager**
1. Getting all contract parties to understand the importance of BIM and get them to use it correctly. **2. Getting all existing infrastructure into the model.** **3. Knowing the potential with BIM before we have a problem that BIM could easily solve.**	1. Technical issues (not good enough computers for this massive BIM model and ambitious use). 2. Convincing everyone to use; BIM makes everyone's everyday work easier. 3. Creating mutual understanding of the processes of BIM as opposed to 2D-drawings.	1. Model too complex for computer limits, user knowledge. 2. Some designers approached BIM in parallel to drawings, instead of BIM first and drawings just as a result. 3. Constructability not always as easy to check - would expect more from BIM rule sets.
Q3: How has the information flow in design processes been affected by the ambitious BIM plan?		
Owner's Rep	**Project Manager**	**Design Manager**
1. Not too informed, but understand that it has had a notable effect on the design team.	1. Clearly a better information flow, better mutual understanding. Problems solved quickly and more visually creates less confusion.	1. Tremendously improved. A picture says s 1000 words. Still potential to communicate IN the model rather than screen shots.
Q4: How has the information flow from design to production been affected?		
Owner's Rep	**Project Manager**	**Design Manager**
1. Have a feeling that there is much more potential with focus on HOW we use the tools.	1. BIM-kiosks ensure updated, correct design information, correct data is available instantly, easier to understand and communicate.	1. Not too much knowledge, but hearing that the BIM kiosks are very popular.
Q5: What are the three things you will do differently when implementing BIM on your next project?		
Owner's Rep	**Project Manager**	**Design Manager**
1. Using the model more for safety and site planning. **2. Could use design status marking of objects more often.** **3. Explored more opportunities beforehand for further benefits form BIM.**	1. Implement BIM as early as possible. 2. Follow the contractor's BIM manual more precisely to ensure correct element data. 3. More BIM training before project starts to understand tools better and see more opportunities.	1. Specify in the beginning that BIM comes first and drawings second, not parallel worlds. 2. More focus on laser scanning existing infrastructure early. 3. Have resources and time to check that everything was in the model and no are objects missing.

DISCUSSION

Using Sacks et al. (2010) Lean-BIM interaction matrix as a model, it is possible to map the actual BIM-Lean interactions discussed in this case study and further identify interactions identified as most important to the project team in the BIM survey (Table 2).

Table 2: Case Study Specific BIM-Lean Interaction Chart (Numbers correspond to Case Study sections)

	Lean Principle						
	Flow				*Value Generation*		*Problem solving*
BIM Functionality	Reduc e Varia	Reduce Cycle Times	Institute Continuous Improveme	Use Visual Management	Focus on Concept	Verify and Validate	Go and See for Yourse

	bility		nt		Selection		lf
Visualization of form	1	1		1, 3	3		2
Rapid Generation of Design Alternatives	1	1		1, 3	3		2
Reuse of Model Data for predictive analyses				2		2	
Maintenance of Information and Design Model Integrity	1	1		1, 3	3		2
Automated Generation of Drawings and Documents	1	1		1, 3	3		
Collaboration in Design and Construction						5	5
Rapid generation and evaluation of multiple alternatives				3	3		
Online and Electronic based Communication			4			5	5

By far, the largest perceived benefit of BIM was related to visual management of the project. First, the visual communication helped bridge a project specific language gap. More universal findings included that visual management enabled a better information flow and clarifications were quicker to get, consensus was easier to reach, and the contractor could easily demonstrate compliance with owner intent. The project also demonstrated benefits on the design side, e.g., reduced cycle times and variability; and on the execution side, e.g., verification and validation. Using this study as a model for BIM execution, the most beneficial way to introduce BIM is as a visual management tool.

CONCLUSIONS

This paper aimed at presenting how BIM could be implemented in projects with little or no tradition for using BIM, and which effects can be achieved. The authors indicated which Lean effects were achieved in the project as a result of BIM. The case study provides evidence that an ambitious BIM implementation is possible even with challenging prerequisites such as no contractual BIM demands from the owner, little pre-existing knowledge about BIM in the project team and significant geographical distance between team members. The key finding was that a project culture of willingness and helpfulness overcame challenges and solutions were found. The project management team clearly stated in interviews that they would have liked to start even earlier with BIM planning and training to utilize BIM tools more often and to gain further benefits from

BIM. Regarding Lean effects achieved, the case study strongly supports the previous theoretical foundation of the BIM-lean synergy matrix of Sacks et al. (2010).

FUTURE RESEARCH

Some BIM functionalities were not fully implemented and utilized in this case. Opportunities to achieve added benefits of the joint implementation of BIM and Lean are:

Production planning: The project could have visualized 3 week-lookahead plans, either through simple classifications in the BIM model checker or through a 4D scheduling software, enabling them to build virtually first to find improvement opportunities in sequencing and workflow.

Cost monitoring: The owner's representative was curious how to use BIM to communicate cost over time. This could have been achieved using a 5D software.

Safety training: The BIM model could be used for site safety simulations, such as fire hazard escape routes. Simple visualizations could be a basis for training, to analyse the need for marking, and measure time to exit buildings.

Logistics: BIM could be used to visualize plans for loading equipment and materials into facilities, both for safety and efficiency reasons.

Facilities Management (FM): The owner received a model well-equipped with information. A conversation from project inception regarding the quantity and quality of information for FM would have resulted in a more valuable FM model.

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MODELING DESIGN WORKFLOW: INTEGRATING PROCESS AND ORGANIZATION

Malak Al Hattab[1] and Farook Hamzeh[2]

ABSTRACT

The advancement and increasing complexity of design requirements result in the rapid proliferation of information that needs to be properly integrated and coordinated among multidisciplinary parties. Inefficient planning, the ill-defined and iterative design nature, and poor communication disrupt design workflow, consequently creating waste such as increased cycle times, cost, rework, and errors. Sub-optimal design workflow has captured researchers' interests who have developed frameworks tackling design task structuring, measuring flow, or understanding the organizational network involved. However, a formerly unexplored perspective is one that integrates both the process, i.e., flow of design information, and the social network, i.e., interactions among design teams. This integration and communication between teams enables the design intent to properly flow and be transformed into value adding output. Accordingly, this study approaches workflow at the intersection of the social and process aspects of design to understand, measure, and analyze information flow within communication networks. Agent-based modeling and social network analysis are used to dynamically capture the impacts of lean practices and Building Information Modeling (BIM) on communication. This novel design management strategy focuses, simultaneously, on interaction dynamics and information diffusion to assist design teams in enhancing design flow, knowledge transformation, and value generation while reducing wastes.

KEYWORDS

Work flow, communication, lean design management, Building Information Modeling (BIM), Agent-based modelling (ABM).

INTRODUCTION

The design phase is considered to be one of the most challenging processes as it is concerned with the creativity and efforts of human minds in order to create, innovate, test, and transform ideas and inputs into value adding services, products, or facilities for clients or end users. Any deficiencies and complications resulting from design can have

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detrimental impacts throughout the project' life cycle. In fact, the highest levels of effort and influence on the project are attributed to the early design stage (Macleamy, 2004), whereas the cost of changes is the least during early design. Therefore, the proper management of building design is critical for ensuring a successful delivery of projects as the impacts of design propagate and augment when moving downstream along the project's phases.

BUILDING DESIGN CHARACTERISTICS

Building design is characterized by a high level of uncertainties due to the ill-defined nature of requirements, solutions, or outputs. Design requirements can be well understood, whereas the solutions and resulting outputs cannot be defined in advance and are generally vague at the beginning. The "wicked problem" case happens when the requirements, solutions, and outputs are all ill-defined, unpredictable, and poorly understood. Moreover, design tasks and efforts are iterative in nature. Multiple alternatives are considered, developed, evaluated, and reconsidered or discarded in order to reach an unconstrained and satisfying set of solutions (Maier & Storrle, 2011). Additionally, the intensive interdependence of design information and tasks of a large number of trades, makes design further complex.

Furthermore, the design environment is built on the interaction and communication of multi-disciplinary teams whose processes and information are intertwined. With the increase in interdependence and complexity of design tasks, the need for more synchronous communication becomes vital (Knotten et al., 2015). Therefore, design management should be targeted to address these specific characteristics of processes and teams involved for a proactive navigation of the project towards its successful completion.

The complexity and interconnectedness of design make real time information exchange, transparency, and flowing with changes a necessity for design management. Traditional project management has ignored the needs for design management, specifically design workflow management, where upstream design disciplines neglect the needs of each other as well as the needs of downstream disciplines. In fact, project management is solely concerned with the transformation process and task completion with little to no attention given to workflow and value generation (Ballard, 2002; Ballard & Koskela, 1998). Therefore, relying on the same management techniques can be counterproductive. The efficacy and challenge of design management is rooted in appropriately managing its work flow.

DESIGN WORKFLOW MANAGEMENT

Managing design workflow has to do with managing the people involved in the design process as well as the flow of information between them to enable for design solutions to progress. When planning design tasks, the lack of consideration of their interrelatedness often leads to tasks being planned with insufficient, obsolete, or faulty information, leading to poor productivity, delays, cost overruns, and an inferior ability to generate value for the client or end user.

The rapid proliferation of information needs to be properly integrated and coordinated among multidisciplinary parties. Failing to plan and relate information flows to the respective tasks and responsible parties, delays in sharing the right information can result in delaying the progress of design task completion, out-dating existing information, and causing design deliverables to have missing data necessary for their conformance with requirements or completion. Unfortunately, such issues are usually concealed and only appear in later stages of construction, where the cost, time, and resources required for changes and rework are high. A study by Al Hattab and Farook (2015) examines the impact of design communication and BIM-lean use on the management and reduction of design error diffusion that usually results from poor design workflow.

Sub-optimal workflow has captured researchers' interests who have developed frameworks tackling design task structuring, measuring flow, or understanding the organizational network involved. However, a formerly unexplored workflow perspective is one that integrates both the process, i.e., flow of design information, and the social network, i.e., interactions among design teams. Accordingly, this study approaches workflow at the intersection of the social and process aspects of design to understand, measure, and analyze information flow within design networks. Lean practices and BIM functionalities can enable, through their focus on team work and information integration and sharing, a better design workflow. Agent-based modeling and social network analysis are therefore used to dynamically capture the impacts of lean practices and BIM on communication. This novel design management strategy focuses, simultaneously, on interaction dynamics and information diffusion to assist design teams in enhancing design flow, knowledge transformation, and value generation while reducing wastes.

GAPS IN CURRENT WORKFLOW APPROACHES

When addressing design workflow, some studies tend to isolate the topology of team interactions from the flow of information between individuals by only considering design task transformation while neglecting the flow of design information, or by targeting the social network structure of involved individuals and ignoring information diffusion, or by analyzing information diffusion and ignoring team coalitions. Some gaps in existing research are presented below and summarized in Figure 1:

Research and industry do not commonly consider the importance of information flow between designers which results in poor workflow practices. Informal surveys conducted with design teams revealed that negative iterations (rework) constitutes an approximate 50% of design time (Ballard, 2000). Obsolete or missing information that was not promptly shared can result in such rework. During conventional design, individuals and teams work in isolation without realizing that information they are withholding is useful for other team members and the overall design requirements.

The drawbacks of poor workflow are not clearly understood or observed which limits instilling flow into design practice. Some studies developed flow diagrams to qualitatively map the flow of design deliverables through different stages of the design process (Baldwin et al., 1999). However, this flow has not been mapped across multi-disciplinary teams to highlight the interactions between trades with diverse needs and outputs. Therefore, the impact of these relationships on information flow was not thoroughly evaluated.

Current methods for quantifying flow metrics are not very comprehensive nor sufficient, making it hard to measure performance. Measuring performance is an important step to assess design workflow and implement the required changes. Tribelsky & Sacks (2011) developed metrics to measure design information flow rates on projects by tracking database logs and showing trends of indices reflecting design workflow. Such studies provide important metrics to understand information flow patterns based on database logs, yet they neglect a critical controlling factor in the process of information flow: individual and team interactions. Social network structures and their impact on flow of design work and design quality are not taken into account when measuring information flow.

The intersection of flow dynamics and interactions between design individuals is not considered when studying workflow. Some studies highlight the importance of realizing design and construction projects as social networks constituting design players and their communication (Pryke, 2014), whereas others extend this notion to develop a modeling method that links design tasks to the responsible people within a social network (Parraguez, Eppinger, & Maier, 2015). Some efforts developed metrics of collaboration and team work and related them to the ability of information to reach people depending on their position in hierarchical networks (Lopez, Mendes, & Sanjuan, 2002; Durugbo et al., 2011). Although these studies give insight into the integration of design activities and people involved, they do not model the information exchange necessary for performing tasks, which prevents the realization of workflow patterns within such networks.

As a result, this study is driven by the urging need to address these problematic areas and explore a new approach that accounts for the dynamics of information flow within social networks. It also puts forth a way to assess the impacts of lean design management and BIM-based design on leveraging workflow of conventional design by enabling more interaction, transparency, better communication, and real-time exchange of information. Achieving better workflow can potentially reduce common design wastes such as rework, long cycle times, bottlenecks, and defective designs.

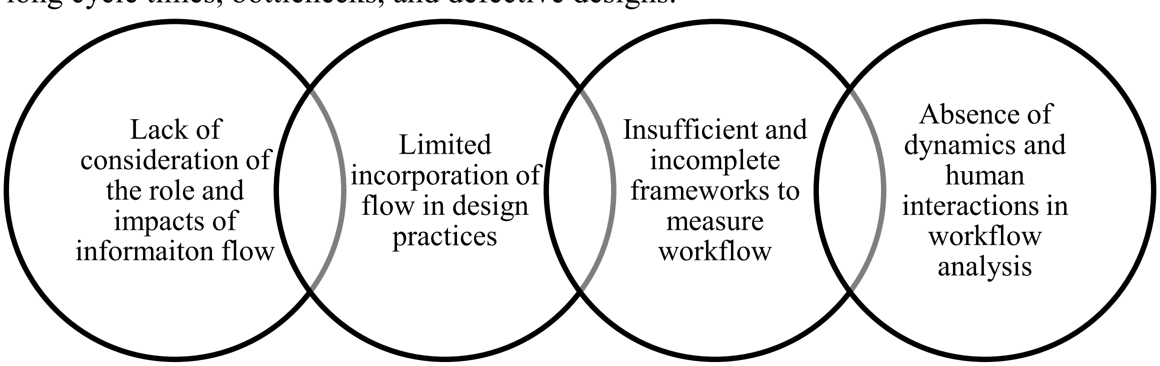

Figure 2: Gaps in design workflow research

AN ALTERNATE METHOD FOR MODELING WORKFLOW

The new method presented in this paper integrates the social and process perspectives to study design workflow. Agent-based modeling is used to reflect the complexity of the design process: the social network topology and design information dynamics. Building design is an intricate system consisting of many individuals working within geographically dispersed teams with different skills who are all gathered to deliver a project with limited time, cost, and information. With current shifts from traditional project delivery to the adoption of lean philosophies and BIM-based technologies for life-cycle management, it becomes obsolete and ineffective to analyze design workflow independent from the interactions of teams that bring about the design delivery process.

Agent-based modeling (ABM) is a new approach for simulating the behavior and interactions of autonomous agents with complex interdependencies. Agent-based modeling is the simulation of occurrences as dynamic systems of interacting agents to analyze their collective behavior within a system in order to understand underlying phenomena and apply certain improvements for the whole system and individual agents as well. Agents can represent people, cars, information, resources, companies, atoms, etc. ABM regards the modeling of agent interactions and relationships with other agents as well as modeling its behavior which depends on the situation and environment it exists in (Macal & North, 2009). ABM allows us to capture the emergence of new behaviors and performances resulting from aggregate interactions and dynamics of agents, which is not possible to inspect separately within complex and highly intertwined systems.

The system considered is a social network, depicted schematically in Figure 2, consisting of two types of agents: (1) the person (design participant) agent and (2) the design information deliverable agent. This topology represents nodes as the people performing design or involved in the design decision-making process, links (edges) as interactions and communication between the people agents. These links, in earlier studies, have been regarded just as mere connections and what flows within them has been disregarded. Figure 2 shows a schematic representation revealing what flows during design within this vague box of transformation.

These interactions as well as the exchange and interdependence of information create an emergence of new information flow patterns. Using social network analysis (SNA), these interactions and the topology of connections between designers helps visually understand some characteristics of the social network structure. Not only does SNA examine the structure of the network, it also studies the natural mechanics occurring within. SNA helps researchers understand the network data visually, convey the results of the analysis, and reveal any hidden properties that might not have been captured through qualitative analysis. Quantitative assessments can also be performed for relationships, connections, and characteristics pertaining to an individual node and to the network structure as a whole using some metrics presented in Table 1. Such metrics reflect the environment of communication, where individuals might work as cooperative teams or as isolated entities, exist as segregated clusters or one coherent network unit, work within a centralized or decentralized decision making hierarchy, facilitate the flow of information or make it interrupted based on their interactions. Other insights can be obtained through the observation and analysis of network topologies.

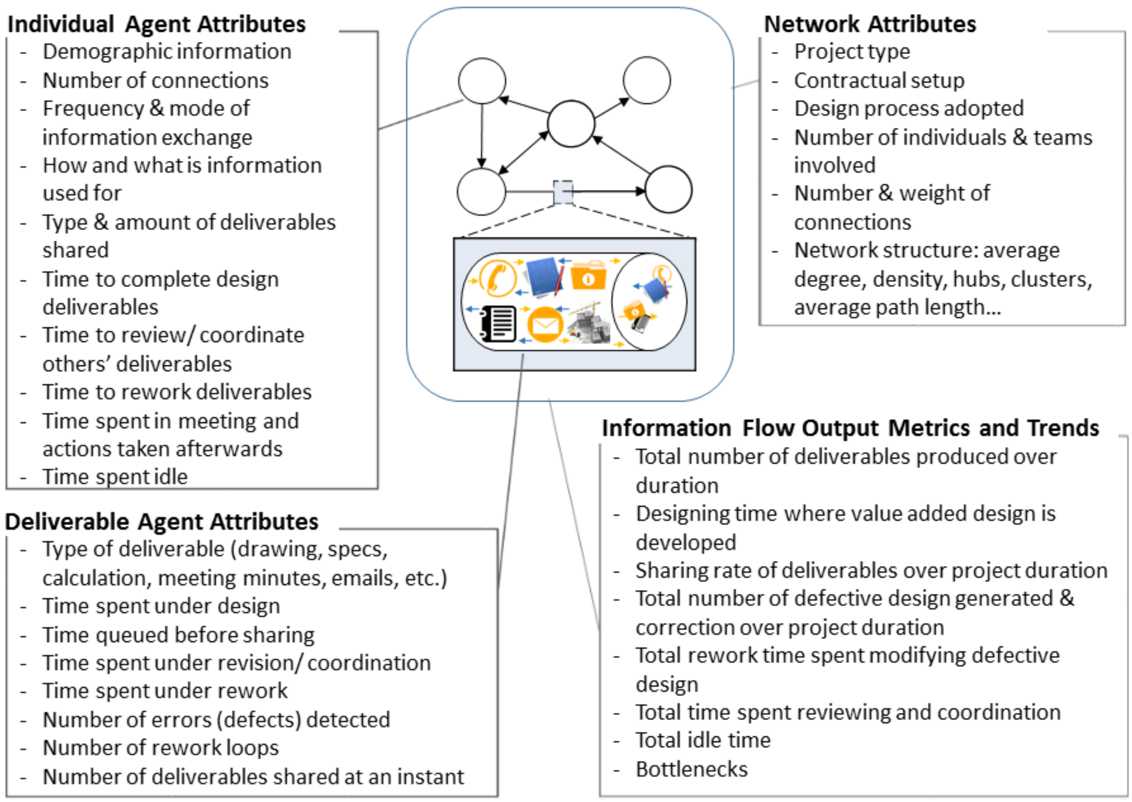

Figure 3: Social network topology, agents' attributes, and output metrics

In the topology presented in Figure 2, and in order to account for information flow within these links, an information deliverable agent is created representing design information deliverables such as BIM models, design drawings, calculations, emails, meeting minutes, etc. While ABM takes a reductionist approach that transforms the real world into a simplified model, it more importantly allows us to capture emergent behaviors of the overall network behavior that cannot be obtained by simple observations or assumptions of individual agent behavior, better understand how design information flows between participants, and underline the role of the social structure in influencing the diffusion of design information. By measuring and analyzing the behavior of individuals and information flow within the entire network through ABM, unpredictable outcomes that are hard to see are made clearer and more understandable. Traditional analytical methods fail to capture the resulting emergence of collective behavior and dynamic relationships between agents, and they usually represent a static description of the system at one frame in time. These limitations of regular approaches discussed earlier lend the need to use agent-based modeling to model the behaviors, interactions, exchanges, and formations of teams and organizations that influence individuals and the overall system emerging performance.

Table 2: Social network metrics

Type	Metric	Definition (this metric describes)
Node	Degree centrality	Measures the number of links an individual has with others
	Betweenness	Measures the number of node pairs that an individual connects or bridges (serving as a broker or intermediary)
	Closeness	Measures the number of links from an individual to others; how reachable a person is by others
Network	Density	Measures how many actual links exist between nodes divided by the number of total possible links to reflect cohesiveness of the network
	Clustering	Measures how clustered groups of people are compared to the rest of the network indicating existence of closed triads and small communities
	Average path length	How many steps, on average, nodes require to reach each other
	Modularity	How dense the connections between nodes within groups as compared to nodes with other groups

ABM SETUP FOR LEAN-BIM BASED WORKFLOW

AnyLogic is a simulation tool that performs discrete-event simulation, system dynamics, and agent-based modeling. AnyLogic is used in this study to develop a model for understanding and measuring design workflow resulting from lean and BIM-based design network topologies. The model interface consists of two agents that were defined earlier (people and information deliverable agent). The behavior of each agent is represented through a "State Chart" that defines the behaviors or states of each agent, and provides the rules for changes in behavior and interactions with other agents.

A person agent can have these interchanging states: "designing, integrating/coordinating, reworking/modifying design deliverables, sharing deliverables, in a meeting, being idle". The interchange or transitions from a state to another, as shown in Figure 3, is dictated by interactions and requests from other people in the design process. For example, if a person is designing and someone requests input from him/her, he/she moves to the "Share" state after completing a certain design. The time invested in each state, and the transitions between states, are based on data that can be collected through surveys and observations of individuals and teams. The behavior of each agent throughout the project can then be simulated to show the changing dynamics throughout the design project and how the design process and exchange of information is flowing within the design network.

Similarly, the information deliverable agent possesses a different set of states. This agent exchanged between designers. This kind of agent is a mobile agent (it is transferred and exchanged) and its behavior is controlled by the behavior of its superior agent (designers). An information agent can have these states: "In progress, ready for sharing, ready for coordination, under integration/ coordination, approved, clashes detected, or under rework". The interchange or transitions from a state to another is dictated by the decisions and behaviors of the designer agents. For example, a BIM model, moves from "Ready for coordination" state to "Under integration/ coordination" state when the people responsible for coordinating it start the "Integrating/coordination" state process. Data pertaining to the number of BIM models and deliverables exchanges over a time period, whom each person exchanges information with, how frequently deliverables are exchanges, the means of communication, the number of revision cycles of a deliverables, and other input can be collected through questionnaires addressed to the designers and by tracking data logs of such exchanges. Figure 4 is a sample state chart of a BIM agent.

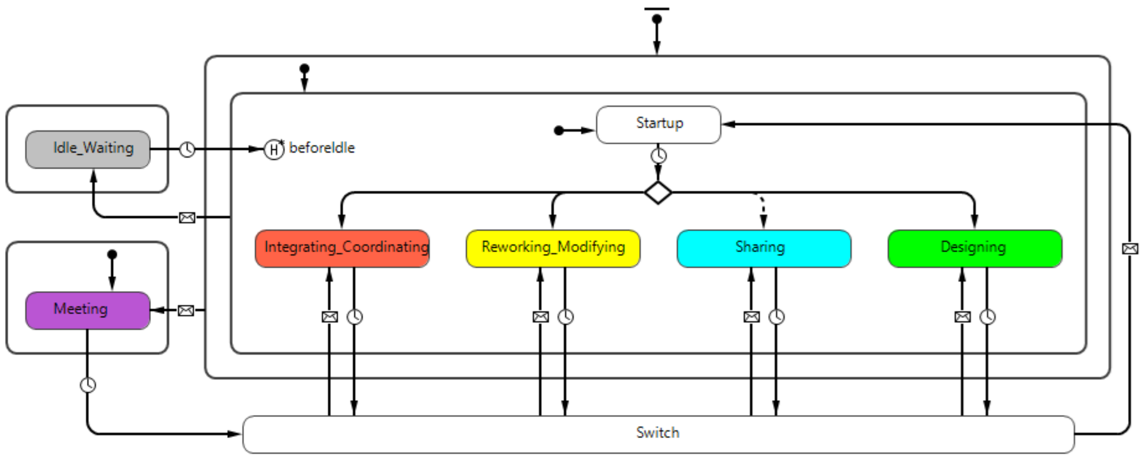

Figure 4: Designer state chart of behaviors

WORKFLOW ANALYSIS THROUGH SIMULATION OUTPUT

The characteristics of design workflow exchange of each individual, the state of each information deliverable, and the overall dynamics of information flow of the entire network can then be obtained. On the designer agent level, the simulation of the model can highlight interesting trends such as: the number and durations of design cycles which can help detect phases of idle time or non-value adding design and how time is divided between different design activities, number of rework and revision cycles conducted by the designer that can imply potential problems with design information and error diffusion mechanisms as well as conformance or non-conformance with design requirements and the introduction of client changes during design, and other attributes that can be explored in-depth in further research. Value-adding design workflow can be assessed from several lean perspectives, for example: sharing trends and frequencies which can reflect a smooth flow of information or batch interrupted flows that can result in efficiencies, queueing time experienced by information deliverables, the number of rework cycles which can reflect if information exchange patterns are efficient in delivering important data to the right people at the right time or turning data into obsolete information resulting in errors that require rework, and other trends that can reflect underlying issues in the communication processes involved in the design process. On the information deliverable level, the simulation can show the length of time a model can be held in queue with a designer before it is shared, reviewed, reworked, or before a decision is taken on it. Moreover, the number of times it is revised, reworked, modified, shared, and the number of errors or design non-conformances can be tracked for each deliverable.

On the collective network level, several insights that describe design workflow on social networks can be obtained. Figure 5 is a sample of project sharing trends. For example, patterns can reflect whether workflow is smooth or interrupted, whether information is being shared continuously between designers or stored in silos then shared in batched resulting in outdate data that can be later manifested as errors in other deliverables. Bottlenecks in processing times (reviewing, coordinating, designing, or sharing) of individuals or teams can also be detected and help indicate where actions need to be taken. The overall quality of design information reflected in the dynamic generation and diffusion of errors between teams over a time span can also be observed to highlight root causes of resulting trends. In addition, design information production patterns can show when and how information is being produced, stored, queued, and can provide insight on drivers or preventers of design generation. Further insights on design workflow attributes and the influence of interactions and topologies of networks can be explored.

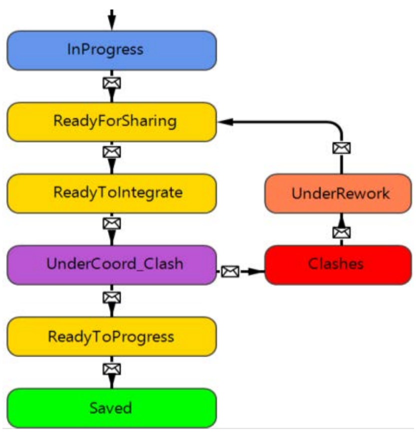

Figure 6: BIM model state chart

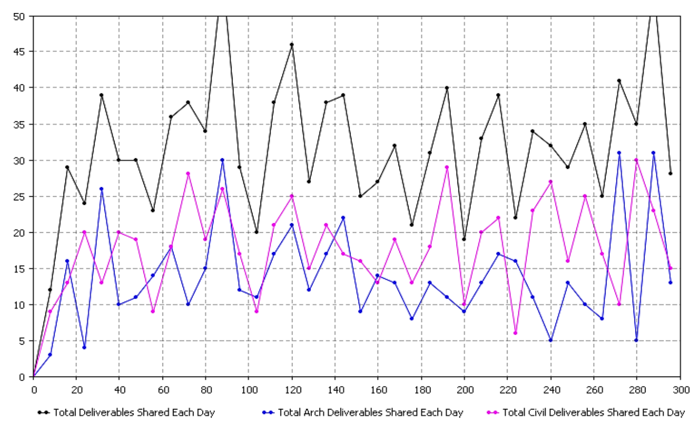

Figure 5: Project design information sharing trends

CONCLUSIONS

The proposed method of integrating social topologies and design process dynamics through ABM can provide a different perspective for understanding the diffusion of information between parties involved in the design process. The developed approach is an attempt to improve on and bridge the gaps of the existing methods to accommodate complex systems in terms of involved teams, sophisticated requirements, integrated technological interfaces, and large amounts of information that needs to be coordinated and effectively exchanged. The social network topology metrics and the resulting patters of workflow dynamics can be cross-checked to highlight potential relationships of communication and team coalitions on shaping the quality and flow of information. Moreover, the proposed approach can allow for a quantitative and qualitative analytical comparison of lean-BIM design processes to traditional design trends. These comparisons can set a working standard, highlight potential benefits resulting from lean-BIM use, and benchmark performance to desired standards. This analytical method can be further explored on the project-life cycle as a whole and tailored to model complex interdependent systems that are continuously changing over time.

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THE ROLE OF CONCEPTUAL MODELING IN LEAN CONSTRUCTION SIMULATION

M. Poshdar[1] , V. A. González[2], M. O'Sullivan[3] , M. Shahbazpour[4], C. G. Walker[5], H. Golzarpoor[6]

ABSTRACT

Simulation can validate lean construction concepts prior to their field implementation. It enables efficient analysis of the impacts of lean construction theory on a project by supporting a variety of procedures including model sensitivity and scenario analyses. However, to date, the organization of the elements in lean construction simulation models has mainly followed the traditional perception of construction workarounds. They often assume the project will adhere to the work breakdown structure created by the planners before the execution phase. In order to implement the pull-driven approach, as one of the lean construction principles, managerial interventions during the project execution are inevitable and may include a change in the planned sequence of the work process. Hence, an efficient lean construction model has to explicitly capture the management feedback and decision linkages within the project. A review of the applied modeling approaches in lean construction simulation research indicates a weakness in this area. The methods do not apply a systematic framework that supports identifying the crucial elements of the project and includes the level of detail required in the model. This study investigates likely solutions to overcome the indicated shortage. It traces the roots of the deficiency back to the conceptual phase and investigates the implications of conceptual modeling in lean construction simulation research. It is demonstrated that undertaking a conceptual modeling stage can provide a good level of transparency about the elements that are necessary for abstracting the project reality. Therefore, this study suggests conceptual modeling as an effective solution to enhance the success of a lean construction simulation study.

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KEYWORDS

Simulation, Variability, Production, Process, Managerial Intervention.

INTRODUCTION

Construction operations are highly complex and dynamic, involving multiple interacting factors that produce unpredictable outcomes (AbouRizk et al., 2011). In such a complex environment, managerial decisions need to be carefully examined (Peña-Mora et al., 2008). An examination in a real project will be expensive, time-consuming and difficult to undertake (Al-Sudairi et al., 1999). Simulation can provide a low-cost, low-pressure alternative for experimenting with multiple scenarios. It assists in identifying the problematic areas and in defining possible solutions (González et al., 2013). Simulation models can represent the processes and their surrounding environment both quantitatively and logically, a capability which has proved to be valuable for analysis (AbouRizk et al., 2011). These analytical capabilities can be used in lean construction to test and estimate the achievements of its principles before their actual field implementation (Halpin and Kueckmann, 2002).

Despite its prospective capability, to date the use of simulation in lean construction projects has been limited (Farrar et al., 2004). This limitation can be attributed to the level of complexity and difficulty involved in the lean construction modeling process. We contend that such a level of complexity is the result of the mismatch between the fundamental principles of lean construction and the assumptions made in the traditional modeling approaches applied to construction processes.

Most construction simulation models are developed based on a traditional perspective about the organization of the project elements. They assume that the work breakdown structure of construction projects can be represented as a queuing system. In this system, crews of various trades move from one location to another to provide services and operate production processes. Their completed products are stationary and play the role of consumer of services for the next crew (Tommelein et al., 1999). In such a traditional approach, also known as a push system, the project will always adhere to the planned work structure. Therefore, each process passively waits to receive the planned input before starting its operation. Such strategy causes waste in production that takes the form of waiting time and slow work in some processes and overproduction in some others (Poshdar, 2015).

Lean construction contrarily strives to keep the waste minimized by pursuing pull techniques as a principle. Under this strategy, each process is supposed to acquire the required resources precisely as needed. The resources are pulled not only from the queues immediately preceding the activity but also from any other areas of the project that can supply the requirements (Tommelein, 1998). It offers a dynamic work breakdown structure, which may involve deliberate changes to the planned sequence of processes or the operations within a process. The managers decide the changes based upon feedback and decision links established between different parts of the project. An efficient lean construction modeling strategy should explicitly account for these links and the likely managerial interventions to implement the pull strategy. So far, no specific approach has been provided in lean construction simulation research that can support the modelers in recognizing the crucial elements and including the level of detail that are necessary to build an efficient lean construction simulation model.

In order to address this issue, we first develop a critical review of the existing literature on lean construction simulation. Further, we identify the state of the art in simulation research in other areas. Afterward, the paper establishes a linkage between the systematic approaches developed in simulation research in other areas and the limitations found in the lean construction simulation studies. The study reveals conceptual modeling as a crucial process in simulation modeling that has received less attention from modelers. Accordingly, this paper proposes a systematic framework that can assist the modeler to move from a problem state to a solution that enables the development of a robust lean construction simulation model. Finally, we will demonstrate the utility of the proposed framework to model part of a real project involving the construction of a multi-story building.

SIMULATION RESEARCH IN LEAN CONSTRUCTION

As simulation can efficiently model and analyze production processes, for many, lean thinking and simulation are closely related (Halpin and Kueckmann, 2002). Tommelein (1997) utilized discrete-event simulation to generate system-level information about two construction projects. The study demonstrated the use of the information generated about the flow and conversion, and the effects of adopting different strategies of work sequencing in redesigning the construction processes and making them leaner. She discussed the use of simulation in understanding the so-called matching problem on construction sites. Many construction processes include an operation on unique materials in specific locations; materials and locations must match before the operation can take place (Tommelein, 1998). Al-Sudairi et al. (1999) examined the effects of five lean principles on a steel erection process based on a computer simulation analysis. Halpin and Kueckmann (2002) further explored the relationship between simulation and lean construction. They recommended that lean thinking provides a structured framework to redesign production processes while simulation offers a methodology for evaluating the benefits of it. Farrar et al. (2004) proposed a generic set of guidelines to test lean principles in a simulation model. Sacks et al. (2007) developed a game named LEAPCON based on a lean model for construction management of high-rise apartment buildings. The game simulates the execution of interior finishing activities required in a multi-story building with customized apartment designs. They used the computer simulation to validate the results of the live experiment; establish and implement an improved base plan; and test the marginal contribution of each lean intervention as well as the effects of variations on the management model. Mao and Zhang (2008) suggested a framework with eleven steps that provides guidelines to streamline the construction process and create innovative construction methods. They incorporated computer simulation techniques into their framework to assess the efficiency and effectiveness of the reengineered processes designed through the framework. González et al. (2009) proposed a generic simulation-optimization and multiobjective framework to design work-in-process buffers in repetitive projects using lean principles. Abbasian-Hosseini et al. (2014) used computer simulation to quantify and evaluate the results of applying lean principles in the bricklaying process. Nikakhtar et al. (2015) did the same to quantify the effects of lean principles on a reinforcement process.

The review shows that lean construction simulation models often assume the project will keep the work breakdown the same as created by the planners before the execution phase. They model the systems, assess the potential gains from implementing lean construction concepts, and re-design the work breakdown to increase the potential gains overlooking the fact that often circumstances arise in the execution phase in which decisions need to be made about reallocation of resources and reorganization of processes. As such, a lean construction approach demands a dynamic work breakdown structure that may change based on managerial feedback and decision information during execution. Thus, the simulation modeling approach should be able to represent such dynamics. This necessity is confirmed by Peña-Mora et al. (2008), and AbouRizk et al. (2011) who emphasize the vital importance of robustness of simulation experiments and the significance of including all the influential factors that may arise during the execution phase. This paper proposes a systematic model development approach that can help to capture all the significant factors of the project, including likely managerial interventions in the execution phase, and enhance the robustness of the lean construction simulation experiment. To do so, it acquires a certain structure for developing the simulation experiment that has already been proved to be useful in other simulation research areas. The next section discusses the details of the established structure.

A SYSTEMATIC STRUCTURE TO DEVELOP SIMULATION STUDIES

According to Balci and Ormsby (2007), three major abstraction stages take place to develop a robust simulation. **Conceptual Model:** The conceptual model is a simplified, software independent representation of the real system. It enables the modeler(s) to move from a problem situation, through model requirements to a definition of the necessary elements of the model. This stage of modeling provides some advantages such as less demand for data, short development time, and more flexibility for future changes. **Model Design:** This stage involves specifying the paradigm that the model will follow. It also includes the selection of the simulation platform that will be used in the implementation stage. It can follow either object-oriented or procedural paradigms. The platform can be chosen to be a general or a special purpose package such as STROBOSCOPE (Martinez, 1996), or a programming language such as C, C++, or Java (Law, 2007). **Model Implementation:** The final phase involves implementing the designed model in the adopted simulation platform.

Revisiting the current lean construction simulation research shows that the models often focus on the design and implementation stages. However, a successful simulation process requires effective conceptual modeling (Robinson, 2014). Robinson (2014) argues that the importance of conceptual modeling is probably the least understood aspect of simulation modeling. Accordingly, in this paper, we explore the conceptual modeling stage in lean construction simulation research and its important role in building a robust model.

DEVELOPMENT OF A CONCEPTUAL MODEL

Three basic approaches can be identified for developing conceptual models

(Robinson, 2008a). **Providing principles of modeling:** A set of principles is provided that give general guidelines for building a conceptual model. The central theme is to start with simple models and gradually add scope and detail (Robinson, 2008a). **Methods of simplification:** These methods act primarily as a redesigning tool in contrast to a design approach (Robinson, 2008a). They aim to simplify the components of an existing model while a sufficient level of accuracy is maintained (Zeigler et al., 2000). **Modeling frameworks:** A framework provides specific steps for developing the conceptual model. The purpose is to provide a modeler with an understanding of the development process of a conceptual model.

The first approach is useful to provide some guidance to the conceptual model designer; however, it does not provide any details on developing the model. The second approach requires the model to be already available and focuses on its improvement. Only, the last approach supports extended guidelines to build a conceptual model from scratch (Robinson, 2014). A modeling framework provides a greater sense of discipline to the conceptual modeling activity. The higher discipline formalizes the basic tasks and can encourage greater creativity (Robinson, 2008b). However, when a conceptual modeling framework is utilized, its underlying assumptions can significantly affect the model as well as the consequent design and implementation of the model. Therefore, it is of particular interest to outline a conceptual framework in this paper that is able to effectively capture the fundamental concepts of lean construction and hence improve the quality of lean construction simulation.

A conceptual modeling framework for lean construction simulation

A conceptual model of lean construction must be able to represent all the elements that can take the job further than the queuing network arrangement underlying traditional approaches. Just recently, some researchers have discussed the role of conceptual modeling in testing the foundation stone of queuing networks in the simulation arena. In that respect, Robinson (2015) and Furian et al. (2015) proposed conceptual models that are not based on queuing networks and Furian et al. (2015) provide a framework for developing conceptual models with control structures that are not queue-based. They proposed a hierarchical control conceptual modeling framework that explicitly captures high-level policies and decision-making alongside typical operational control mechanisms. In this study, we will refine their framework by adding two post-modeling phases for presentation and validation. Figure 1 shows the organization of the proposed framework, which consists of six sequential phases.

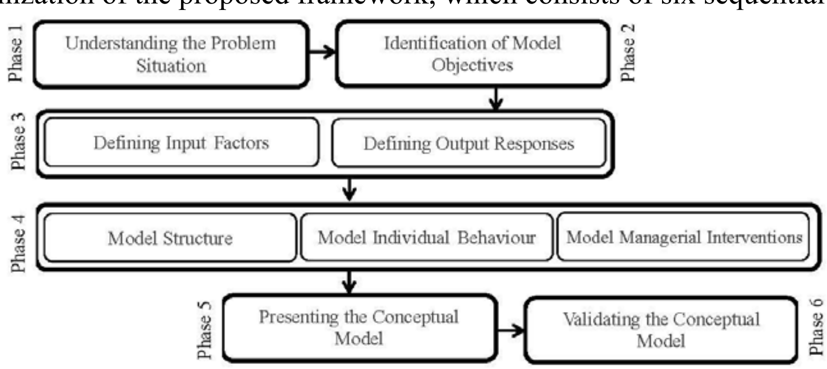

Figure 7. The Conceptual Modeling Framework

In order to demonstrate the utility of the framework in practice, we also illustrate the application of each phase in the modeling of a real project. It involves a simplified version of the processes related to "fabricating doors and windows offsite and their installation in 17 apartments on site" (Figure 8). The offsite process includes fabricating four different types of products with specific dimensions, materials, and decorative designs. The onsite process involves installing the products into their corresponding wall openings (Figure 9). The processes are designed to complete the operations on each of the types of products in a certain order (shown in Figure 8). The potential contribution of the conceptual modeling process in developing robust lean construction simulation experiments is discussed as follows:

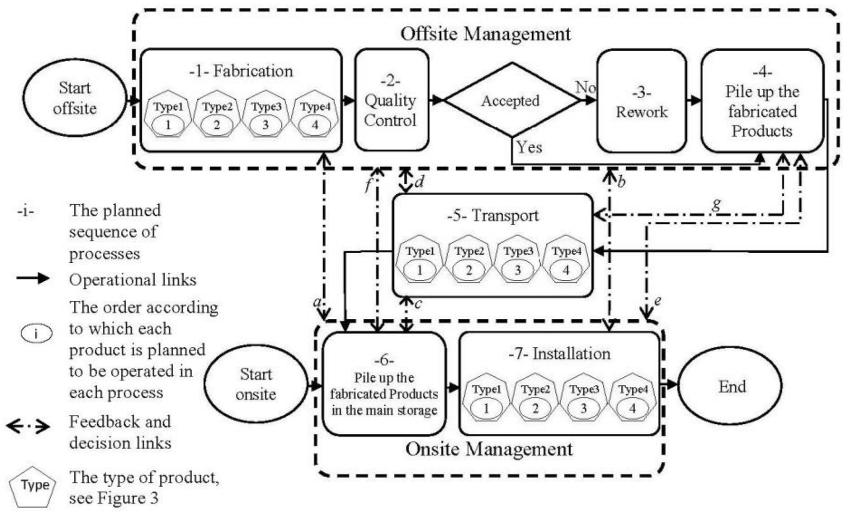

Figure 8. An illustrative process flow diagram of the project

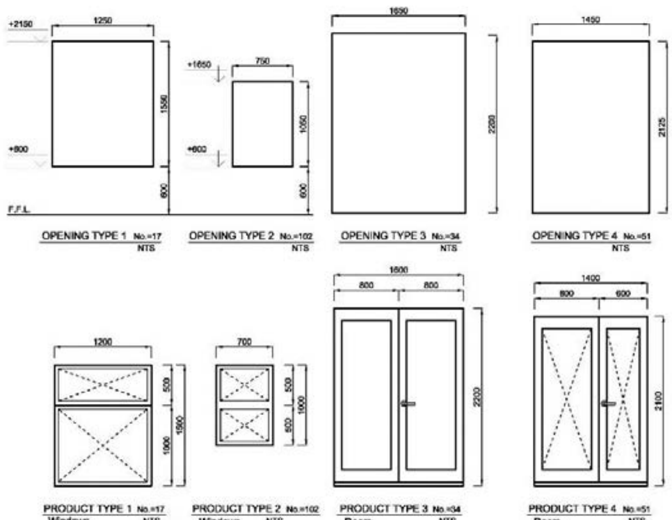

Figure 9. Four types of products offsite and their match openings on site

Phase 1: The starting point of any simulation study is to develop an understanding of the problem situation. This stage exposes any areas of limited knowledge and understanding that then necessitates making certain assumptions (Robinson, 2008b).

The case project: The project includes installation of four specific types of doors and windows with certain characteristics specified in the architectural drawings. The prominent aspects of the problem are as follows: The product types and the available openings must match before installation can take place. In an actual case, however, the planned sequences of work are affected by unexpected conditions that can cause a mismatch between the fabricated products offsite and the available openings on site. The problems can include dimensional errors in the fabricated products or their corresponding openings on site, misaligned bottom plates, or imperfect floor leveling. A delay in the construction process of the wall openings can also be another reason for hampering the installation process. As a part of the management's actions that keep a pull strategy running, they may decide to change the planned sequence of processes or order of operations within a process.

Phase 2: A clear definition of the model objectives is the key to the development of a successful model. The objectives are concerned with the overall aim of the organization, and the specific modeling objectives (Robinson, 2008b).

The case project: The overall aim of the organization was to minimize the inventory, minimize project completion time, and maximize project productivity. In addition, the model needed to consider different constraints such as available space for product inventory. The specific objective of the simulation study was to make an accurate estimate of the likely contribution of applying a pull strategy in the project.

Phase 3: The third phase of the conceptual modeling process is to identify the experimental factors and responses as the primary inputs and outputs of the model.

The experimental factors are the model data that can be set as variables to achieve the modeling objectives. The responses typically are set to determine the extent to which the modeling objectives have been achieved and to identify the reasons for any failures (Robinson, 2008b).

The case project: The experimental factors of the project include the performance of different teams (measured by required time to complete an operation) and the size of the buffers utilized. A review of the key performance indicators as the model outputs could fulfill the specific objective of the project.

Phase 4: This phase involves the determination of the model contents. Robinson (2008b) suggests that simulation models may involve four types of components: entities, activities, queues, and resources. These four elements can properly model the push strategy applied by the traditional management approaches. As explained earlier, in traditional approaches the activities are intended to comply with the planned sequence of processes at the expense of a significant increase in waste.

In a pull system, the managers may give priority to some resources over others if they are known to match up with resources already available further downstream (Tommelein, 1997). Hence, in a pull-driven approach, the work breakdown structure of the processes may dynamically change. Therefore, it is not enough to model only the operational components, the management control policies must also be part of the model.

The case project: Table 1 summarizes the main components of the project model according to the definition by Robinson (2008b), which enables modeling of a traditional management approach.

As explained, in a pull-driven decision environment, the managers may change the planned work breakdown based on the project status. For instance, if the fabrication process operates ahead of the planned schedule, the on-site managers may decide to skip piling up the products in the main storage (process 6), and send them directly to the installation crew (process 7). It can help to avoid the waste of waiting in process 7, while also reducing the waste from production occurring too early in process 1. For this purpose, a feedback and decision link must be established between process 1 and the onsite management team (link *a* in Figure 8). Similarly, the establishment of a feedback tie between the offsite management team and process 7 (link *b* in Figure 8), enables adjustments to the fabrication operation with the completion of construction and availability of openings on site. Hence, the fabricators may change the planned sequence of production and give priority to a certain type of product that matches with the availabilities on site. The development of a conceptual model also can expose other potential connections for exchanging feedback between the project processes and management teams. The project managers may consider links *c* to *g* to transmit feedbacks and build up the pull system.

Table 1: Main operational components of the conceptual model

Ite	Activity	Entities		Queues	Resources
		In	Out		
1	Fabrication	Drawings, Materials	Fabricated doors and windows	Design files, and materials	Fabrication Crew, Materials, Machinery
2	Quality Control	Fabricated doors and windows	(a) Accepted quality (b) Rejected quality	Fabricated doors and windows	Inspection Crew
3	Rework	Products with rejected quality	Corrected products	Rejected products	Fabrication Crew
4	Off-site warehousing	Products with acceptable quality, Corrected Products	Piled up and packed products	Products that are ready to be transported	Offsite storage Crew, Storing Area
5	Transport	Piled up products	Transported products	Piled up products	Transportation Crew, Machineries
6	On-site warehousing	Transported products	Piled up packs of products	Arrived packs of products	Onsite storage Crew, Storing area
7	Installation	Apartments ready for installation, products from item 6	Completed work	Ready apartments, and Piled up products	Installation Crew, Machinery

However, the inclusion of the additional links will increase the model complexity that has an inverse effect on usability and run-speed. Therefore, the modelers need to achieve a balance between the level of detail included in the model and its usability. Robinson (2008b) suggests referring to the judgment of the modeler, clients, and domain experts; experience; analysis of preliminary data about the system; or prototyping as some potential solutions to establish the proper balance.

Phase 5: The developed model should be expressed in a manner that can be communicated and understood by all parties involved in a simulation experiment. A range of methods has been proposed for representing and communicating simulation conceptual models. For instance process flow diagrams, activity cycle diagrams, Petri nets, event graphs, simulation activity diagrams, and tables describing the model rationale and content have been among the suggested approaches (Robinson, 2008b).

The case project: Figure 2 uses a basic outline of the components to enhance the transparency of the elements that are necessary for abstracting the project reality. Additional logic flow diagrams or pseudocode could elucidate the way in which the feedback links *a* to *g* dynamically determine the flow of items in the system.

Phase 6: Once developed, the model has to be validated. It is a vital part of the process for the success of the simulation study. A validation process ensures fulfillment of the simulation objectives with the required accuracy (Robinson, 2014). It is, however, almost impossible to measure the accuracy of the conceptual model until at least a full computer representation becomes available. Before the computer modeling stage, validation of the conceptual model will be mainly based on the opinion of the modeler with additional support from the clients and the domain experts (Robinson, 2008b).

The case project: The feasibility and the extent of effectiveness of the designed links can be consulted with the project experts.

CONCLUSION

A systematic framework has been discussed for lean construction simulation modeling with three major abstraction phases including conceptual modeling, design, and implementation. Among them, the conceptual modeling phase has received the least attention from the simulation modelers in construction. This study revisited the conceptual modeling process as a vital part of the lean construction simulation procedure. A lean construction project involves managerial interventions during the execution phase. A model with a fixed queuing arrangement of the processes may be inadequate to represent a project with such interventions. Accordingly, a modeling framework was discussed that does not rely on a fixed work structure of activities. It involves the managerial decisions as an explicit part of the model. The framework provides the modeler with a good level of transparency about the decision links and effects. Hence, it enables modeling of the selective control utilized by the pull systems based on real-time information from project processes including downstream processes.

Further development of this research includes implementing the proposed structure in a real construction project and capturing the users' specific requirements.

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AGENT-BASED SIMULATION OF CONSTRUCTION WORKFLOWS USING A RELATIONAL DATA MODEL

Ling. Ma[1] and Rafael. Sacks[2]

ABSTRACT

To what extent is uncertainty concerning process status a cause of waste in construction workflows? Work studies and action research are expensive methods for investigation of such questions concerning construction workflow control policies and their results have limited applicability. Agent-based simulation (ABS) is particularly suitable for modelling peoples’ behavior and interaction in complex settings, like in construction, and therefore represents an alternative. We present a parametric ABS system (EPIC 2.0) developed using a relational data model for modelling construction workflow; the model enables users to specify the construction subjects (subcontractor trade crews), their work methods, the amount of work, the workspaces (locations), dependencies between the works, etc. The simulation encapsulates both variability and uncertainty in the construction workflow. Variability arising from design changes, quality checks and working conditions may lead to random change in workload and performance. Uncertainty arises from the fact that agents do not have full or perfect information. The major advantages of this ABS system are its ability to run differently configured virtual projects in terms of work crews, locations and production system control policies and to test the relative impacts of various approaches to communication of process status information. Simulation results conclude information asymmetry causes erroneous task maturity judgments and inappropriate work assignments, and of course affects the construction workflow.

KEYWORDS

Agent-based simulation; construction workflow; uncertainty; relational data model.

INTRODUCTION

Sacks et al. (2015) presented computer simulation as a powerful alternative to expensive ‘in-situ’ work study (e.g., Amaratunga et al. 2002) and action research (e.g., Azhar et al. 2009) for research of production flow in construction. Discrete-event-simulation (DES) has been the most commonly used method (e.g., Brodetskaia et al. 2013; Sacks et al. 2007; Tommelein et al. 1999). DES of construction projects execute the virtual site activities according to pre-planned construction operations with predetermined inputs and view construction production as a centrally controlled

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process. However, they fail to incorporate the inherent variability and emergence that arises from the independent construction subjects' behavior as they interact on a construction site (Watkins et al. 2009). Modern construction management theory has highlighted various kinds of variability (Koskela 2000), the inherent limitations of pre-planned control (Laufer 1997) and the presence of decentralized control in construction (Howell 1999). DES is limited in applying these principles in the simulations.

Agent-Based Simulation (ABS) is an appropriate method to model those principles of emergence that apply to social activities (Sanchez and Lucas 2002). It focuses on modelling the distinct behavior of individual subjects and their interactions (Macal and North 2009). ABS has been implemented to model construction activities for different purposes (Sawhney et al. 2003). Watkins et al. (2009) used ABS to investigate the space congestion problem on a construction site; Tah (2005) presented the use of ABS to explore different project supply chain networks; and Kim and Kim (2010) used ABS to evaluate the traffic flow of construction equipment on a construction site. These efforts have highlighted the advantages of using ABS to model construction activities for different research purposes.

However, none of these attempted to model emergent outcomes resulting from the information-dependent decision-making of individual agents, which is central to the problem of researching the flow of crews on construction sites. Ben-Alon (2015) presented a unique ABS named EPIC (Emergent Production In Construction) which models the impact of product and process information flows on site superintendents' and trade crew leaders' decisions about workflow in construction. The agents were driven by tailored utility functions and an emergent production environment. However, the system was restricted to a given project configuration without the ability to parametrically configure the variety of different project setups needed for such research. It also stopped short of quantifying and monitoring the information flows.

This paper presents a new ABS system (EPIC 2.0) and developed for modelling the subcontractor trade crews' short-term work planning in a construction site subject to variability and uncertainty. The system facilitates investigating the impact of information flow on construction workflow. The following sections present the development of this system using a relational data model, a typical project configuration used to demonstrate the system's capabilities, the results of this project, and brief conclusions. The example highlights the ability to parametrically configure a project, to simulate different information exchange principles, and to quantify and measure the information flows and the resulting workflows. It illustrates how the impact of information transparency on the construction workflow can be explored. The potential to extend the simulation to investigate more complex emergent phenomena in construction is discussed.

DATA MODEL AND SYSTEM DESIGN

The ABS system is based on a relational data model and relational algebra. Relational modeling is an approach to formalize certain concepts in reality using a structure and language consistent with first-order predicate logic. It has been widely implemented in database management systems. A relational model is both human-readable and computer-readable; it clearly reflects human's communication and thinking manners. Relational modeling is therefore appropriate for modeling the information flows through communications on site and the crews' perceptions of project state. Relational algebra operations such as Selection (σ), Rename (ρ), Projection (Π), Group (γ), Natural Join (⋈), Union (+) and Minus (-) are used to model the project progression, crews' information processing and their short-term task planning.

The Entity-Relationship diagram of the data model is shown in Figure 1. It has three major parts:

Project configuration data have a prefix '*Fact_*';

Project progression data have a prefix '*Log_*';

Project event data have a prefix '*Event_*'.

MODELLING CONSTRUCTION PROJECT CONFIGURATION AND WORKFLOW

Construction project configuration includes relations among project, crew, work method, task, task dependency, and workspace. In the project configuration data, the user can define different crew trades, their workload and production rates, their workspaces and workspace priority, and also work dependencies ('*Fact_*' data in Figure 1).

The simulation is executed iteratively, and each iteration simulates one day in the virtual construction site. The project progression is logged, including date, crew ID, location ID, production rate, and remaining workload ('*Log _*' data in Figure 1). The crews can decide their subsequent location to work or wait based on their perceptions of the work readiness in that day. Due to the concerns of task dependency, workspace capacity and other constraints in task planning, each crew holds a perception about the project status as a whole, including not only their work but also others' ('*KnowledgeOwner'* in '*Log_*' data in Figure 1). For example, if crew A think all the precedent work for their work is not complete, they would wait; if crew A think crew B is working on floor 1, they won't go there. The simulation performs the Group (γ) operation on project progression data to retrieve the agents'/crews' latest perceptions of the project state in the following way:

$$\sigma(latestTaskState) = \sigma(Log\_Task) \bowtie \rho_{ID/Max(ID)}\left(\gamma_{KnowledgeOwner,TaskID,Max(ID)}(Log\_Task)\right) \quad (1)$$

MODELLING THE UNCERTAINTY AND VARIABILITY IN WORKFLOW

The simulation encapsulates both variability and uncertainty in construction workflow. Variability arises from design changes, quality checks and changes in working conditions Uncertainty, as a subsequence of the variability, arises from the fact that agents do not have full or perfect information about the project state. Only the data representing crews' perception of their own work manifests the true state of the project. The simulation performs Selection (σ) operation on result in Eq (1) to get the fact data in following way:

$$\sigma(latestTaskStateTrue) = \sigma_{SubName=KnowledgeOwner}(latestTaskState) \quad (2)$$

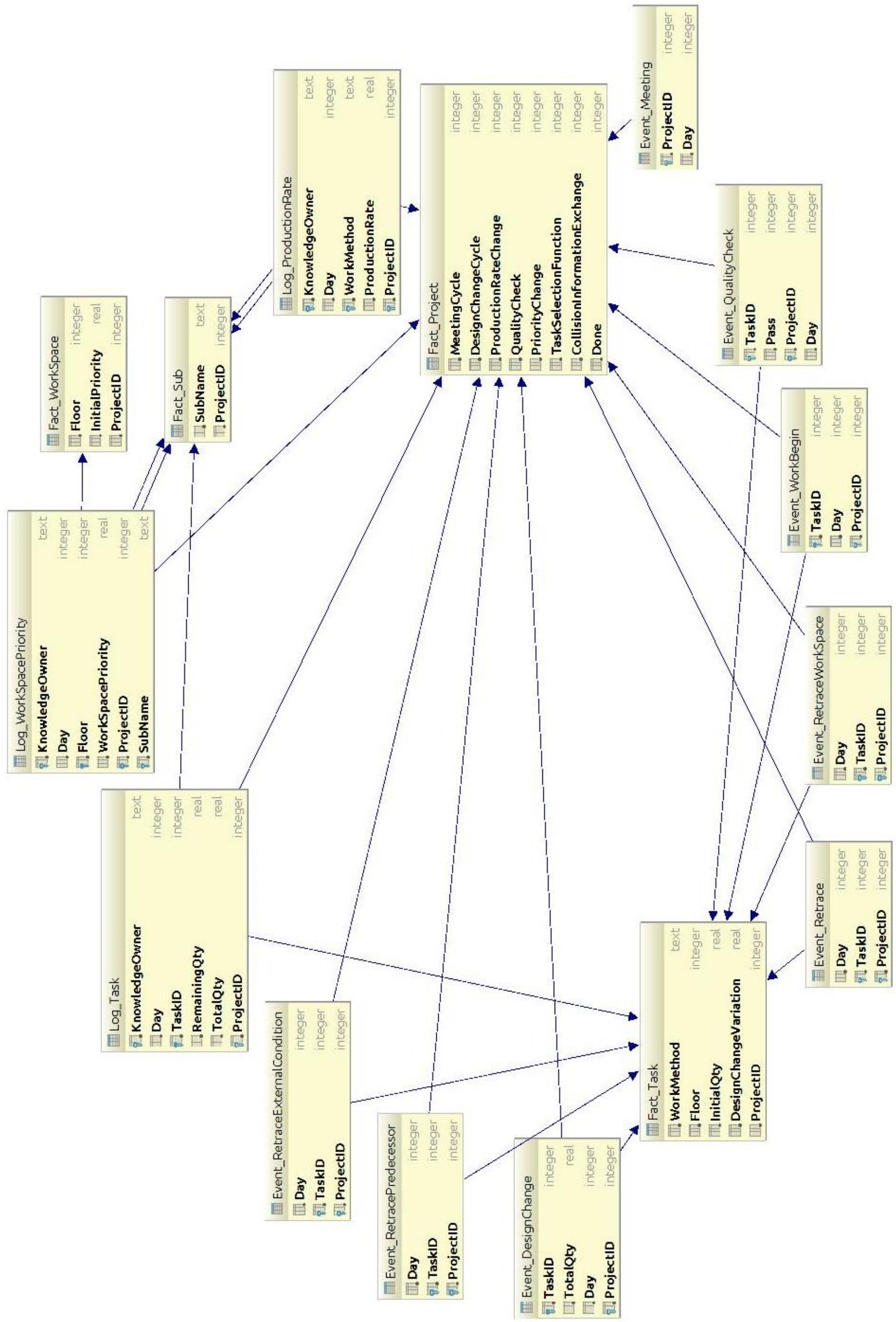


Figure 1. The data model of the simulation

The uncertainty exists, because the result in Eq (1) may not consistent with the result in Eq (2). For example, on day 7, A may think that B finished its work on floor 3 on day 5, based on his earlier observation and perception of B's production rate. But in fact, B is still working on floor 3 but at a lower production rate. At this time, if A makes a wrong decision to work on that floor, he will face a workspace conflict and waste one day on site, and data entry of such occurrence will be added to project event data ('*Event_Retrace'* table in data model having a prefix '*Event_*'). However, whenever A goes to a floor *i*, having workspace conflict or not, he will update his perceptions of all the work belong to floor *i*. To simulate this fact, the system gets the result in Eq. (2), selects the data part of floor *i*, change the knowledge owner to A, and copy this result to the project progression data. In addition to the variability in production rate, design change and quality check events also cause variability (changes in remaining workload) in the simulation.

User can set a periodical design review, and a higher project's completeness (CP) results a lower probability of design changes in the review. Therefore, in the simulation the occurrence of a design change follows a binomial distribution with a probability of 1-CP. If the value drawn from this binomial distribution is 1, the design change event is triggered; a task is randomly selected, and the remaining workload is either increased or decreased by a randomly selected proportion of the original work.

User can enable a quality check once a work is complete, and the work is assigned a base quality rate (QR) representing its average historical quality conditions. A frequently repeated work has higher probability passing the quality check due to the learning curve effect. Therefore, a calibrated quality check pass rate is:

$$QR' = 1-(1-QR)(1-WC) \tag{3}$$

WC is the percentage of the completed workload in all the workload of the same type indicating the crew's proficiency in this type of work. The quality check result is drawn from a binominal distribution with probability of QR'. If the value is 0, the task fails to pass the quality check. Both the design change and quality check are logged in project event data ('*Event_*' data in Figure 1).

The variability causes uncertainty in agents' perceptions, but such uncertainty can be reduced by agents' communications in site meeting and random meeting. The user can specify the frequency of site meetings, in which the agents synchronize their perceptions of poject progression and other agents' production rate. To simulate such phenomena, the system duplicates the result of Eq. (2) in project progression data for each agent. Agents' random meeting also triggers this operation, but the information synchronization is only executed among the agents meet in the same workspace. In both situations, since the agents' latest perception is updated, the result of Eq. (1) will also change accordingly when it is retrieved next time.

SIMULATION EXAMPLE CASE

An example project simulates the execution of interior finishing work in a residential building with five floors. Four crews perform the same four work on each floor under 'finish-start' work dependency (Figure 2).

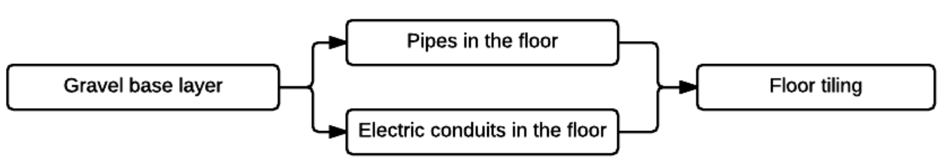


Figure 2. Task dependencies in the project

Table 1 specifies the initial production rate, productivity variability, quality rate, and workload. The quantity and production rate are normalized to comparable non-unit values.

Table 1. Initial parameters in the simulation

Crew name	Work method	Initial production rate	Quality check pass rate	Production rate std.	Total work qty. per floor
Gravel	Gravel base layer	1	0.9	0.1	5
Plumbing	Pipes in the floor	1	0.9	0.1	5
Electricity	Electric conduits in the floor	1	0.9	0.1	5
Tiling	Floor tiling	1	0.9	0.1	5

Only one agent can work at the same space ad the same time. The design review occurs every 10 days. The simulation ran 20 times: in 10 run the agents synchronize the information in 7-days site meetings, but in the other 10 run they only update their perceptions of project progression in a work space when they go there, but they never get update when they meet each other.

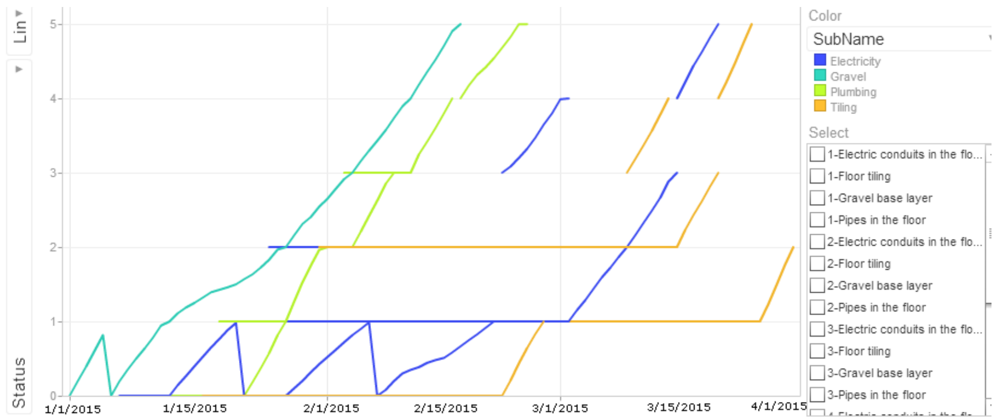
RESULTS OF THE EXAMPLE SIMULATIONS

The simulation results differ in different information exchange configurations. The system compared such difference quantitatively based on logged project progression data.

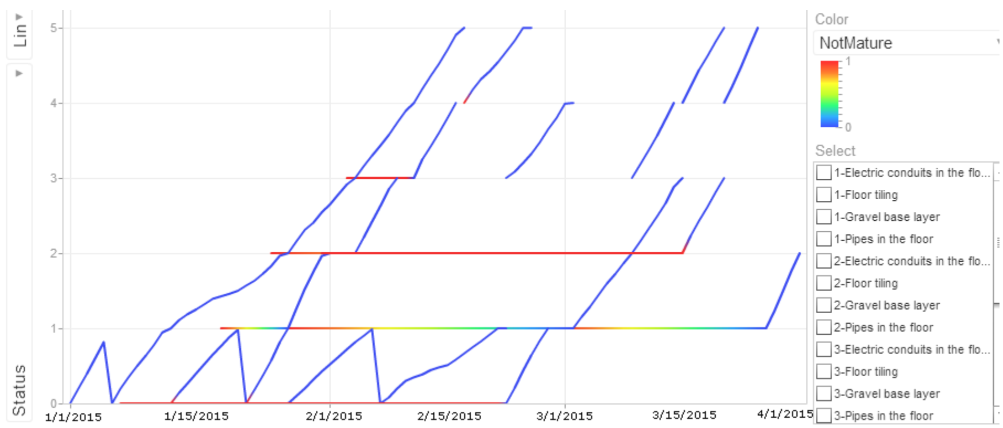
VISUALIZATION OF THE RESULTS

The construction workflow is presented in Color-coded flow line charts (Figure 3). The horizontal axis represents the time starting from 1/1/2015; the vertical axis represents workspace starting from floor 1 to floor 5. The system can group and color the lines by agents'/subcontractors' name (Figure 3a), work methods and events. For example, the agents' error decision of working on an unready work is colored in red at that time spot (Figure 3b), and failures of tasks in quality check are colored in red (Figure 3c). The line becomes blue when the agents enter the space and the work is actually ready.

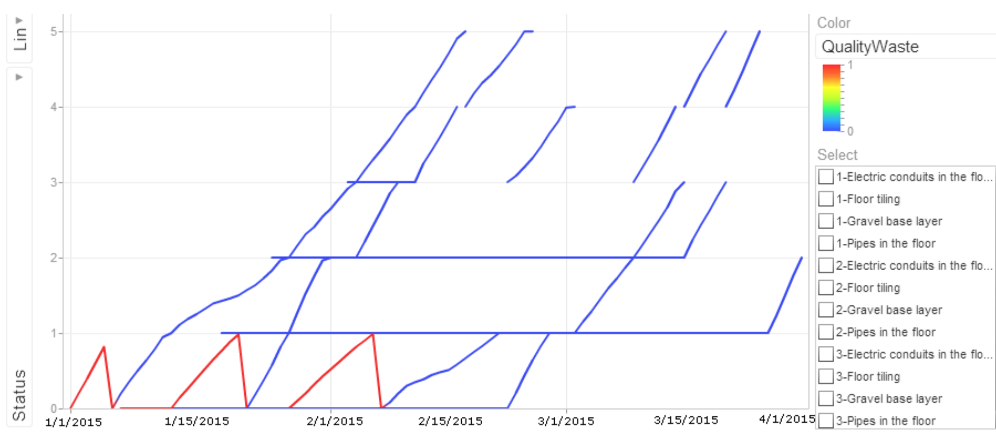
By combining the three figures, the project workflow can be quantitatively analyzed. The electrician thought he could work on the electricity in floor 1 on 1/7/2015 (Figure 3a), however, he found the work was not mature until he re-entered there on 1/15/2015 (Figure 3b), because his precedent work - gravel base layer was completed late (Figure 3a). The gravel agent's failure of quality check on 1/6/2015 (Figure 3c) caused his delay and also affected the plumbing and tiling (Figure 3a).



(a) A view of the work flow color-coded by work method



(b) Color-coding representing task maturity level



(c) Color-coding indicating failure of quality checks.

Figure 3. Workflow chart of a typical simulation.

The system can also visualize the information flows. The pieces of data the agents synchronized represent the volume of information they exchanged in each day (Figure 4). In a site meeting event all the crews would report the status of their tasks, so the volume of information exchanged is the rows of result in Eq (2). When agents meet randomly, the volume of information exchanged is the rows of the data entry the system added. The two scenarios are colored differently in Figure 4.

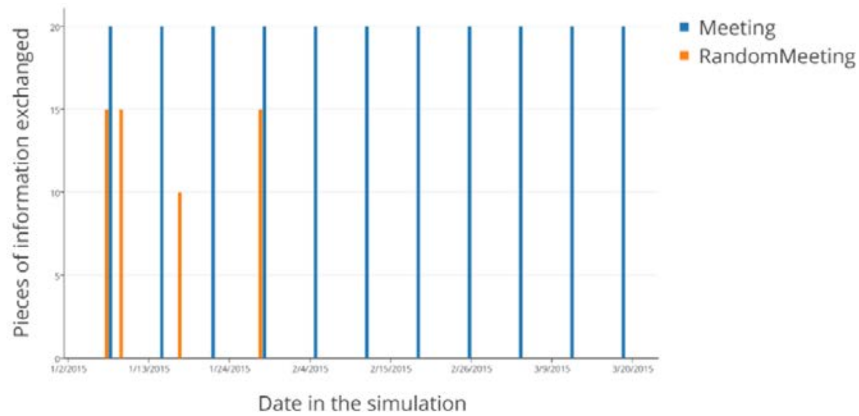


Figure 4. Information flow about task status

ANALYSIS OF SIMULATION RESULTS

The simulation run 40 times, and in each time metrics were recorded as shown in Table 2.

Table 2 Project performance metrics of 4 of the 20 simulations

Information exchange	Total duration (T)	Work conflict times	Quality failure times	Design change times	Total waste days	Sum of add value days (A)	Percentage of value-adding work (A/T)
No	187	28	27	2	29	134	72%
Yes	124	6	6	10	16	105	85%
No	189	31	0	35	35	132	70%
			……				
Yes	134	8	0	5	5	122	91%

A/T reflects the quality of construction workflow (Kalsaas 2013). Table 3 compares the A/T of the two simulation scenarios with information exchange or not.

Table 3 Summary of the A/T ratios for 20 simulations in two groups

Groups	Count	Sum	Average	Variance
No exchange	10	8.0503	0.8050	0.0086
Exchange	10	8.9580	0.8958	0.0028

An Analysis of Variance (ANOVA) is performed on the two groups of data with a null hypothesis that they have the same mean value (Table 4). The P-value is smaller than an acceptable α value of 0.05, so the null hypothesis is rejected. In other words, the added-value portion in the two groups of simulations have statistically significant differences. As a result, it can be concluded that improving information flow in construction has a positive effect on construction workflow.

Table 4 Analysis of variance of the variable - add value portion in two simulation groups

Source of Variation	SS	Degree of freedom	MS	F	P-value	F critical value
Between Groups	0.0412	1	0.0412	7.1907	0.0152	4.4139
Within Groups	0.1031	18	0.0057			
Total	0.1443	19				

CONCLUSIONS

An ABS system (EPIC 2.0) for modeling the emergence of construction workflow has been developed based on a relational data model. The system models the variability and uncertainty in construction, the information exchange between construction agents, and the changes in their perceptions of project progression that affect their decisions in task selection. The system can generate rich datasets and visualize the construction process using enhanced line of balance charts. A case study demonstrates its suitability to investigate and confirm the positive effects of information transparency on the construction workflow performance.

The system can perform more complex simulations than the example project by changing the parameters such as more agents, more complex task dependencies, higher task granularity etc. The data model can also be extended to incorporate additional aspects of the construction workflow, such as individual utility motivated decision-making, dynamic material supply, learning curves in productivity etc., by adding new fields to the data model. These are the focus of future research, and the simulation system needs to be tested in a real project.

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IMPACT OF THE BUFFER SIZE ON PRECAST FABRICATION

Chien-Ho Ko[1]

ABSTRACT

Buffer sizes between production stations are one factor that influences production performance. Current practices in precast production ignore buffer size between stations typically induce unfeasible production plans. Research questions for this paper are 1) how would buffer sizes between precast production stations affect precast production plans and 2) how could computational techniques help in arranging precast production plans? To answer those questions, a program that considers production resources and buffer size between stations is developed. Impact of buffer sizes on production makespan and delivery is analyzed using a case study. Experimental results show that buffer sizes between stations are crucial for acquiring reasonable and feasible precast production plans. A sufficient buffer size larger than the required buffer size could help achieve a better performance with a shorter makespan and lower costs.

KEYWORDS

Process, production, waste, precast, buffer.

INTRODUCTION

Precast fabrication in the construction industry could be categorized as manufacturing (Ray et al. 2006). Using precast components can reduce uncertainty during construction period since these components are prefabricated at the factory (Boyd et al. 2013). Precast fabricators deliver elements to a site according to its erection schedule. Making production plans is one of the most important tasks in precast manufacturing (Tharmmaphornphilas and Sareinpithak 2013). To enhance the competitiveness of a fabricator, production schedulers face the challenges of satisfying multiple objectives since one may conflict with the others (Chan and Hu 2002).

Due to the large volume of precast components, the fabricator requires a rather large space when manufacturing. Furthermore, since precast components are heavy, they cannot be moved without cranes. While the precast factory is under construction, the facility layout and crane positions are pre-determined. Therefore, the production line is regarded as a resource which cannot be adjusted. The other key factor impacting precast fabrication is the number of molds (West, 2006). Precast fabricators generally use steel

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molds rather than wooden since steel is more durable than wood. However, steel is much heavier and expensive than wood. To reduce the cost of a mold, fabricators endeavor to use as few as possible.

The current practice of making precast production plans depends on the scheduler's experience. Due to inaccurate planning methods, inefficient resource utilization and overstocking are commonplace in the precast industry (De Athayde Prata et al. 2015). Researchers have begun using computational techniques to manage scheduling issues (Benjaoran et al. 2005; Alghazi et al. 2012; Jeon et al 2014). Although precast fabrication requires a rather large space while manufacturing, previous studies have ignored buffer sizes between stations, thereby resulting in unrealistic production schedules.

The objective of this study is to analyze the impact of buffer size between stations on production makespan and costs. A limited buffer size between stations is taken into account in the study. Computational techniques are used to calculate production makespan and penalty costs with different buffer sizes.

INVENTORY WASTE

Toyota has popularized a production system designed to eliminate waste. Designed primarily by former Toyota executive Taiichi Ohno, the system is characterized by low costs, small batch sizes, and diverse production. Ohno defined waste as any activity which fails to comply with the standard efficiency of the production system and does not create value in either the production line or product development flow. Ohno (1988) specified seven valueless activities, namely: 1) overproduction, 2) transport, 3) waiting, 4) inventory, 5) defects, 6) motion, and 7) over-processing.

Precast fabricators strive for business success on delivering productions on time (Ko and Ballard 2005). To achieve this goal, fabricators starts manufacturing precast elements once they receive orders, which generates inventory. This type of waste refers to unprocessed raw materials, work in progress, or goods which cannot be completed. Unnecessary inventory could result excess purchasing of raw materials or manufacturing of larger than necessary batches, which leads to longer lead times, and obsolete or unneeded products. Excess inventory leads to the stagnation of raw materials in storage and added costs for handling and storage (Ko and Kuo 2015). The larger the buffer size, the higher the inventory level. Buffer sizes between production stations may be regarded as a kind of inventory, which influences production flow and inventory cost (Ko 2013).

PRECAST PRODUCTION PROCESS

To analyze the impact of buffer sizes between precast production stations, precast production process is identified. Precast production can be divided into six steps: 1) mold assembly, 2) placement of reinforcement and all embedded parts, 3) concrete casting, 4) curing, 5) mold stripping, and 6) product finishing, as depicted in Figure 1 (Ko and Wang 2010). The mold assembly activity provides a specific dimension. In general, fabricators use steel molds for the purpose of reuse. A precast component generally contains two kinds of materials, i.e., concrete and steel bars. Reinforcements and embedded parts are placed in their positions after the mold is formed. Embedded parts are used to connect and fix with other components or with the structure when the precast components are erected. The concrete is cast when the embedded parts are in their positions. To enhance the chemistry-solidifying concrete, steam curing is implemented; otherwise, the component concrete requires weeks to reach its legal strength. Moving, erecting, or erecting components before the legal strength is achieved may cause damage. The molds can be stripped after the concrete solidifies. Due to the cost of developing steel molds, fabricators reuse them once they are stripped. The final step in production is finishing. Minor defects such as scratches, peel-offs, and uneven surfaces are treated in this step.

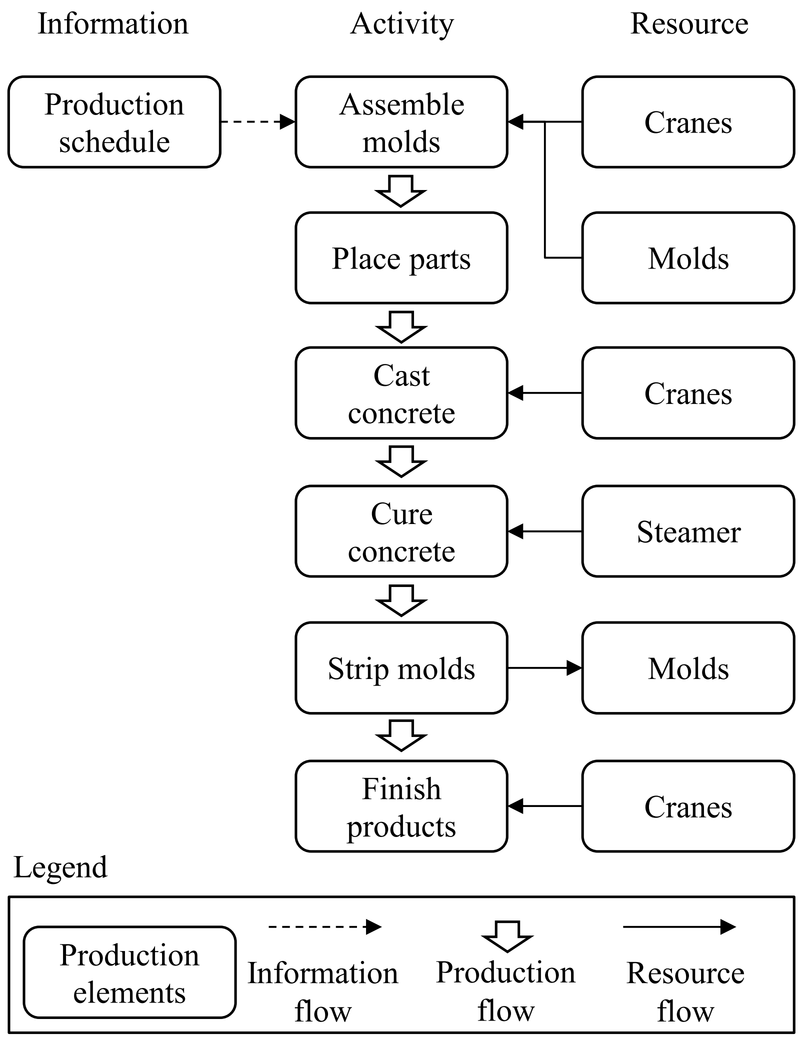


Figure 1: Precast Production Flow

The traditional flowshop sequencing problem regards production as a continuous flow. The typical equation used to calculate the completion time is shown in Eq. (1):

$$C\left(J_j, M_k\right) = Max\left\{C(J_{j-1}, M_k), C(J_j, M_{k-1})\right\} + P_{jk} \quad (1)$$

where $C\left(J_j, M_k\right)$ denotes the completion time for the jth element in k machine and P_{jk} is an operation time for that element ($P_{jk} \geq 0$).

Eq. (1) assumes an infinite buffer size between stations so that the production flow can be continuous. In practice, due to the large size of the precast elements, the buffer size between stations is limited. As a result, the regular flowshop sequencing model derived in Eq. (1) cannot meet the needs of precast production. This formula is therefore reformulated as Eq. (2):

$$C\left(J_j, M_k\right) = Max\left\{C(J_{j-1}, M_k) + WT_{j-1,k}, C(J_j, M_{k-1})\right\} + P_{jk} \tag{2}$$

where $WT_{j-1,k}$ is the time for the (j-1)th element in k machine waiting to be sent to buffer, which can be represented by using Eq. (3):

$$WT_{j,k} = \begin{Bmatrix} C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} - C\left(J_j, M_k\right) ....if..C\left(J_j, M_k\right) < C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} \\ 0...if...C\left(J_j, M_k\right) \geq C\left(J_{j-B_k}, M_{k+1}\right) - P_{j-B_k,k+1} \end{Bmatrix} \tag{3}$$

A decision maker faces challenges in achieving multi-objectives while devising production plans. Generally, the goal is to simultaneously minimize cost and production duration. Scheduling performance is therefore evaluated by its makespan and penalty costs (Ko and Wang 2011). Makespan, also called maximum completion time (C), denoting the period needed to complete all jobs, can be calculated by using Eq. (4):

$$f_1\left(\sigma\right) = C_{\max} = C\left(J_n, M_m\right) \tag{4}$$

To achieve the goal of delivering products Just-In-Time (JIT), the tardiness cost is considered (Pathumnakul and Egbelu 2006). However, the inventory cost can be decreased by considering the earliness penalty in production scheduling (Sawik 2007). The total penalty costs are computed as in Eq. (5):

$$f_2\left(\sigma\right) = \sum_{j=1}^{n} \tau_j \cdot Max\left(0, C_j - d_j\right) + \sum_{j=1}^{n} \varepsilon_j \cdot Max\left(0, d_j - C_j\right) \tag{5}$$

where d_j denotes the desired completion time for job j; τ_j the unit cost of late delivery for job j; and ε_j, unit inventory cost for job j.

MAKESPAN AND PENALTY COSTS ANALYSIS

To understand the impact of buffer size between precast production stations, production makespan and penalty costs are analyzed. This study adopts multi-objective genetic algorithms to automatically calculate production makespan and penalty costs due to different buffer sizes. The mathematical programming model used to minimize makespan and penalty costs is shown in Eq. (6):

$$\begin{aligned} &\text{Minimize } z = \left(f_1\left(x\right), f_2\left(x\right)\right) \\ &\text{subject to } x \in X \end{aligned} \tag{6}$$

where z represents the objective vector; x the decision vector; and X the feasible area.

Multi-objectives are represented by a weighted sum approach. This target vector minimizes the distance in objective space to a given goal vector. The objective function is obtained in Eq. (7):

$$f(x) = \omega_1 \left(f_1 \left(x \right) \right) + \omega_2 \left(f_2 \left(x \right) \right) \tag{7}$$

where ω_1 and ω_2 are positive weights ($\omega_1 + \omega_2 = 1$); $f_1(x)$ the makespan function obtained in Eq. (4); and $f_2(x)$, the penalty function calculated by Eq. (5). The plan generation process is represented in Figure 2 (Ishibuchi and Murata 1998).

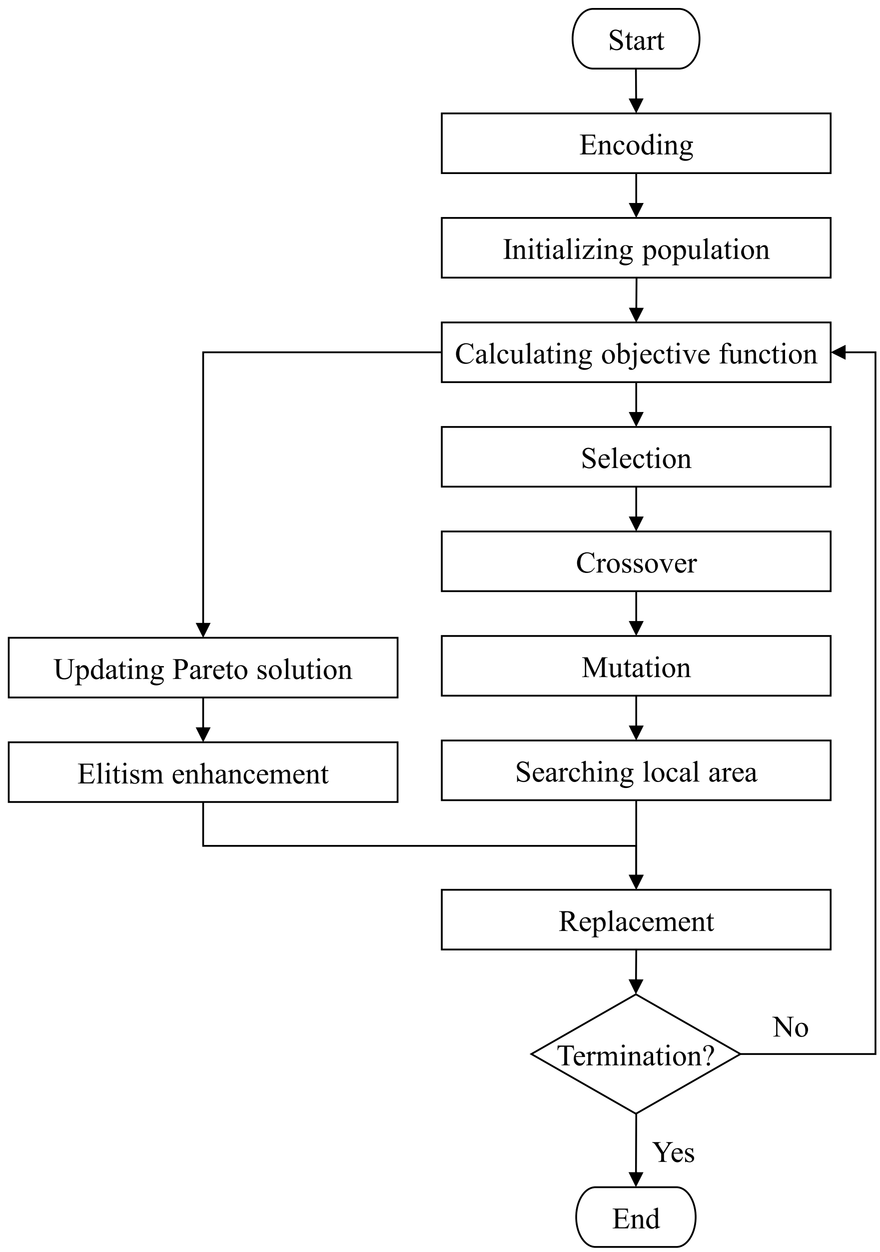


Figure 2: Calculation Procedure for Production Makespan and Penalty Costs

It is time consuming and difficult to manually calculate production makespan and penalty costs. Application software is thus developed. The high-level system use case diagram is demonstrated in Figure 3. Use case diagram is a representation of user's interaction with the system, which shows the relationship between the user and use cases (Gemino and Parker 2009). In the Figure, users are responsible to configure parameters required for arranging production schedules. Parameters settings include algorithm parameters, production information, facilities, and objective functions. Once the parameters have been set, users can use the application to generate production plans. The application user interface is shown in Figure 4.

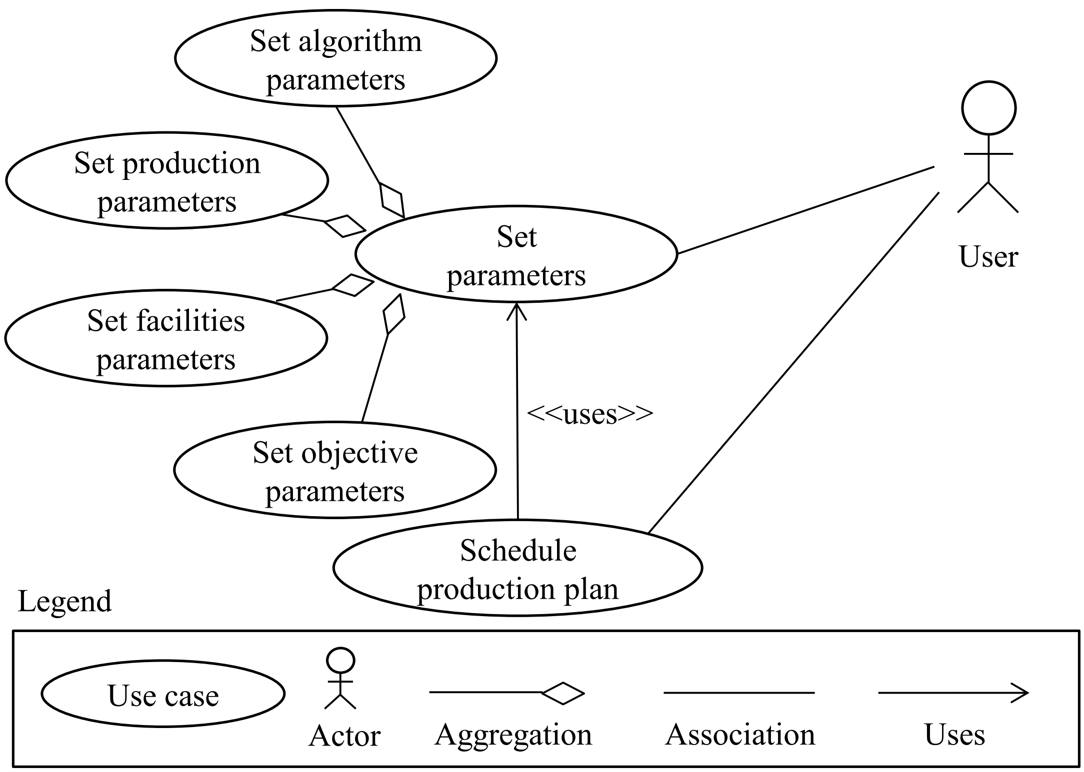
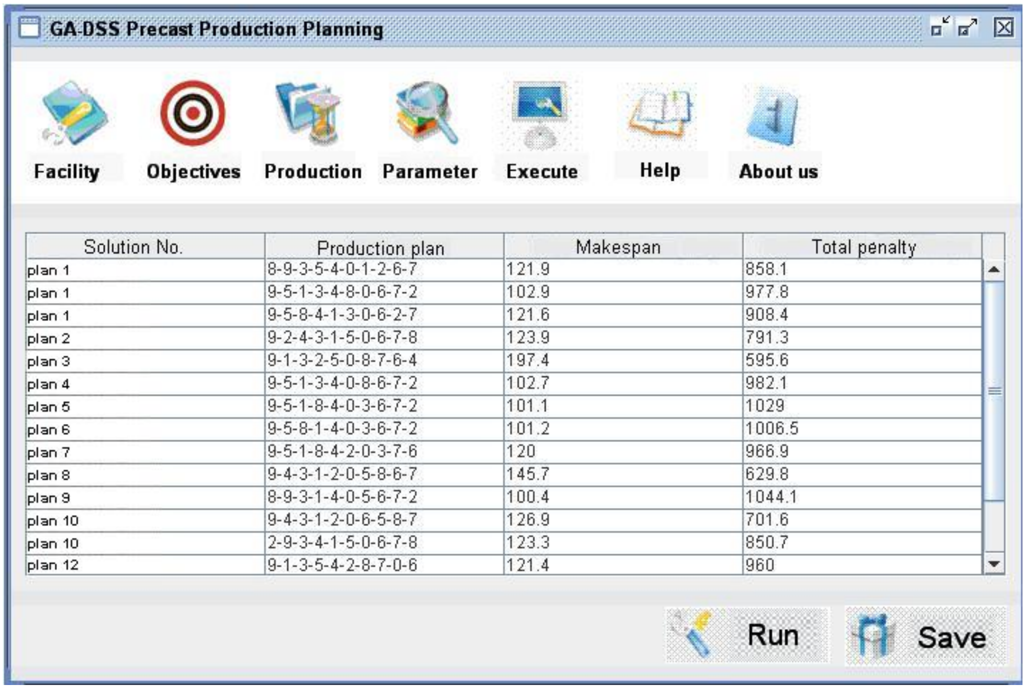


Figure 3: Use Case Diagram



Solution No.	Production plan	Makespan	Total penalty
plan 1	8-9-3-5-4-0-1-2-6-7	121.9	858.1
plan 1	9-5-1-3-4-8-0-6-7-2	102.9	977.8
plan 1	9-5-8-4-1-3-0-6-2-7	121.6	908.4
plan 2	9-2-4-3-1-5-0-6-7-8	123.9	791.3
plan 3	9-1-3-2-5-0-8-7-6-4	197.4	595.6
plan 4	9-5-1-3-4-0-8-6-7-2	102.7	982.1
plan 5	9-5-1-8-4-0-3-6-7-2	101.1	1029
plan 6	9-5-8-1-4-0-3-6-7-2	101.2	1006.5
plan 7	9-5-1-8-4-2-0-3-7-6	120	966.9
plan 8	9-4-3-1-2-0-5-8-6-7	145.7	629.8
plan 9	8-9-3-1-4-0-5-6-7-2	100.4	1044.1
plan 10	9-4-3-1-2-0-6-5-8-7	126.9	701.6
plan 10	2-9-3-4-1-5-0-6-7-8	123.3	850.7
plan 12	9-1-3-5-4-2-8-7-0-6	121.4	960

Figure 4: Derived Production Plans

CASE STUDY

To analyze the impact of buffer sizes between production stations on production makespan and delivery, a case study with different buffer sizes is discussed. Production data of the case study is extracted from Benjaoran et al. (2005). Ten precast elements are used in the experiments, as shown in Table 1. The transportation time is included in the makespan. Penalty costs include inventory cost and late delivery penalties. Scenarios with different buffer sizes between production stations are analysed using the developed software. Without the software, it seems difficult to manually calculate production makespan and penalty costs by simultaneously considering production resources, mold type and amount, working hours, and allowable overtime. The results are demonstrated in Figure 5. In the figure, the provided buffer size is the greatest capacity in the production system. In this case study, the maximum buffer size required in the system is two. When the provided buffer size is far larger than two (such as five), it has nearly no influence on the makespan and total penalty cost. However, if the buffer size is smaller than the required buffer size, the makespan and total penalty cost increase. The trends of both makespan and total penalty cost keep descending while larger buffer sizes are provided. In Figure 5, total penalty cost dramatically adjourns at the provided buffer size three and keeps flat after provided buffer size four. An on-time delivery can be reached if buffer size four is provided and no extra penalty cost occurs. On the other hand, minimum makespan can be found at provided buffer size four. The makespan for 10 precast elements cannot be shortened even a larger buffer size is provided. In this case, buffer size four is the most profitable decision for precast fabricators to delivery on time with the lowest inventory cost.

Table 1: Production Data (Benjaoran et al. 2005)

Element No.	Steel mold type	Due day (h)	Penalty costs	
			Inventory	Tardiness
1	A	112	2	10
2	B	112	2	10
3	A	112	1	10
4	A	112	1	10
5	C	208	2	10
6	A	128	2	10
7	C	144	2	10
8	B	144	2	20
9	A	144	1	20
10	C	240	1	20

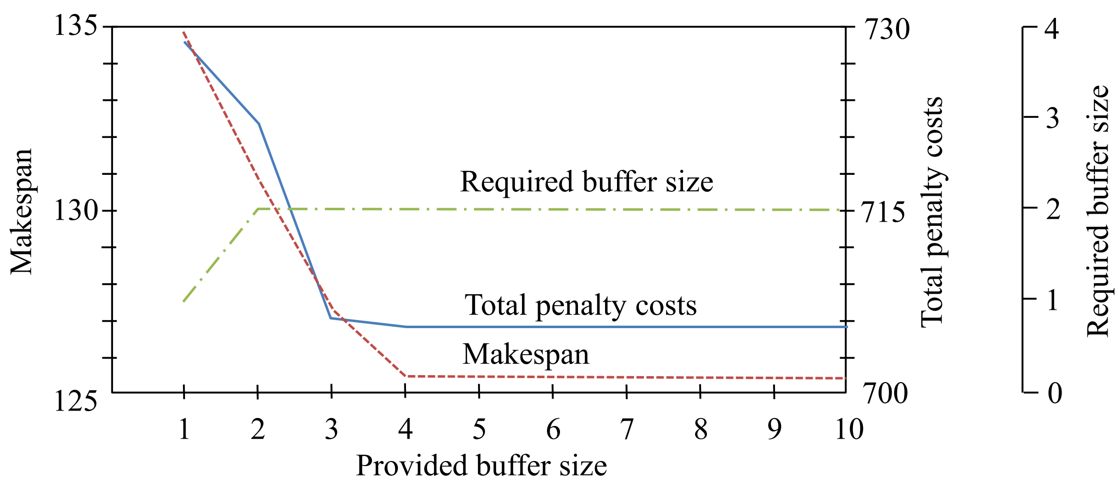


Figure 5: Buffer Size Experimental Results

CONCLUSIONS

Current practice of precast production planning assumes that the buffer between stations is infinite. However, precast elements require a lot of space for moving and storage. Production plans might be unrealistic if the actual buffer sizes are not taken into account. This study deals with the impact of buffer size on production planning. Case study shows that if the provided buffer size is sufficient for the needed buffer size, both makespan and total penalty costs could be reduced. To the contrary, if the provided buffer size is insufficient for the needed buffer size, makespan and total penalty costs increase, due to inflexible resource allocation. An appropriate buffer size for precast fabrication is also related to factory space. Redundant buffer size may add no value to production and need to pay attention for regular maintenance, which is wasteful. The study also found that the provided buffer size could be larger than the needed buffer size. A shorter makespan with lower penalty cost could be reached if sufficient buffer sizes are provided and larger than the needed buffer size.

It is time consuming and complex to manually analyze appropriate buffer sizes between precast fabrication stations. The best decision could be obtained through computer experiments. Production resources, mold type and amount, working hours, allowable overtime, and buffer sizes could be simultaneously considered in the developed application programmed using JAVA language. These computational techniques may assist managers in arranging production plans with a sufficient manner, and provides alternative production plans for decision-making.

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OPTIMIZING THE VALUE STREAM – APPLICATION OF BIM IN FM. STATUS QUO IN GERMANY.

Sebastian Beck[1], Sarina Schmalz[2], Jakob von Heyl[3] and Florian Binder[4]

ABSTRACT

Facility Management includes all services that are necessary to support the core business of a company in a building. Therefore, a lot of information is required, for example building elements, operational costs, contract types, room allocation, logistics or maintenance. This data is essential to organize all processes, both effectively and efficiently. However, a lot of data gets lost throughout the building lifecycle, due to the temporary participation of many different parties, e. g. planners, contracting companies, service providers or owners, and various interfaces between them. Retrieving this information is both arduous and time consuming, if even possible. In order to reduce this unnecessary effort, to eliminate waste and to enable a continuous improvement of all facility management processes, new methods and tools should be considered.

Building Information Modeling, as a promising method to provide data not only in the planning and construction phases but throughout the whole lifecycle, can help to overcome the challenges described above. This paper aims to identify the area of application of BIM and its possible benefits in Facility Management. The integration of BIM in computer aided facility management tools in Germany will be illustrated and examined. In a single-case study, selected IT-applications will be further analyzed and development needs regarding standards for the implementation of BIM will be outlined.

KEYWORDS

Building Information Modeling, Facility Management, Collaboration, Benefits Realization, Flow

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INTRODUCTION

Over the last years, Building Information Modeling (BIM) has become an important tool within the construction industry. In Germany, the German Ministry of Traffic and Digital Infrastructure published a masterplan regarding the integration of BIM in December 2015. The ministry defines BIM as a collaborative working method which gathers and administrates all lifecycle-relevant information and data of a building consistently in a digital building model. The digital model enables a transparent communication and the handover of data for further work. According to this plan, national standards have to be developed and from 2020 on all federal infrastructural building activities have to be planned and constructed with BIM (BMVI, 2015). Other countries like USA, UK or Finland have already implemented standards like these (Borrmann et al., 2015).

Furthermore, BIM meanwhile is an approved method within the Lean Construction community as it supports the project participants in achieving Lean Principles like eliminating waste, cutting costs and improving team productivity (Gerber et. al, 2010).

Facility Management (FM) is an important sector of industry although often underestimated. In Germany, it generated a gross value added of 130 bn Euros in 2012, which was about 5.4 % of the German gross domestic product. The construction industry generated about 109 bn Euros, in comparison to 94 bn Euros of the automobile industry (Thomzik, 2014). Due to this economic importance FM should be brought into focus in order to improve all related processes and to induce a continuous value stream. Therefore, not only Facility Management itself, but every individual building including its lifecycle should be considered.

BIM is a promising method to support the operation and maintenance (O&M) phase and FM, as examined in recent studies and literature (Becerik-Gerber et al, 2010, Oskouie et al., 2012, Teicholz, 2013). The possible value regarding the whole lifecycle becomes apparent by combining two different kinds of studies. Studies concerning the lifecycle costing show that the major part of lifecycle costs occurs during the operation and maintenance phase, whereas the ability to impact these costs decreases over time (Schulte, 2008). Other studies point out that the planning effort with BIM takes place in earlier phases of the project, compared to the "traditional" planning effort without BIM (Egger et al., 2013). In the following figure, the figures of both studies are matched. Accordingly, lifecycle costs can be better influenced via BIM.

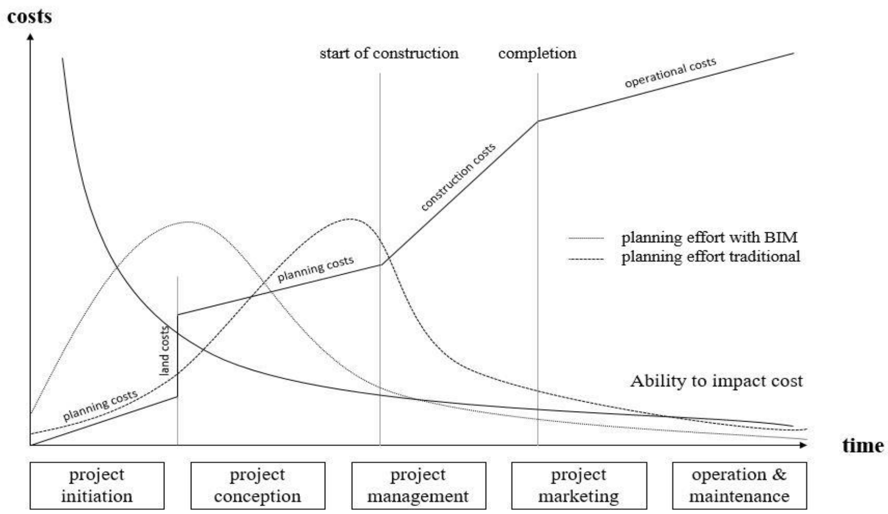

Figure 1: Cost trend during the lifecycle (Schulte, 2008 and Egger et al., 2013)

In the following, the areas of application of BIM in FM and its additional value will be outlined. Subsequently, the Status Quo of BIM in FM in Germany will be illustrated and examined. Via a single-case study, three selected IT-solutions have been further analyzed. The approach and the results of this study will be presented. Furthermore, development needs regarding standards for the implementation of BIM will be outlined.

BIM AND FACILITY MANAGEMENT – ADDITIONAL VALUE

COMPUTER AIDED FACILITY MANAGEMENT

FM in Germany is often supported by Computer Aided Facility Management (CAFM). CAFM-applications are IT-solutions that normally consist of a database and a user interface. They facilitate processes like e. g. management of space, maintenance, equipment, health and safety, locking systems, cleaning, helpdesk and many more. In English-speaking countries, similar software-applications are also known as facility management software or Computerized Maintenance Management Systems (CMMS). In Germany, Austria and Switzerland there are about 60 companies which offer different CAFM-solutions.

A study of the German Facility Management Association shows that users identify the following points as the main advantages of CAFM-solutions:

- better transparency regarding costs and services
- better documentation regarding the operator's responsibility
- more efficient services
- cost savings
- better space utilization
- less business interruptions

Furthermore, the study points out that serious challenges by implementing CAFM systems are the correct estimation of effort (time and personnel) and the generation of a sufficient data set (GEFMA, n.d.).

BIM AND FACILITY MANAGEMENT

By combining BIM and FM, additional value can be created, as shown in recent studies. For example, the following BIM application areas enable advantages during operation and maintenance: Locating Building Components, Quantity Survey, Cooperation, Facilitating Real-Time Data Access, Space Management, Personnel Training and Development, Visualization and Marketing, Checking Maintainability, Creating and Updating Digital Assets, Planning and Feasibility Studies for Noncapital Construction, Emergency Management, Controlling and Monitoring Energy (Becerik-Gerber et al., 2011, Teicholz, 2013). Some of these advantages can also be realized to some extent via well-tended "traditional" CAFM-solutions, but of course, the use of BIM facilitates work even more. This can be led back to visualizations and finally the data which is stored within the digital model and can be accessed easily.

As shown in figure 2, the importance of the different types of data is changing throughout the lifecycle, irrespective of using BIM or not. In the planning phase graphic data is very important for the owner, to get an impression for the building, whereby attribute data (e.g. materials) is secondary. In contrast, attribute data is very important during operation & maintenance and thus for FM (Teicholz 2013). As attribute data turns a 3D visualization into a building information model, it becomes apparent that a digital building model is the best data platform for FM (Eastman et al., 2013).

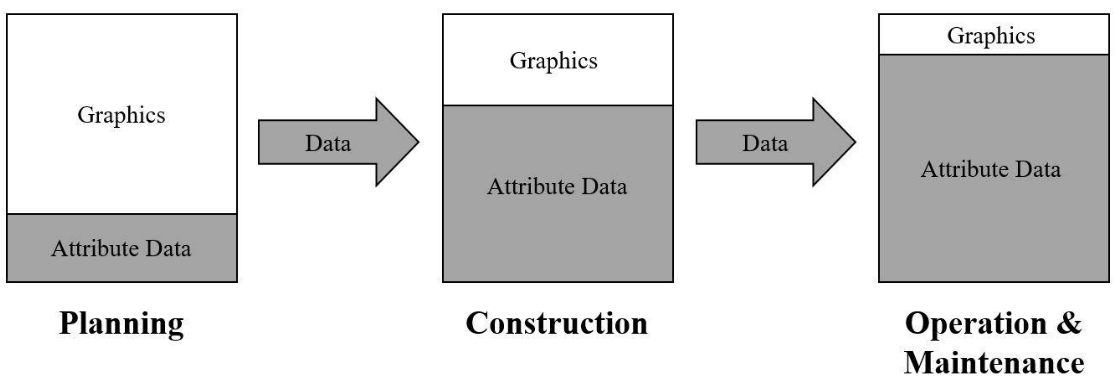

Figure 2: Mix of data changes over the building lifecycle (Teicholz, 2013)

Theoretically, FM-relevant data is already stored in the "as-built-model" and can be taken over from the construction team. Figure 3 shows the idealized flow of information with BIM. In this ideal conception, all information is stored in the model without any losses throughout the whole lifecycle and can be handed over for reconstruction or change of ownership. In practice, there are still interfaces and some of the information gets lost during the hand-over from one phase to the next (Eiberger and von Heyl, 2015). Compared to traditional methods, these losses are smaller and will be further optimized in future. Accordingly, the use of BIM is beneficial regarding flow and value stream.

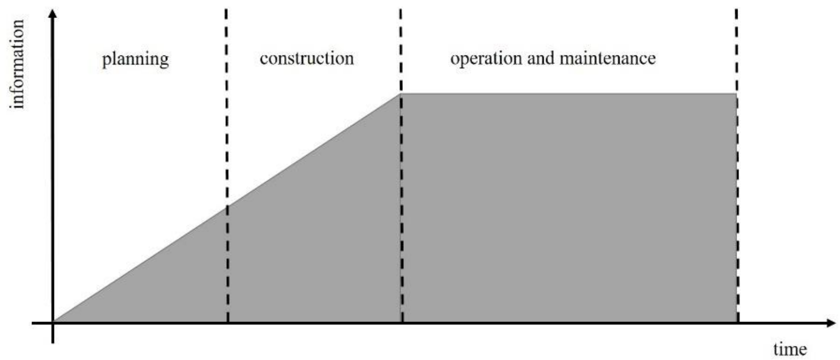

Figure 3: Idealized flow of information with BIM (Eastman et al., 2013)

As information is the basis for BIM, it is very important to clarify who is responsible for each model and necessary changes or additions of data not only during the planning and construction phases, but during all phases of the lifecycle (Becerik-Gerber et al., 2011). During operations and maintenance, all participants need access to the digital model, e. g. the facility manager, craftsmen, caretakers etc. To avoid unintended and wrong input, most IT-applications offer a detailed authorization concept so every user can access information, but only authorized personnel is able to alter data.

Teicholz summarizes the following points as the main benefits of connecting BIM and FM (Teicholz, 2013):

- cost reduction (accurate and complete data ready for use)
- integration of systems (CMMS, CAFMS, BAS)
- improvement of performance (more complete and accessible data allows faster analysis, happier and more productive users)

Regarding lean principles, the integration of BIM in FM enables a continuous value stream and therefore also a better flow. Additionally, it improves collaboration. On the one hand, it helps to interlink the different phases within the lifecycle. On the other hand, the different participants in the O&M, like owner, users, facility manager, caretakers, craftsmen etc. can be linked and decisions can be facilitated, e. g. via visualizations. Furthermore, BIM enables a higher quality which minimizes waste and rework.

STATUS QUO IN GERMANY

MARKET RESEARCH

In the German-speaking market, the integration of BIM into FM is mostly managed via CAFM-solutions.

As mentioned above, there are a lot of different solutions on the German-speaking market. Since 1999, the "CAFM Market Survey" is yearly released by the German Facility Management Association, the journal "The Facility Manager" and VALTEQ (part of CBRE). The survey intends to give potential users an extensive, objective and up-to-date overview of CAFM-software. In 2015, the survey presented 34 CAFM-solutions via standardized datasheets (GEFMA, 2015). The market research on BIM in FM is based on this survey. Of course, further software-manufacturers which offer "BIM-able" products were included as well.

The first step of the research was to examine which IT-solutions are "BIM-able". BIM-able means that the CAFM-software supports the neutral data format IFC and/or has a direct interface to a BIM-able CAD-software, so the model and the CAFM-software can be connected. 21 of the examined CAFM-solutions correspond to this definition. By only considering the BIM-able CAFM-applications, it becomes apparent that 80 % support the neutral IFC data format. Proprietary interfaces to Nemetschek Allplan®, Graphisoft ArchiCAD® and Autodesk Revit® are only supported by 25 % - 40 % of the applications.

In the next step, the BIM-able CAFM-applications were analyzed regarding their solutions for the different branches of FM: technical, infrastructural and commercial FM. Considering the BIM-able CAFM-tools, only 35 % support all three application areas (to fulfill an application area, the software has to process 66 % of the possible tasks in this area). Regarding the application areas separately, 90 % of the tools support the technical as well as the infrastructural FM, 45 % support the commercial FM. Commercial FM is often processed with ERP-systems so many BIM-CAFM-manufacturers rely to this specialized software and only offer interfaces to transfer necessary data.

SINGLE-CASE STUDY

To further examine the BIM-ability of CAFM-software, three applications have been selected to conduct a single-case study. One of the products is relatively new and particularly specialized in BIM; the other two products are well-established on the CAFM-market and have been extended regarding digital building models over the last years.

The study is based on a digital model of an existing office building (acknowledgments to Ed. Züblin AG, Stuttgart, Germany). The architectural as well as the installation model of the office building were generated in Autodesk Revit® 2013 so they had to be transferred into a later version, Autodesk Revit® 2015, before they could be connected in order to compile a comprehensive model. Subsequently, the model had been imported into the BIM-able CAFM-software. Within the software-products, the model had been used and tested in different categories. The following table shows the results of the single-case study.

Table 1: Results of the single-case study

	Software A	**Software B**	**Software C**
Short description	stand-alone CAFM-solution or plug-in for Graphisoft ArchiCAD®, Autodesk Revit®; Modules: maintenance, keys, tenants, relocation	stand-alone total CAFM-solution for technical, infrastructural and commercial FM; additional plug-in for Autodesk Revit®	stand-alone CAFM-solution, additional plug-in for Autodesk Revit®; Modules: commercial 1+2, technics, web, app
BIM-able interfaces	Graphisoft ArchiCAD®, Autodesk Revit®	IFC, Autodesk Revit®	Autodesk Revit®
Data-transfer BIM-CAFM	- interface Revit-CAFM-Server - configuration of attributes and parameters is quite complex, but can be saved for further models/projects, if parametrization is identical - transfer of all attributes and parameters	- interface Revit-CAFM - customizable templates for query-regulations; configuration of attributes and parameters is quite complex, regulations can be used for other models - transfer of all attributes and parameters	- interface Revit-CAFM-Server - only information contained in room stamps can be transferred - building parts like doors or windows can be transferred but without parameters - installation parts could not be transferred
Type of interface	bidirectional	limited bidirectionality via separate reports	limited bidirectionality via separate reports (not included in the demo-version)
Building space utilization book	- existing (customizable) templates - visualization possible	- existing (customizable) templates - visualization possible	- existing (customizable) templates; contains only information, that could be transferred
Inventory	- relocations via CAD or CAFM - list of inventory - quantity takeoff	- relocations via CAD or CAFM - list of inventory	- relocations only via CAD - by transferring the data a duplicate is produced in CAFM

Cleaning	- quantity takeoff of different surfaces (glass, different floor coverings) - Compilation of a bill of quantities - export to MS-Excel or GAEB	- quantity takeoff of different surfaces (glass, different floor coverings) - export to MS-Excel	- quantity takeoff possible, but more complicated - discrepancies to the quantities identified by the other programs - export to MS-Excel
Maintenance	- additional mobile version - real-time data access during maintenance walk-throughs	- additional mobile version - real-time data access during maintenance walk-throughs	- additional mobile version - only via lists, data model is not interlinked
Visualizations, virtual walkthroughs	only in combination with CAD-software	2D, 3D only in combination with CAD-software	only in combination with CAD-software

The single-case study shows that the three examined CAFM-solutions facilitate working with BIM during the O&M phase to different degrees. In two out of three cases it has been possible to import the building information model and all FM-relevant data into the software. In the third case the import was possible as well, but the configuration of the mapping could not be customized freely so not all FM-relevant data could be transferred. After some preparatory work, the import could be completed quite quickly. This is confirmed by another case study; about 98 % of time could be saved by integrating BIM in FM (Eastman et al., 2013).

The information model used for the study is a model from the late planning phases. Still, it contained a lot of data which is not FM-relevant. As-built-models may contain even more data which is not necessary for FM (e. g. formwork drawings). Furthermore, they are very extensive in size and therefore difficult to process. Thus, some clients of construction companies demand separate FM-field models. Irrespective of this consideration, it is very important that the facility manager determines at an early stage of the project which data is relevant for operation and maintenance so the information is parameterized and included into the model. Depending on the CAFM-software, the parameters have to be defined in a certain way to be readable by the FM-application. This is essential for an accurate and quick import of the information into the CAFM-tool.

The single-case study also shows that proprietary interfaces are working well at the moment; the information is exchanged quickly and completely. The neutral format IFC (IFC4) promises an easy data exchange but often some of the information gets lost during the process. The usage of Excel sheets or the exchange via databases is not recommended as it is very difficult to configure and to filter the information. Additionally, the CAFM-application would only be linked with the information, but not the model itself. To profit from advantages like visualizations or simulations, a link between the CAFM-application and the model has to be established. Next to the CAFM-tool, a CAD-tool is required.

Also considerable is the bidirectionality of the interfaces. After appropriate configuration in software A, information that is included or changed within the CAFM-software could be added to the digital model (and the other way round). Like this, the model is always up-to-date and can be used one-to-one for modifications of the building, modernization or demolition. The interfaces offered by the other two CAFM-solutions are based on separate reports and therefore limited, but the manufacturers are working on better interfaces at the moment.

CONCLUSIONS

Via the use of building information models, Facility Management processes can be supported optimally. Compared to traditional CAFM-software the use of digital information models enables additional functionalities, reduces time effort, improves collaboration and provides a continuous data flow throughout the lifecycle of a building. To this effect, the connection of BIM and FM complies with important lean criteria.

To integrate BIM in FM appropriate software is necessary. On the German-speaking market several IT-solutions are available. Most manufacturers of CAFM-software have already realized that the connection of BIM and FM offers numerous chances. Thereby, import and transfer of data are very important topics. As these solutions are relatively new at the moment they still have some weaknesses and processes need to be improved. In this context, structure and extend of the model should be mentioned. Presently, separate models for O&M are generated as many CAFM-solutions cannot process the "whole" model of the planning and construction phase. To eliminate this additional effort (waste), the systems should be further optimized.

The digital information model used for FM has to contain as many FM-relevant parameters as possible. In order to ensure this, facility managers should be integrated in an early phase of the project.

Furthermore, the requirements of each CAFM-software are different. Depending on the software, parameters in the model have to be defined in a certain way to be readable by the FM-application. This is supposed to change in future, so that BIM-parameters can be allocated to FM-features via separate configurations. Currently, only few software manufactures offer such a function.

At the moment, there are no technical standards to interlink BIM and FM in Germany. The German CAFM-Ring, an association of Software manufactures and operators, works on this topic. The CAFM-Ring focuses on the neutral interface IFC which is enhanced by buildingSMART as well. In this context, international data-standards like COBie (Construction Operations Building Information Exchange) which help to capture and record important FM-relevant data should be further followed up in Germany.

Finally, it seems that the foundation for connecting BIM and FM in Germany is laid. To use all resulting possibilities, further work regarding interfaces, systems, processes etc. is necessary. In future, more methods and tools of lean construction should be examined regarding their applicability to Facility Management.

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ALIGNING NEAR AND LONG TERM PLANNING FOR LPS IMPLEMENTATIONS: A REVIEW OF EXISTING AND NEW METRICS

Samir Emdanat[1] and Marcelo Azambuja[2]

ABSTRACT

Several metrics are used to measure the performance of Last Planner® System (LPS) implementations. Percent Planned Complete (PPC), Reasons for Variance (RV), Tasks Anticipated (TA), Tasks Made Ready (TMR) are common measures of lookahead and weekly work planning. However, research to correlate the various measures to the effectiveness of the LPS implementation and the overall reliability of work execution has been challenging and time consuming. Recent studies suggest that implementations have been inconsistent. Tracking on a regular basis has been difficult because the tools used are fragmented, and, even the definitions of the metrics themselves might be misunderstood by project teams. This paper overviews common LPS metrics definitions, introduces new metrics, and presents guidance on how the metrics can be applied. This study advances the knowledge in understanding LPS metrics and their impact on schedule performance. An integrated database driven software tool that supports the LPS implementation was used to mine, analyze, and visualize large amount of data in order to review the existing metrics and evaluate the predictive nature of the propose metrics designed to align near-term and long-term planning.

KEYWORDS

Last Planner® System, Percent Plan Complete, Theory, Production Planning and Control

INTRODUCTION

The Last Planner System (LPS) improves workflow reliability by continuously aligning what will be done on projects with what should be done through collaborative planning and a systematic application of the Make Ready Process (MRP). MRP ensures that all the known constraints on the remaining activities are identified, planned, and resolved before they impact the required dates of the downstream activities (Ballard and Howell, 1997). The systematic adherence to this process, in its entirety, creates a steady stream of unconstrained work that can be performed with more certainty.

Ballard and Howell (1997) proposed characteristics for measuring the quality of Weekly Work Plans (WWP) to protect workers from variation. Namely that the work

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should be done in the proper sequence, that the team performs the right amount of work, and, that only the work that can be done is committed to be done. They defined the right amount of work as the work that uses the labor and equipment capacity as directed by the schedule. Original research on LPS made references to the need to control production flow (Ballard 2000) but focused primarily on shielding the last planners from variability through the collaborative planning processes of creating sound assignments, tracking commitments, and continuous improvement. Recent exploratory research suggested the potential of improving LPS implementations by introducing complementary production management techniques that emphasize workflow to improve the quality of the Phase Schedules. Examples include the combination of LPS and Location Based Management System (LBMS) (Olli and Ballard 2010) and the combination of Takt-Time planning and LPS (Frandson et.al 2014).

Regarding LPS metrics, the predominate measures of an LPS implementation are the Percent Planned Complete (PPC) and the Reasons for Variance (RV). Both are designed to measure the reliability of the near-term plans. PPC was first proposed in the late nineties (see Ballard, 2000) and its definition remains unchanged in the most recent set of manuals published by the Lean Construction Institute (LCI) to its membership (LCI 2016). LCI defines PPC as the basic measure for "how well a planning system is working". It is calculated as the percent of completed commitments to the total commitments for any given planning cycle. Higher percentages are considered better. LCI recommends a target PPC range of 75% to 90%.

$$PPC = Did/Will$$

Hamzeh et.al (2012) proposed two additional metrics to align the work plan assignment with the lookahead. Namely they introduced the Tasks Anticipated (TA) and the Tasks Made Ready (TMR) metrics. TA represents the percentage of tasks on a work plan that were anticipated in a previous work plan 14 days earlier. TMR represents the percent of completed tasks on a given work plan that were anticipated in a prior work plan. Those authors could not however investigate how improvements in TMR and TA would improve overall schedule performance citing inconsistent datasets.

$$TA = Will/Can$$
$$TMR = Did/Can$$

While there is demonstrated evidence that LPS improves collaboration and reduces variability in near-term work execution, the effects of LPS on long term phase milestones and overall project schedules have been difficult subjects for systematic analysis. Moreover, the PPC, TA, and TMR metrics as absolute task counts of what can be done, what will be done, and what was done do not provide the metrics necessary to measure against what should be done at any given planning cycle.

Various researchers that attempted to study the impact of LPS on production control report common challenges to rigorous research in this area (Dave et al. 2015, Porwal et al. 2010, Hamzeh et.al. 2012). Common contributing factors include lack of standard planning workflows, lacking or incomplete data sets, and inconsistent recording (Hamzeh

2009) or inconsistent and intermittent application of the system (Porwal et al. 2010). Additionally, current industry practices for documenting LPS data using incompatible tools and the use of manual and redundant tracking systems such as sticky notes, various excel sheets, and scheduling software (Dave et al. 2015), makes it virtually impossible to perform any kind of analysis on the data.

This study advances the knowledge in understanding LPS metrics and their impact on schedule performance. An integrated database driven software tool (namely vPlanner®) that supports the LPS implementation was used to mine, analyze, and visualize large amount of data in order to review the existing metrics and evaluate the predictive nature of the propose metrics designed to align near-term and long-term planning.

RESEARCH METHOD

The studied sample size ranged from two thousand activities to over 60,000 activities in total. On smaller projects, an average lookahead contained 300 activities with approximately 50 activities consistently added or completed on a weekly basis and observed for several months. On larger projects an average lookahead contained over 3,500 activities with approximately 400 activities consistently added or completed on a weekly basis for several years. On the larger projects the work was managed my multiple teams responsible for their own work plans and coordinating with other teams on the handoffs among the various work phases from underground work, to primary structure, enclosure, rough-in, finishes, and commissioning. In comparison, smaller projects utilized less complex team organizational structures.

All data was recorded using the same database driven LSP software solution. Project teams followed a variety of workflows that reflected the state of the industry and the common practices of implementing LPS. The data was documented in the same way in the database including activities, logic ties, durations, revision history, and weekly work plan data (including reasons for variance and their root causes). The system calculated the priority of all activities on the work plans in a uniform way regardless of how each project team decided to apply the process. Some teams planned complete work phases in ways that emphasized workflow and others focused on improving the reliability of near-term planning against target dates defined in the master schedule. Since the software database records the data in a consistent way over time, it provided context to evaluate LPS metrics on large datasets and compare them across various workflows. In addition, it provided the opportunity to evaluate these metrics against past data sets to test various assumptions about the new metrics against previously recorded data in ways not possible otherwise.

The database represents pull plan activities as directed acyclic graphs. The software tool includes an integrated calculation engine that prioritizes the activities using pull techniques. For any activity in a workstream, the software automatically calculates its priority and records its Late Start (LS) and Finish dates (LF). Therefore, this calculation identifies what should be done on the project and when. Priorities are determined by the insertion of target dates within a workstream. The system also automatically calculates the Forecast Start (FS) and Forecast Finish (FF) date for each activity based all its predecessor activities and the sequence of the work. This calculation determines when the work as planned by the last planners including all known constraints identified in the MRP can be done. When the MRP identifies constraints that cause the target dates to be delayed, the team will have to perform additional planning to realign the remaining work with the targets. During work execution, if the project team does not maintain their remaining work in alignment with the targets, then this calculation would also identify all the activities that should have been completed to maintain the target dates and late paths would be highlighted. In general, during the MRP step, teams are expected to perform four related activities when using the software solution:

- Review and screen the activities on the lookahead for constraints.
- Plan and integrate the constraints into the overall network (not on a separate log).
- Review the plan to ensure that the updated plan still aligns with the targets.
- Re-plan any emerging late paths to realign with the targets.

One of the characteristics of the system is its ability to handle ongoing activities that overlap work plan cycles. Ongoing activities are those that do not require intermediate handoffs, start when promised, and complete when promised with durations that span at least two work plan cycles. Those kinds of activities pose an interesting challenge to teams that implement LPS as there is no documented best practice for how to represent them on work plans and how to account for them. All projects in this study implemented the same standard process for tracking ongoing activities. If an activity must overlap multiple work plans, it is tracked for starting on-time, its duration can then be reduced, and it would count towards percent planned complete if its remaining duration still fits within its promised date.

METRICS TO LINK SHOULD/CAN/WILL/DID

This study proposes additional metrics to complement the PPC, TA, and TMR that align the short term work execution planning with the overall phase schedule and master schedule targets thus aligning what should be done on a project with what can, will, and did get done. The proposed metrics are designed to be reviewed not as isolated instances but to identify trends across multiple planning cycles.

The proposed metrics are designed to provide insights regarding the alignment of work execution controlled by multiple competing target dates or complete workstreams of networked activities for interconnected phases of work that emphasize flow. The metrics are as follows:

Commitment Level (CL): measures the total committed required activities as a percentage of the total required activities for any given work plan cycle each time a new work plan is created. An activity is considered required if its LS date falls within the work planning cycle window of time. The criticality of an activity is the difference between its calculated FS and LS dates. Those calculations are performed automatically by the system for any given activity based on its position in the network, its sequence, and duration. This happens regardless of the kind of underlying network or the control methods used. It produces consistent results from fragmented networks with various target dates, networks with competing target dates, or workstreams pulled from specific target dates and controlled via Takt or LBMS techniques to improve workflow. Aligning the capture of this information with the work plan creation date is important so that any adjustments made to create a reliable forward looking plan due to the performance against the previous work plan are incorporated in the metric.

CL = Required Will / Should

Percent Required Completed or Ongoing (PRCO): This is a metric that measures the percentage of the required activities that are completed on or before their promised completion dates including the required ongoing activities that are projected to be completed on or prior to their promised completion date after the responsible team members update the remaining duration to align with the remaining work.

PRCO = (Required to be Done + Ongoing On Track) / Required Will

When PRCO is reviewed in conjunction to CL on an ongoing basis it provides a comprehensive metric that captures that the level of completion of critical activities on the near-term plan is in alignment with the long-term target milestone dates. Criticality is automatically calculated by the system based on the plan to complete the remaining work and thus is not left to the subjective evaluation of the team. Thus teams that fail to collaborate on a regular basis and consistently plan their remaining work to achieve their target dates would begin to see a decrease in their CL as the remaining work will exceed their resource capacity after a few cycles of higher PPC trends.

Figure 10 illustrates various possible patterns of data and how they could be interpreted. Figure 10-A shows the performance of a high performing team characterized by a steady commitment count, a high CL, and equally high PPC and PRCO. This team would be expected to also hold their milestone target dates. Figure 10-B shows the performance of a team that appears to be overcommitting on a regular basis and completes more backlog activities than critical activities. They hold a high CL but lower PRCO than PPC. The steady task count indicates that they continuously shift their target dates on a regular basis to compensate for the lost time. Figure 10-C shows a team that is working on the wrong priorities. They maintain a high PPC but their CL and PRCO are trending lower which would indicate that their target milestone dates are slipping each work plan cycle without proper re-planning of the remaining work. Figure 10-D shows a team that is improving. The CL metric reflects the team's attempts to commit to more of the required work and an effort to complete as much as the required work as possible. The variance in task count indicates that the team attempts to adjust resources increase their commitment level and gain time.

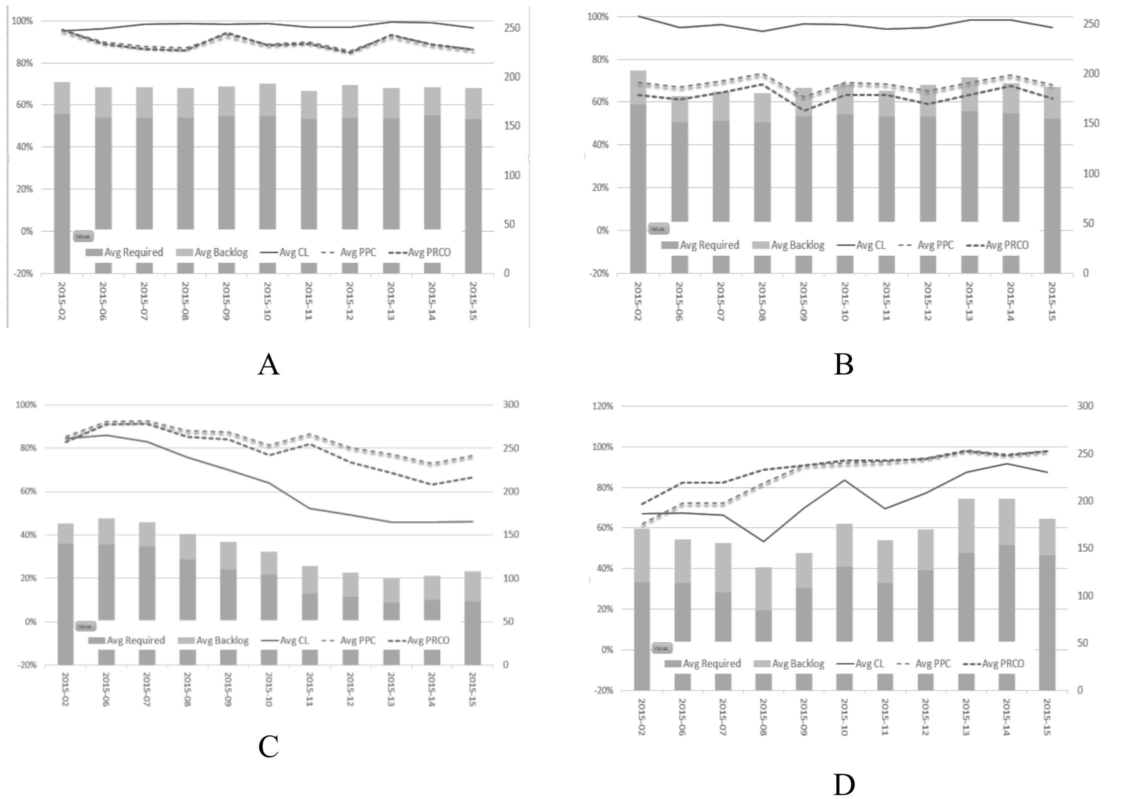


Figure 10 PPC, PRCO and CL Patterns

Milestone Variance (MV): reports on the variance in days between the forecast to complete all remaining activities against the milestone required date. It is designed to be reviewed in conjunction to the CL metric to provide context to the reported CL percentages and ensure that the remaining work is in alignment with the original milestone targets. MV records any changes to the milestone target dates as well as the forecast to completion for each milestone. Figure 11, for example, represents the standard deviation of all the milestones associated with a given team. The trend illustrates the team's efforts align the remaining work with the target milestone dates. However for an extended period of time the late paths in their plan ranged between 5-15 days.

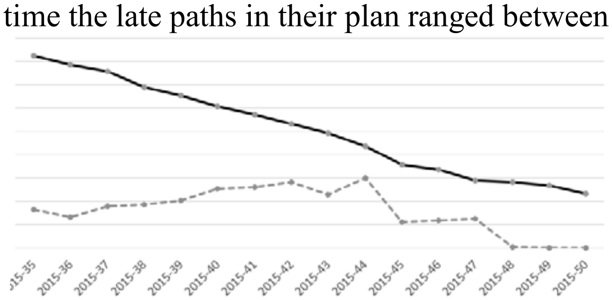


Figure 11 Milestone Variance

The CL, PPC, PRCO, and MV are complementary metrics designed to provide a rolling snapshot of how the team short-term plan aligns with the overall project targets. The metrics are designed to capture, on an ongoing basis, how well teams keep their promises, their ability to commit to the right amount of work each week, and their ability to maintain alignment between the remaining work and the targets.

FINDINGS

Impact of Lack of Proper Long Term Phase Planning: Teams that focused on short-term MRP (3-6 weeks) without proper application of Phase Planning and adequate emphasis on resource planning exhibited cyclical patterns of PPC similar to what is shown in Figure 12 which illustrates data compiled from work plans generated from multiple parallel work phases.

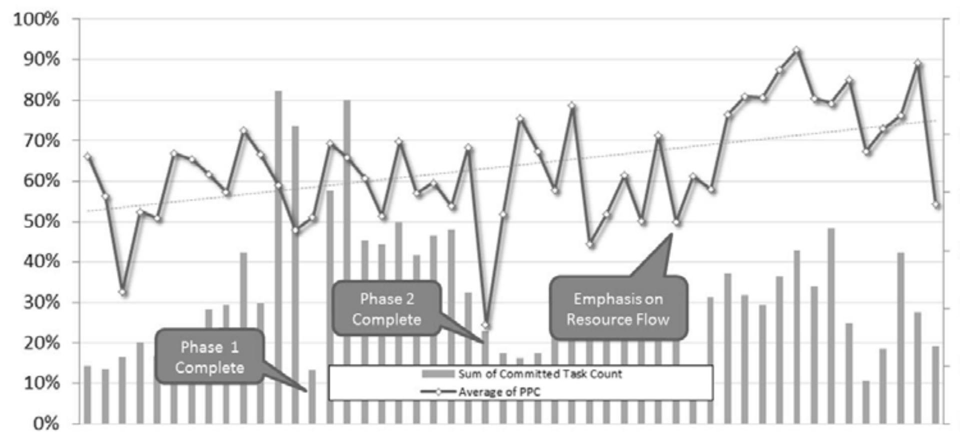


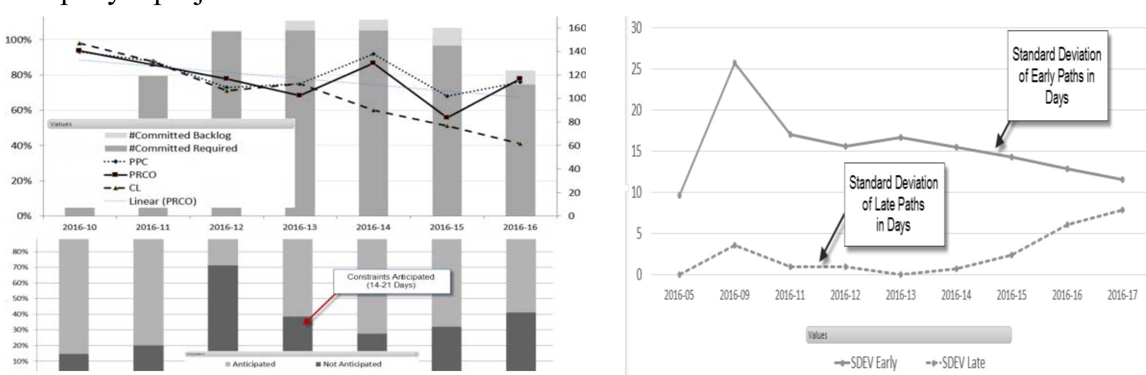
Figure 12 – PPC Graph with Focus only on Near Term Performance

Initially, task priorities were set by the project superintendents based on what was planned in the master schedule. The master schedule was maintained in an external tool and the Make Ready Planning was performed against those priorities at a greater level of detail. The figure shows a cyclical pattern of a short term increase in the average number of committed tasks accompanied by an improvement in PPC followed by a decline. Initially, the team focused on work sequencing and identification of constraints during MRP. They were, however, reluctant to link many of the constraints to the specific workstreams in the database, and, instead continued to follow the conventional LPS practice of creating separate constraint logs in excel and assigning various team members to track and resolve those constraints.

Significant effort was required to maintain alignment between the lookahead plans, the constraint logs, and the master schedule. In addition, the cycle time to synchronize near-term plans, constraints, and update the master schedule exceeded the duration of the planning cycle time. This meant that the team was uncertain about their new priorities when they attempted to commit to the next set of work plan activities. The average PPC improved but remained below the 75% mark. This meant that many assignments on a work plan could not be completed as promised and also meant that the number of late paths continued to increase making it increasingly more difficult to maintain alignment across the various tools used to track constraints, make ready plans, and the master schedule.

The team implemented a number of improvements to the workflow to reduce the cycle time and integrate the tracking tools. Many constraint types including RFIs, change orders, and design revisions, were integrated into the workstreams and removed from the individual constraint tracking logs. Construction work was re-planned into smaller batches that maximized the opportunity for workflow in the least constrained areas of the project first to allow more time to resolve issues in the more complex areas of the project that obstructed work flow. Those changes resulted in an observed steady improvement of PPC between 70% and 90% (see last third in Figure 12). This was accompanied by a steady increase in the number of tasks committed for each planning cycle. In addition, the cycle time between finalizing a previous work plan, analysis of late paths and variances and the start of the next plan based on new priorities was reduced to a few hours instead of several days. These findings confirm the original observations made by Ballard and Howell (2007) and by Hamzeh et.al (2012) that better integration between near-term planning and long-term planning can improve workflow reliability.

Evaluating the Lookahead Reliability: Initial analysis of the data shows no positive correlation between TA and TMR metrics and a team's ability to reliably achieve milestone targets. Figure 13-A, for example, shows that a relative increase in Tasks Anticipated within a 14-21 lookahead window could result in work demands that may exceed the team's resource capability as evident in the decline in CL and PRCO metrics during the next few work plan cycles. This had a negative impact on MV for the same time period (see Figure 13-B). However, it was observed that the measurement of the standard deviation of the forecast start date for the same activities on the lookahead tracked on a rolling basis of 21 days and the standard deviation of the FS and the LS dates within the same lookahead window appears to be a better indicator of lookahead stability. This observation was first made by Hongseok Cha, Business Intelligence Manager, Boulder Associates Architects in collaboration with one of the authors while evaluating data collected using vPlanner from various lookahead plans on one of his company's projects.



A B

Figure 13 Increase of TA o have a negative impact on Commitment Level

This observation was confirmed by reviewing other datasets. Figure 14-A shows the PPC, CL, PRCO, MV metrics for a project team captured over several planning cycles. Despite a stable short-term plan, the team initially struggles to commit to the appropriate amount of work that would satisfy the critical chain. Fluctuations in CL correlate in an increase in late paths and a decrease in float (Figure 5-B).

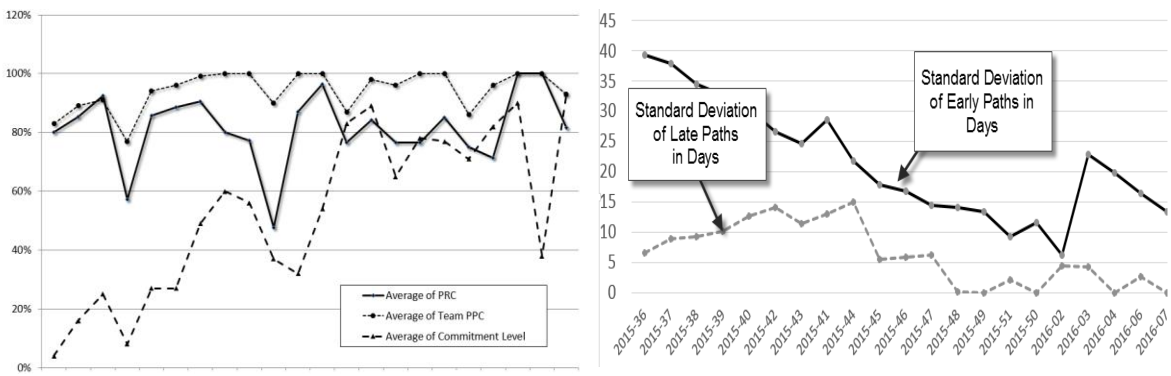


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Figure 14 Measuring Lookahead Stability

Teams that constantly re-plan to maintain CL, PRCO, and PPC appear to have lower overall MV (typically below 5 days) and appear to maintain better alignment between their near-term plans and their long-term plan target milestones and are thus more reliable. Very reliable teams maintain an overall average standard deviation of 2.5 days or less across all their phase milestones. Design phases seem to show higher variance than construction phases.

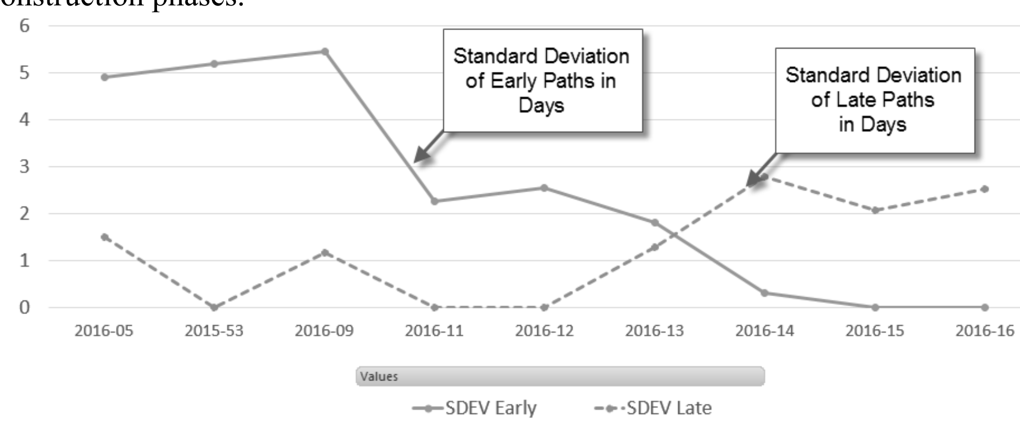

Figure 15 PRCO Focused Teams

CONCLUSIONS

This paper presented an overview of the common LPS metrics designed to measure near-term planning reliability and introduced new metrics designed along the same principles to measure the reliability of the long-term planning and improve the association between near-term and long-term planned activities. The initial findings do not support the hypothesis that TA and TMR, as commonly defined in the literature, correlate to improvements in long-term planning reliability. The study suggests that the standard deviation of forecast dates of lookahead activities captured on a rolling basis at the time work plans are created may serve as a better indicator for overall planning reliability.

The correlation of this metric with the standard deviation of forecast dates against late dates for the same lookahead activities serves as a better indicator of reliability especially when reviewed against the proposed CL, PRCO, and MV metrics that are captured at the same time as the capture of the standard deviation metrics. Additional research continues to monitor these metrics on a larger project sample and for longer periods of time to confirm the initial conclusions.

The alignment of near-term and long-term planning requires a systematic adherence to the processes of the LPS workflow from Phase Planning to Weekly Work Planning and Commitment Management, and, the continuous capture of the data in an integrated and uniform way. This cannot be achieved by makeshift tools commonly used in the industry to manage LPS workflows. Those makeshift tools and associated processes result in data fragmentation, redundant entry, long cycle times, and introduce errors into the process. This research demonstrated some of the advantages that integrated database driven tools can bring to improve LPS data collection and presented an overview of some of the opportunities presented by those tools to align near-term and long-term planning to improve reliability.

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SECTION 6: PRODUCTION PLANNING AND CONTROL

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. Available at: <www.iglc.net>.

INTEGRATING LBMS, LPS AND CPM: A PRACTICAL PROCESS

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ABSTRACT

Despite the lean construction community criticism of Critical Path Method (CPM), it is impossible to ignore its widespread use. Furthermore, CPM is commonly considered a contractual requirement demanded by owners. On the other hand, Location-Based Management System (LBMS) and Last Planner System (LPS) have been successfully implemented in many construction projects. This article puts forward the proposition that there are synergies between these tools and their combined use could provide great benefits and fill some gaps.

The aim of this paper is to propose a practical process for integrating LBMS, LPS and CMP, in an attempt to improve planning and controlling processes in general, besides filling gaps related to delay analysis. A constructive research was developed through a case study, collecting data of a planning and controlling system used by a large construction company, which applies CPM and LPS tools. The processes and the main decisions of the project team were systematized in an integrated model, taking into consideration the project phases. Two additional propositions were formed to be validated in future case studies. Firstly, the integrated sources of data will help professionals to support decisions. Secondly, the schedules created with this integrated approach are better able to model workflow.

KEYWORDS

Location-based management, Last planner system, Critical path method, production, delays.

INTRODUCTION

There is a widespread use of Critical Path Method (CPM) in construction projects. In addition, in some countries such as Brazil or United States, this tool is commonly a contractual requirement demanded by owners. Furthermore, Galloway (2006) conducted a survey in the USA where 63% of the respondents indicated that they use CPM as a contractual requirement. In the same survey, 50% indicated that CPM helps to reduce delays and 46% believed that CPM minimizes the disputes between the contractor and owner. However, CPM has been criticized by the lean construction

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community, especially in relation to the lack of schedule workflow, the focus on project control instead the production control, the poor quality of constraints analysis, the inadequate daily management of activities and the use of highly detailed schedules, even in the projects' beginning, where a lot of definitions and details are unknown. Many papers published in IGLC conferences point out the need of adjustment of CPM for construction (Mendes Jr. and Heineck 1998; Kala et al. 2012; Koskela et al. 2014). Additionally, the lack of a theoretical basis for construction project management has been pointed out in the literature (Halpin 1993; Koskela and Howell 2002; Cicmil and Hodgson 2006).

The term CPM is ambiguous and can be understood as an algorithm for calculating the project's critical path or, in a more complex way, as a planning and controlling technique, which incorporates some concepts such as Gantt charts. In addition, this technique is mainly focused on helping the project team to manage the time in a long term. In this paper, CPM is defined as a planning and controlling technique.

Location-Based Management System (LBMS) and Last Planner System (LPS) are complementary lean production and controlling tools, getting increased attention from lean practioners and have been implemented in many construction projects (Seppänen et al. 2010). These tools aim to decrease waste, increase transparency, improve predictability and improve flow (Seppänen et al. 2015). However, based on the authors' experience, in Finland, where LBMS is widely adopted but there is no tradition of using CPM schedules, time-related disputes are common and there is a lack of accepted rules for the management of delays. On the other hand, in countries where CPM is a contractual requirement, it has been difficult to completely replace it with LBMS and LPS because of risks related to lack of experience of using the tools to justify time extension claims. The practical result has been that the two systems have co-existed in the same project, which has resulted in confusion about which information to use for which decisions. The use of LBMS and LPS for delay analysis and owner reporting purposes would be the best way; however, their use in this situation has not yet been addressed.

The aim of this paper is to propose a practical process for the integration of LBMS, LPS and CPM in an attempt to improve production planning and controlling processes in general and fulfill gaps related to delay analysis. Working together, the three systems can offer a viable solution, as one system tends to compensate the shortcomings of others.

In terms of systems complementarity, Seppänen et al. (2015) explore the integration benefits of LPS and LBMS in the production planning and controlling phases, mentioning that is possible to add more definition to the master scheduling phase by defining the overall Location Breakdown Structure (LBS), which defines locations in the work level. In addition, the integration of CPM and LPS has been analysed and implemented by lean practioners (e.g., Huber and Reiser 2003). On the other hand, previous research with focus on combining CPM and LBMS has not been detailed in a high level, but it is important to remember that LBMS calculations are based on a modified CPM algorithm (Kenley and Seppänen 2010). Despite the additional layers of logic, buffers and forecasting in LBMS being useful for production planning and control purposes, carrying out the delay analysis is a challenging task. Therefore, at least in the short term, there may be a role for traditional CPM for this important contractual aspect.

RESEARCH METHOD

This research can be classified as constructive research. This approach aims to generate scientific knowledge, developing an artefact to solve a real problem (Holmstrom et al. 2009). Despite their different underlying philosophies and controlling mechanism, the authors put forward the proposition that there are possible benefits of integrating LBMS, LPS and CPM in the course of all phases of the project. In addition, new process and best practices are required to support the project team decisions. An exploratory case study was developed to obtain a deep comprehension of the problem. The generated artefact is the proposed integrated model. Both artefact and proposition's development need to be tested in practice in future research.

The case study was carried out through data analysis of the main processes and tools used on planning and controlling system of a large Brazilian construction company, acting in the real estate market since 1980, with focus on construction projects for residential buildings, corporative and mixed use. The company has a matrix structure, where its projects apply the same processes, procedures and tools. The work of development and updating of planning tools is done by own teams. The company has a strong tradition in using LPS and CPM planning and controlling technique.

The main data were collected through electronical documents, considering procedures, schedules, spreadsheets and tools, used in a set of twenty already finished real projects. Furthermore, one of the authors of this work followed the performance of the projects on field. The unit of analysis used was the planning and controlling system. More than 100 documents were analysed during two months, considering the four main aspects of LBMS and LPS, i.e., (i) buffers, (ii) workflow, (iii) management of subcontractors and (iv) constraints. The main documents analysed were: CPM schedule, procurement schedule and EVA (earned value analysis), constraints meetings sheets, WWP (Weekly Work Plan), PPC (Percent Plan Completed), WBS (Work Breakdown Structure), measurements criteria, sequence patterns and attack plans.

After the case study analysis, the integrated model was developed. Firstly, the main processes related to scope and time were identified, for each project phase. Secondly, each process was classified in CPM schedule or LBMS schedule. Thirdly, the main decisions related to the project team were analysed. The processes and decisions were organized in a chart and were numbered from **[1]** to **[30]**, to facilitate following the model. Finally, the processes and decisions were described considering their main characteristics and an analysis of their impacts.

RESULTS

The case study shows that the main processes and tools of the company are strongly rooted on traditional project management principles. Thus, as a characteristic of project management, the focus is on project control and not on production control, trying to obtain the production goals indicated in the CPM and EVA. There is a clear lack of attention in items such as locations, labor, resources, buffers management and continuous flow. Table 2 shows the main results taking into consideration the planning and controlling phases.

Table 2: Case study main tools and processes

Planning phase	Controlling phase
CPM schedule - The CPM schedule is the basis of the system and has as end date that agreed with the managers, which is different from dates promised to the customer (usually at least two months earlier). - The schedule is structured according to WBS and usually has more than 5,000 activities, which are based on the divisions and on measurement criteria established. The company adopts pattern-sequencing models for the activities. **Attack plan** - This plan divides the project into small packages and defines the buildings' tasks sequence of infrastructure, foundations and concrete structure. **EVA** - The estimated cost for each task is inserted in the CPM schedule, generating information for the development of the EVA. **Procurement schedule** - A procurement schedule is defined based on the CPM dates and definitions of procurement time, mobilization of subcontractors and delivery time of materials.	**Updating of CPM schedule and EVA** - The updating process happens only once a month. The actual start and finish dates of each task are inserted, considering completed activities. The analysis is often limited to the month production and to the critical path. - Considering that there is no LBS applied, the level of detail of WBS is not enough to attend the production team needs. **Spreadsheet of production goals** - The link between CPM and production teams: besides the activities to be done in the period, each task' percentage share of costs are shown and it is highlighted if the task belongs to the construction critical path. **Look ahead planning** - There is no scheduling during the look ahead process. The look ahead meetings are used only to analyse the constraints. **WWP** - The PPC measurements are presented every week to the subcontractors and managers. There is a procedure, which indicates the meeting steps. New tasks divisions are done in the WWP.

BUFFERS

As the company only uses the CPM schedule, there is no formal buffer analysis, either in the planning phase or in the controlling phase. The critical path follows the general rule considering only zero float activities. Some floats are analysed only when the critical path indicates a time overrun during the tracking process. In these cases, the activities' durations are reviewed, new resources are planned or some activities are rescheduled to be parallel with the predecessors. Eventually, alerts are sent to the board of directors when the critical path cannot be reached or when the monthly EVA goals grow very high.

The average project duration is 24 months, without buffers. As a pattern for each project, the company adopts a project buffer of two months, inserted in the end of the project. This is basically a process to minimize delay risks of customers' dates. However, this buffer is "owned" by the organization. The project team's goals consider the project end date without any buffer. Thus, there are two main dates to be considered: the team goal date and the customers date. These two dates are known by the whole team and subcontractors.

WORKFLOW

There is no formal workflow analysis, even during the planning phase. The managers prefer to work with the original pattern of CPM schedule and links defined by the company. The basic rule is to start tasks as soon as possible. Managers usually argue that there are a lot of uncertainties in the beginning of each task and, during this period, the crews work with a lower rate than their normal rhythm of production. Thus, no buffer analysis is formally applied and frequently there are no tasks with continuous workflow in the CPM schedule. After the concrete structure and masonry tasks, most of the activities are planned with the same duration, in a clear attempt to offer nonstop work to the subcontractors.

The company applies prerequisites sheets to start new tasks for the first time and to evaluate the conditions of work. When a task which cannot create value is identified, it is removed from the process, the work instruction is reviewed and the task is no more planned on the WWP. When the work instruction is modified, a formal instruction is given to the work team, in a short training managed by the quality team, in compliance with the quality procedures. No actions are formally registered in order to reduce processes' lead times and variations, but sometimes some instructions related to process improvement are verbally given directly to the production team. Some processes are simplified during the commitment planning, especially when the subcontractors are involved in the discussion.

MANAGEMENT OF SUBCONTRACTORS

The company usually works with a lot of subcontractors in its projects. Rather than using large subcontractors, the managers prefer a relationship with small subcontractors, specialized in each task, which frequently have less than thirty workers on the construction site. It is very common to find specialized subcontractors working in a lot of construction sites at the same time. The subcontractors are involved in the project scheduling discussions related to the WWP only. The majority of them have no ability to develop their own schedules or even discuss a long term plan. Usually, they follow the goals established in the CPM schedules, which are attached to their contracts. Each subcontractor's performance is monitored by the construction team, but delays are very common. On the other hand, claims are well controlled by contractual clauses.

There is a procurement schedule, which monitors around eighty main construction resources (such as steel bars, cement and waterproofing). This schedule considers the main tasks and the times required for the supply chain process, such as negotiation time, documental analysis and mobilization time. Procurement is weighted based on the representative budget of each resource. During controlling phase, the schedule is updated monthly and the needs are evaluated based on the constraints meetings. The schedule progress is monitored by the planners and engineers. The subcontractors' performance is analysed in the commitment plan and in a specific software.

CONSTRAINTS

Referring to LPS tools, the company uses spreadsheets for identification, following up and removal of constraints and WWP. Last Planner System has been implemented only partially, for example, there is no phase scheduling involving the subcontractors. Constraint analysis meetings occur monthly, with a high emphasis on the correct identification of constraints. The meetings with production teams are weekly and their results are registered in spreadsheets. In these meetings the goals are informed and discussed, in addition to presenting PPC results from previous periods.

With the adoption of LPS, generally speaking, the company obtains good results with the monthly constraints analysis meeting, increasing the productivity and helping the team to discover bottlenecks in the production process. They usually analyse the tasks three months ahead and, in some cases, specific resources that will be needed in the future. The company applies a procedure which indicates the necessary steps to conduct the meetings, including a set of constraint groups, the documents required and the professionals who must participate. An indicator which shows the percentage of removed constraints is applied and analysed by the managers.

GAP ANALYSIS

There is a procedure where the subcontractors' performance is monthly evaluated, in aspects related to time, quality, safety and cleaning. In addition, the commitment plan process evaluates the subcontractors' performance, but only considering aspects related to short term. However, even with these actions, there is no formal analysis of delay impacts related to each subcontractor standing alone or working in an integrated way with other subcontractors. Thus, delay analysis is not done systematically.

Despite the adoption of some concepts, LPS is not completely implemented: there is no phase scheduling involving the subcontractors and there is no scheduling on the look ahead planning process, which is focused only in constraints analysis. Furthermore, due to the lack of continuous workflow, the resource use is discontinuous.

The case study company needs a system where flow can be planned and controlled (i.e. LBMS) and LPS is completely implemented without compromising the ability to perform delay analysis and integrate other company functions, such as procurement, using CPM.

MAIN PROCESS AND DECISIONS

Figure 1 shows the proposed integrated model divided into planning and controlling phases. In the following section, the main processes and decisions are described.

PLANNING PHASE

[1] The attack plan is developed based on an analysis of contractual phases (for example, three towers with different delivery dates), constraints of sequencing imposed by retaining walls and foundations, considerations and constraints of logistics, available resources and duration of tasks, weather conditions for each phase of the construction project (retaining walls, foundations, structure, façades and waterproofing) and safety conditions for each situation.

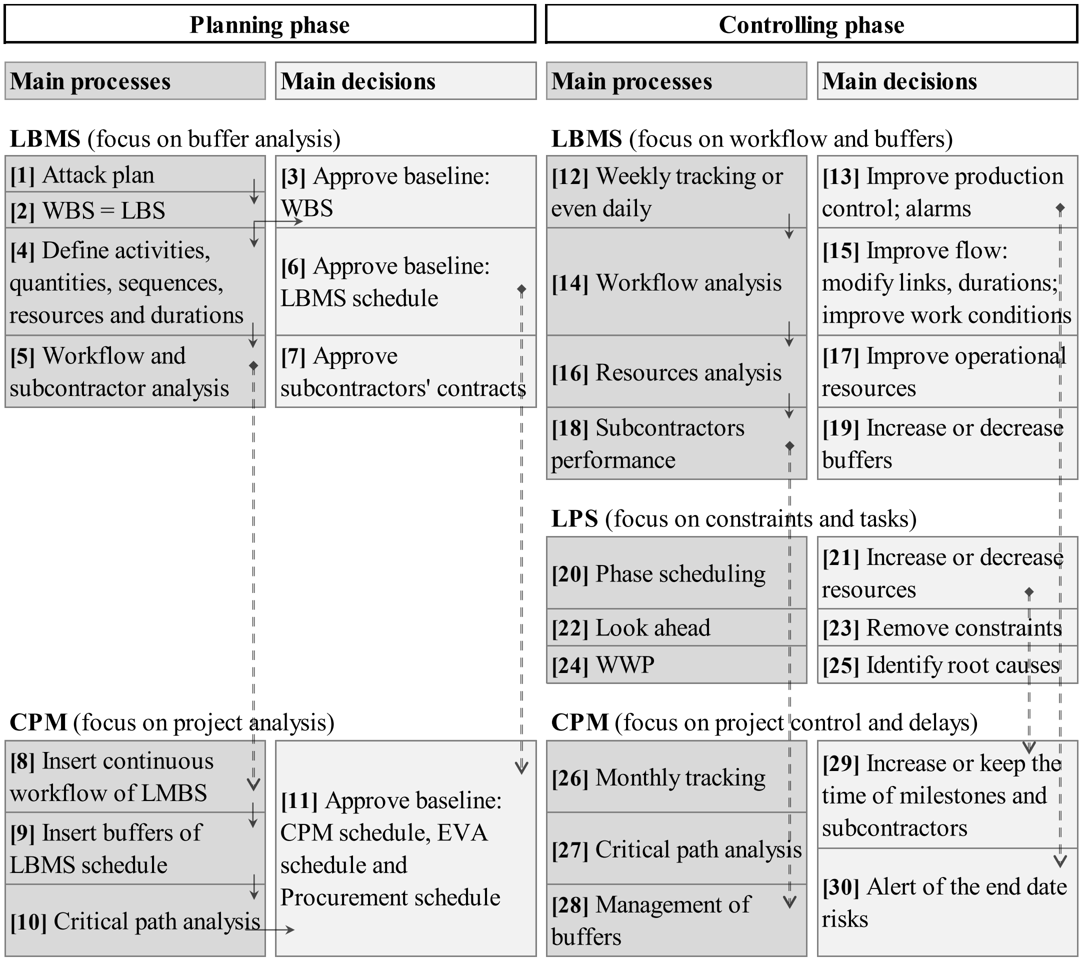

Figure 1: Proposed integrated model, divided into planning and controlling phases and considering the main process and decisions

[2] Both CPM and LBMS schedules need to start with a common WBS and LBS. This procedure seeks to improve the quality of the schedules and the integration between them. The companies usually work with a standard WBS for the development of construction plans. From WBS´s definition, a smaller division for locations is defined, called LBS, which is defined for each construction project, taking into consideration the number of towers, floors and apartments or commercial rooms, the area of each of the units and the technical constraints, such as for example, separation and division of façades in which the elevator is installed. LBS is a fundamental part of LBMS. **[3]** The baseline of WBS and LBS must be approved by the project manager.

[4] The LBMS scheduling process starts with the physical measurement criteria of the tasks, which is targeted at establishing the way the physical progress of the construction project will be measured. After that, quantities and the construction sequence are defined, considering the attack plan definitions. The analysis of resources and activities duration are determined simultaneously during schedule optimization. Finally, buffers are inserted mainly to protect the schedule against cascading delay chains. **[5]** A workflow and subcontractors’ analysis is needed at this moment. **[6]** As a product of this step, adjustments in the costs and project schedule are made, followed by a baseline LBMS schedule. **[7]** During the planning phase, some key subcontractors' contracts are approved by the project team.

The CPM schedule is prepared based on the LBMS schedule on the same level of detail. Firstly, it is necessary to configure both CPM and LBMS calendars on the same basis. Secondly, the activities, links, sequences and durations defined in the LBMS schedule must be inserted in CPM schedule. **[8]** To achieve the same set of initial planned dates as in LBMS schedule, the CPM schedule is adjusted by inserting activity lags to model buffers and continuous flow. **[9]** Buffers must be inserted preferably as a new task or as a lag between activities and contain the same duration as LBMS buffers. **[10]** An analysis of the critical path is made, taking into consideration the main project milestones, the period when the main tasks are occurring, the main subcontractors' tasks and the monthly production required. **[11]** Finally, the EVA and the procurement schedule are developed based on the CPM and both CPM, EVA and procurement baseline are approved.

CONTROLLING PHASE

The proposed integrated model uses LBMS, LPS and CPM systems simultaneously. **[12]** The LBMS schedule is monitored weekly, or even daily. The activities completed are collected in field and updated in the schedules, considering the real start and finish dates and actual resources and quantities. The forecasts are compared with plans to detect future problems. Any identified future problems are discussed and control actions are planned to prevent them.

[13] The LBMS controlling process can be connected with the LPS to guide production control decisions and to generate alarms about upcoming production problems. **[14]** A workflow analysis is done to achieve continuous flow of crews. **[15]** In attempt to improve flow, the main decisions during this process involve modifying links and durations and improving work conditions of the subcontractors. **[16]** A resource analysis is done to evaluate the **[17]** operational resources and the necessity of adjustments. **[18]** An analysis of the subcontractors' performance may help the project team to **[19]** increase or decrease buffers. **[20]** The phase scheduling process involves subcontractors in the definition of common plans and makes it easy to commit to **[21]** increasing or decreasing resources.

[22] Look ahead meetings are done based on the LBMS schedules' update. The aim is to analyse the tasks that will occur on few weeks, listing the constraints that may require changes to plans. **[23]** Every week the constraints must be followed up by the construction project team. From the constraints meetings, the prerequisites of production are monitored and prioritized, evaluating in this way the necessary resources for executing the tasks. **[24]** The WWP process divides the activities by team and by day of the week, who commit to the plan. The success of this WWP is measured by PPC and any plan failures are investigated allowing **[25]** the identification and treatment of root causes for not completing the activities.

[26] The CPM and Procurement schedules are usually updated monthly, based on the information generated by the updating of LBMS. The actual start and finish dates of LBMS are inserted in the CPM schedule. The LBMS forecasts are not inserted in CPM, which keeps the originally planned durations and sequences. If the CPM schedule starts to deviate a lot from LBMS schedule, a schedule revision may be submitted to the Owner based on the process defined in the scheduling specification.

With the tracking of CPM and EVA it is possible to evaluate the progress of the construction project, as well as compare with the established baseline. In the CPM schedule it is possible to monitor delays on the Critical Path and in EVA the percentage progress of tasks. Procurement schedule is updated considering the predicted and accomplished dates of main resources, allowing a follow up of results.

[27] With the insertion of the LBMS actual dates is possible to calculate in CPM the total amount of delays on critical path and evaluate the impact of any change orders and delays, such as weather delays and design delays. In CPM, the same actual start and finish dates will result in different dates because the CPM algorithm does not take into account continuous work or adjust durations based on forecasts. Therefore, it can be used to achieve the traditional project management objectives. The critical path and the main milestones are checked to evaluate the risks of delays. **[28]** The buffers' durations inserted in the planning phase can be modified if necessary. A subcontractors' analysis is applied in attempt to compare the original buffers and milestones with the forecasts.

[29] LBMS forecasts dates will be different from CPM activity dates. CPM will be used to evaluate the critical path and to supply enough information to the project team related to delay analysis and subcontractors' performance, increasing or decreasing the original time of buffers and subcontractors. On the other hand, LBMS is more appropriate to analyse continuous workflow, buffers, durations, forecasts and to determine control actions to recover delays and it is the operational schedule which can be connected with LPS constraints analysis and daily management of activities. **[30]** Both LBMS and CPM schedules can supply information to develop monthly reports to the owner and to the project team. CPM will provide information to analyse delays, and the performance of subcontractors and the project. LBMS will provide information related to production control and the necessary actions to improve flow and recover delays.

CONCLUSIONS

The integrated model systematizes the integration of three distinct, but complementary systems, which are LBMS, LPS and CPM. The processes and decisions were developed based on using LBMS and LPS to run operations but having an aligned CPM schedule which can be used for traditional project management purposes, such as delay analysis. Standing alone, each system is strong in some areas but requires improvements in others. Thus, it is expected that through further artefact implementation, the proposed integrated model can compensate the deficiencies of using the planning and controlling systems in an isolated manner or by running various systems in parallel with no integration. Two additional propositions were formulated and need to be validated in future research. Firstly, the integrated process will help professionals to choose the best set of data to support their decisions, including both project managers and operation team. Secondly, the schedules created with this integrated approach are better able to model workflow, help managers to analyse and communicate delays and to decide about the best approach to the critical path.

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DIFFICULTIES IN WORK DESIGN IN THE CONSTRUCTION SECTOR

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ABSTRACT

Work standards are an essential component of lean production systems. The unique and one-of-a-kind nature of construction products adds an additional layer of complexity when designing work standards in such a particular context. This research focuses the process of designing work standards for construction. The purpose was to highlight the difficulties observed when designing the specifications that make up the standard. An in-depth case study was carried out in a company that had been struggling to meet a stable cycle time for the reinforced concrete structure phase of multi-story buildings. An analysis of the current process was undertaken and a literature review of the work standards was conducted in order to identify possible ways to specify the work elements. The study suggests that a large amount of time is spent on the work design owing to (a) the level of uncertainty (lack of productivity data to support the design of the work packages over the cycle time; frequent moving of the workers from one work package to another; lack of resources near the workstation); (b) a project being created very close to the start of the actual production and, therefore, suffering from conditions imposed by the decisions previously taken; and (c) a team of workers unaware of lean concepts.

KEYWORDS

Standard, Work Design, Workflow

INTRODUCTION

Standardized work is one of the main means used by lean systems to reduce variability. It is based on specifying a work routine for workers that allows production within a certain deadline according to the customers demand, and with a low level of inventory (Monden 1997; Productivity Press Development Team 2002). According to Monden (1997), a work standard must specify the desired work rate (by takt time), work in

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progress, and standard operations routine. The purpose is to organize the way workers should act, the sequence in which they must perform their individual operations, the deadlines they must comply with, and how they can identify the occurrence of deviations that may compromise the results of the production line.

The application of the standardized work concept in the construction context presents difficulties due to the low repeatability of the processes and high degree of variability. Mariz, et al. (2012), after an extensive bibliographical research on the standardized work approaches in construction, recognized that there are only isolated and incomplete applications, using only part of the standardized work original elements. Improving the use of work standards requires adaptations to the conceptual elements involved, so that they become applicable in construction. For this purpose, a series of research studies have been developed in the post-graduate program ENGES/UEL[2]. Initially, Saffaro, et al. (2008) identified the conceptual standardization deficiencies in four construction companies. As a result, Fazinga (2012) identified the standard content for the production of reinforced concrete structures, making relevant conceptual adjustments in relation to the standardized work described in the lean context. As the set of standard elements was identified, there remained a gap in the knowledge concerning the specifications of these elements in a real case (work design) and putting them into practice, on a trial basis called First Run Study – FRS, to validate the contents of the standard. The use of FRS as a tool to develop standard work is described in Hackett, et al. (2015) and Martinez, et al. (2015). The purpose of the article herein is to point out the difficulties faced while developing the above-mentioned work design.

STANDARD ADAPTATIONS IN CONSTRUCTION

Improving and measuring the performance of the workflow has been a common subject in studies investigating lean concepts in construction. Kalsaas (2011) points out that the workflow is influenced by the configuration of several other flows, materials, information, people, and equipment, as well as the conditions of the context in which the production develops, such as the work location and site characteristics. Under these conditions, the work design is a means to adequately combine these mutually dependent aspects, in order to improve the production capacity of teams and ensure stability in results. For Nerwall and Abdelhamid (2012), designing the work to be performed by a team involves determining the number of workers, variety of skills, sequence of operations, and their durations. The specifications of these elements are then tested and the rules are gradually refined. Mariz and Picchi (2013) demonstrated the work standard as a result of an evaluation of the actual situation in the construction site and the design of the future status. This evaluation was based on questions about what operations are really necessary, their duration, how they will be distributed among workers, and the resources and equipment involved in the work. These are different but complementary approaches, which exemplify the current concern in assessing processes and operations jointly, and establishing work standards in order to reduce waste and guarantee stability.

In the Brazilian scenario, the studies by Fazinga (2012) and Mariz and Picchi (2013) stand out. These latter authors focused on the execution of mechanized driven foundation piles. Fazinga (2012) focused on the implementation of reinforced concrete structures. In this last research, the contents of the standard were the results of an eight-

[2]ENGES/UEL: Post-graduation Program in Building and Sanitation Engineering (MSc)

month case study on a construction site. The takt time of each structure's floor (resulting from the long-term schedule) and the conditions that limited or impeded the production development (constraints), such as shared resources and definitions of the work in progress were taken as the starting point for the other specifications. Table 1 reports the elements to be specified in a work design and the evidences justifying them, taken from such a case study.

Table 1 - Standard elements in construction (Table 7 in Fazinga 2012)

Elements	Evidence leading to the elements
Work content (Operations)	- Operations described by the engineer were incomplete
	- There was uncertainty about the volume of work in each floor
Sequence for the operations flow	- Complying to the technical sequence inherent to the construction process
Work packages	- Tendency to work on large batches
	- Work not completely finished and variations of runtime operations
Sequence within each package	- Long walks and constant moving of scaffolding
Number of workers in each package	- Constant variations in the size and team configuration
Resources kit of the package	- Leaving the work station in search of resources
	- Receiving damaged and unusable resources
Transport procedures	- Variation between manual and crane transport
	- Workers engaged in unsafe transport or great physical effort
	- Improvisations during transport
Resources storage	- Changes in the storage location, dirty floor, and blocked access
	- Repeated transport of resources to the ground floor
Key points	- Errors, rework, and constant experimentation
Crane operations routine	- Shared use and apparent work overload of the crane
	- Labor force idle waiting for resources or crane support
Production monitoring points	- Lack of data on the team production capacity
	- Long and variable cycle time

An important peculiarity of these specifications is the need to group the production operations in construction, which supports the notes of Kalsaas and BØlviken (2010). These groups were named "work packages", and were assigned to teams with specific skills. Each package maintained an internal flow of processing operations, transportation and inspection, and waiting situations. In addition, various packages were executed simultaneously, in different locations of the construction, and with dependency relationships between them. The completion of a package indicated its delivery to the subsequent team, although on this occasion, there may be delays, overproduction, waiting, rework, movement of workers and transport of resources to start new packages. To structure the workflow in this context is a very complex task. Therefore, in the content of Fazinga (2012), specifications were included with the purpose of maintaining adequate availability of resources (kits, transport, and storage procedures on the working area), mitigating the effects of shared resources (crane routine), and enabling constant control on the production evolution (monitoring points).

The results of Fazinga (2012) encouraged the continuation of the research on other construction sites of the same town (Londrina, Paraná, Brazil) and same construction company. The advancement refers to the studies of Kremer (2016), showing the difficulties faced in order to structure a work design, i.e. specifying the set of elements, which after tested and adjusted, could become a standard for production.

METHOD

The research strategy adopted was the case study (Yin 1989). Two construction sites were chosen for the work design: both buildings had approximately 22 floors, and the same construction process. Researchers, based on the standard content presented by Fazinga (2012), drew up an action strategy to formulate the work design, as shown in Figure 1.

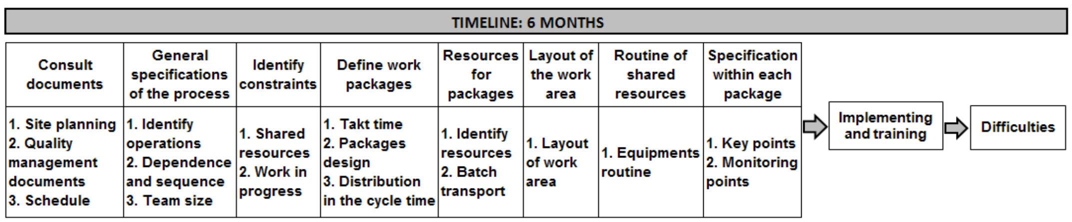

Figure 1- Timeline for the elaboration of the production design

After the analysis of the documents, there was a daily intense observation of one cycle of the production process (third floor of the site 1). The aim of this period of observation was to understand the context (construction system, how to specify the elements proposed by Fazinga). These data resulted a work design that was not implemented because the activity was too far advanced to interfere in the production process. Once the construction system of the both sites was the same, the outcomes of the case study 1 (site 1) supported the elaboration of the work design in the case study 2 (site 2). The collected data (site 1) were discussed in meetings with the engineers of construction site, foremen, and workers team leaders in order to define the specifications (site 2). When the elaboration of the work design started the activity (reinforced concrete structure) was not yet in execution. After the work design was completed, there was a training session for the full team of workers in a classroom with projection of 3D images, including the work packages that should be carried out every day and other specifications of work design. After the training session, there was a period of observation on site, to test the production process and check the relevance of the specifications. The case study 2 lasts 4 months and after this there was a conceptual reflection based on the literature to highlight the difficulties encountered in preparing the design. The detailed work design can be found in Kremer (2016).

CASE STUDIES

Before reporting the results of the studies, it is necessary to present a brief characterization of the construction process, similar to both construction sites. The slabs were of the ribbed type with a metal shoring system on which a floor of wooden plates was laid. Crane equipment for vertical and horizontal transport was available to production. The beams were prefabricated in a central on site. The size and weight of the columns' formwork required crane support for movement and positioning. Each slab for a floor was divided into two stages of implementation, named phase "A" and "B", as shown in Figure 2, with the purpose of reducing the size of the production lot. The teams of workers were divided between the phases of the slab, working in parallel, although always starting phase “B” a few days later, so that some materials could be shared. That is, while one stage was dedicated to work on columns and beams, the other phase was assembling the slab.

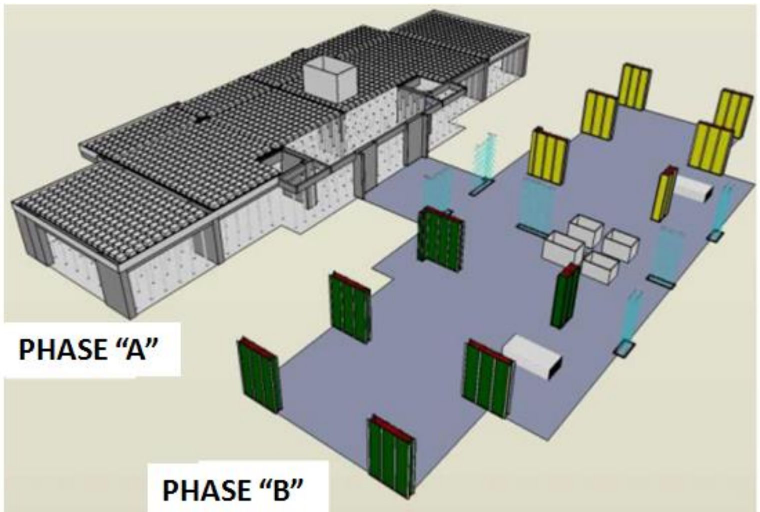

Figure 2 - Representation of the floor and its respective phases of execution.

An initial period of observations on site was held in order to be better acquainted with the construction system and the design of operations flow. Additionally, the observation was held to detect situations that would characterize the occurrence of variability. These situations include frequent changes in the number of workers, constant interruptions in the production, lack of materials, and a strong dependence on crane support without a coherent synchronization of its use between the two stages of the slab. At the stage where the columns and beams positioning were made, the crane was necessary for both the transport of resources to the floor, and to perform the assembly operations of the steel, formworks, and beams. On the other hand, during the slab production, the crane provided resources only, and the operations could be performed manually by the workers. The design of the operations flow of the floor in observation, shown in Figure 3, was too dependent on the site observations, since the engineers did not describe in detail the construction process.

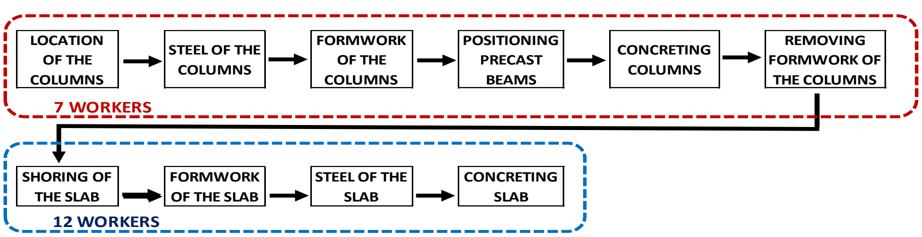

Figure 3 - Flow of operations for the structure floor

In the constraints analysis, a debate took place on the real need for the crane equipment to assist the beams production centre in the construction site. Since the location of the beams production centre in the site restricted the access for the concrete trucks, the participation of the crane in the beams concreting, removing them from the moulds and transferring them to the storage position, had to be maintained. On such occasions, the production in the floors should only contain operations performed manually, restricting the work packages on these days.

The sizing of the work packages was constrained by the takt time. For the first case study, the takt time was 12 days per floor. The engineer decided to structure the work design for a cycle time of 10 days, adopting a buffer of time. On the second case study, the takt time was 8 days and the work design provided a cycle time of 7 days. From then on, the definition of work packages to be executed every day in each of the phases, A and B, was based on the technique outlined in Figure 3 and the identified constraints. The company had no formal and historical data about the teams' productivity, and the duration of the operations was not measured in this study. Therefore, the packages were formatted based only on the experience of the team leaders. They pointed out milestone dates in the evolution of the production (taking as example the first case study) as follows: a) packages related to the columns and beams should finish at the end of the 4th day of the cycle; b) formworks and slab shoring should finish by the end of the 7th day; c) steel of the slab by the end of the 9th day; d) slab concreting should take place on the 10th day, closing the cycle. During the meetings to define these specifications, it was noticeable that the team leaders were concerned about interrupting their activities on site by participating in the meetings, claiming that their role was only to fulfil what had been decided. Only after a few meetings, they began to register their objections.

The researchers encouraged the reduction of production batches formatting small packages, although the team leaders showed difficulties in understanding this principle and favoured, for example, a single concreting for all the columns on each stage of the slab. For mounting the shoring and slab floor, the sectoring of the floor was determined by common consent, i.e., the delimitation of stretches to be executed, one by one, until the total area was completed. It was intended that when the carpenters move on to the second stretch of slab, steel benders could immediately start the first stretch. However, the steel benders' leader was strongly against this kind of operation and virtually demanded that the whole formwork of the slab was finished to start the placement of the steel. The final decision was that shoring and formwork would remain segmented into smaller packages, although the steel would only start when the whole area was ready.

After the definition of the packages, a survey took place on the resources necessary for the execution of each one in order to form resources kits to be transported with the crane. This calculation used the structural design and the observations on the use of resources in the floor, requiring a large amount of time and resulting in a fairly large number of information. However, investigations gathered from the team of workers on the transport of kits revealed some drawbacks, such as, some kits had many items and it was not possible to transport them all at once; others were too small and it seemed incoherent to use the crane only for them; at the start of every package there was a need to separate and count the resources to create the kits and, finally, if there were any adjustments and changes in the packages during the production, all the task for specifying the kits would have to be carried out again. On the other hand, it was thought more appropriate to define transport batches of the same material, and no longer depend on the type of package. In the second case study, only the means of transport (metal boxes of varying sizes) that would be used to supply workstations were defined, in order to make the crane lifting easier. Each box would accommodate resources up to the maximum capacity, and this amount could supply more than one work package.

The amount of resources on the floor had influence on the duration of the packages, as often materials were deposited in places that would disturb the execution of the operations, or that required constant displacements in order to use them. The specification to ease these problems was the design of a storage layout on the floor area. In the second case study, as the dimensions of the transport boxes were known, it was easier to define the layout. However, even so, in both cases it was lengthy specifications with many changes, and full of uncertainties for decision-making. When the layout was finished, the difficulty was then to determine a means to document it for the crane operator to be able to follow the rules. The first attempt produced 14 A3 pages, which is a not suitable option to be used by the operator. After that, 3D drawings were made showing the floor with the representation of the day packages and the transport means positioned on the slab, similar to Figure 2.

The next step was the attempt to specify a routine for the crane operations according to their relevance in the evolution of production. However, there were no parameters for decision-making, as the necessary times to perform the transports were unknown and there was no formal scheduling for the days when the crane was needed at the beams production centre. There were occasions when it was necessary to decide which operation should be carried out first, either the resources supply on phase A or the packages support on phase B; additionally, there was also no defined criteria established for that. Therefore, the routine specifications were abandoned. It was considered that if the operator would follow the storage layout and support to the packages established daily, he would be, indirectly, following a systematized routine on each cycle.

To finalize the work design, specifications relative to the internal operations flow for each work package were missing. The first decision was to define in which sequence each element of the package should be executed; as for instance, by which sequence should the steel or formwork of several columns be assembled. Researchers thought that the sequence would help to reduce the work force displacements and give priority to the work completion in smaller batches. However, the engineer of the first case study was against the specification of the sequence, arguing that it would be a strict rule, making the workers 'operation more difficult. On the second case study, the sequence definition was accepted for the columns related packages only.

There were no investigations on key-points. There remained the definitions on the monitoring points to help the team keeping control on compliance with the takt time. As there was no data for the duration of each package, it was assigned to a work shift (morning or afternoon). In this case, the completion of packages on time should represent a reference to monitor the production speed. Additionally, there were key dates for partial completion along the cycle.

WORK DESIGN TEST

When the work design was completed, one of the researchers provided one day training to the workers team. Another observation period of the construction site was then started to check the relevance of the specifications. There was an initial interest from the workers in checking the specifications of the work design. On several later occasions, the specifications was not followed, with changes mainly in the size of the packages defined, as the workers tended to perform the same operation for the whole floor, instead of focusing on smaller batches as had been defined. One of the main reasons for the lack of adherence in two case studies was the poor involvement of the engineers in the work design implementation. There was an overload of work on the crane and a high number of requests for transport out of the floor, which affected the supplying process and caused waiting periods for the workers. The specifications of the storage layout were not followed by the crane operator, who stated that he was confused in relation to the documents. Regarding the use of transport means, workers related ergonomic unfavourable conditions during loading and unloading of materials, although they reacted positively in relation to the larger quantities of resources transported on each lifting.

Concerning the packages executed, approximately 43% had longer durations (work shift) than those foreseen in the project. However, there was not a single day during the observation period in which the team was complete, due to workers absenteeism. The key date for concreting the columns was accomplished in 60% of the cycles, while the key date for the slab concreting was never fulfilled.

CONCLUSION

In view of the objectives of this article, we should point out the difficulties encountered in drawing up the work design for concrete structures:

a) Limited contribution from engineers. The specification of operations required observations of the first completed cycles to obtain information. Additionally, there was no effective incentive of the engineers in the work design test. This situation caused the FRS abortion.

b) Strategic decisions for the construction site were already taken, imposing constrains on the floor's workflow.

c) Workers team unaware of lean concepts and standards contents, and only modestly participating in the decisions.

d) Difficulties in applying the concept of small-batches production due to the lack of understanding of this concept by engineers and team leaders.

e) Lack of data on the production capacity of the teams to assist in the sizing of work packages.

f) Underutilisation of crane capacity causes overload in the use of this equipment imposing difficulties to establish a routine.

g) Difficulty in organizing the supply of material resources, without ever reaching a specification truly capable of supplying the floor in due time and quantity.

In addition, while using the work design, 43% of the packages had duration longer than expected. However, the results do not lead to the conclusion that the cause was the wrong sizing of packages (durations estimated by the experience of the leaders) or was a consequence of changes in the team size during the execution.

Another difficulty appeared when the set cycle time had an odd number, of 7 days. The floor area was divided into two nearly equal parts, having very similar work volume, however, one of the parts had to be completed with one day less of work.

The preparation of the work design took months, requiring observations and various meetings, which means that the first floors were completed without providing workers with clear rules. After this initial period it became more difficult to intervene and change the working method.

The construction site had many unstable conditions that hindered the inclusion of a standard. The number of workers in teams never remained constant, and the supply of materials depending on the crane did not have an organized schedule of arrival. Additionally, the concreting of beams in the production centre was not following a formal schedule. The workers were not encouraged to understand the benefits of working in a standardized way, nor were satisfactorily informed on the concepts involved in standardization.

It is not possible to consider that the work design developed was solved in such a way as to become a standard for production, requiring further investigation and refinement of specifications. It is important to deepen studies on organization, transport, and storage of materials on the work area, since the work design failed to stabilize the supply of resources. A deeper insight would also be valid on how to specify operations routine for the crane, as there is an extensive reliance on this equipment on the floors and this research has not made progress on this specification. The difficulties faced during work design development in this study must be considered in further researches in order to propose a model to conceptualise the work design. This could help to speed up the process of specifying the work design and the standard work improvement.

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EXPLORING THE FACTORS THAT INFLUENCE THE IMPLEMENTATION OF THE LAST PLANNER® SYSTEM ON JOINT VENTURE INFRASTRUCTURE PROJECTS: A CASE STUDY APPROACH

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• ABSTRACT

There has been an increase in the use of joint venture (JV) especially in the delivery of infrastructure projects. There is also great pressure from the public sector clients for the use of lean techniques such as the Last Planner System (LPS) in the delivery of infrastructure projects in the UK for more certainty in delivery. Previous studies have explored factors that influence LPS implementation under various contracting structures and project types. However, no much study has explored the factors that influence LPS implementation on highways infrastructure project under JV contracting structure. In view of this, the study explored the factors that influence LPS implementation on JV highways infrastructure projects in the UK. Two in-depth JV case study projects on highways infrastructure construction were conducted over a 12 month period. Data was obtained via: document analysis, physical observation and semi-structured interviews. The study reveals that the early inclusion of the LPS practice in the contract and the long term relationship that existed among the supply chains and the main contractors in the JV were among the factors that supported the process. The study established that the JV platform and the LPS implementation synergise each other on the project. Poor promising was identified among the major blockers to LPS implementation on the projects. To overcome this, the study recommends that the five key elements of reliable promising identified should be adopted when implementing LPS on projects.

KEYWORDS

Last Planner System, collaborative contract, joint venture, highways infrastructure, success factor.

INTRODUCTION

Very limited studies have been conducted to examine JV practice in construction (Sillars, 2003). Project based JV in construction is a mechanism that brings two or more

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organisations to work together in order to deliver client's expectation or to out-perform likely competitors (Sillar, 2003; Smith, 1994). The aim of such partnership is to share risk, utilise skill, knowledge and resources of each partner in the JV (Smith, 1994). In the UK, there is an increasing use of JV especially in the delivery of infrastructure projects because of the risk involved and the skills required in the execution. There is also great pressure from public sector clients for the use of lean techniques such as the LPS (or collaborative planning in the UK) in the delivery of infrastructure projects for better project performance in the UK (Pasquire *et al*, 2015).

The LPS is a production planning and control approach that focuses on reducing workflow uncertainty which has been identified as a missing component in the traditional project management kit (Ballard and Howell, 2003). Its implementation in construction is growing and recent studies indicate that it has been implemented in sixteen countries and in all the major continents of the world (Daniel *et al*, 2015). Studies have explored LPS implementation under various contracting structure such as; Integrated Project Delivery (Cheng *et al*, 2011; Hamzeh *et al*, 2009), Integrated Form of Contract (Hamzeh *et al*, 2009) and Lean Project Delivery System (Yong-Woo, 2009; Ballard, 2008). However, no much study has explored the factors that influence the implementation of the LPS on infrastructure project under the growing practice of JV contracting structure, especially in the UK. The research question therefore is; *what are the factors that influence the implementation of the LPS on JV infrastructure construction projects in the UK?*

Previous studies reported high failure rate of between 45-50% on JV projects (Allen *et al*, 2013; Beamish, 1998). However, the LPS has the potential to reduce such risk because of its capacity to engender collaboration and improve certainty of delivery. A clear identification of the factors for successful implementation of the LPS, its blockers, and strategies to overcome them on JV projects evidenced in this study, provides a contribution to future practice of production planning and control practice in the construction industry and on JV highways infrastructure projects in particular.

LITERATURE REVIEW

LAST PLANNER SYSTEM IMPLEMENTATION ON CONSTRUCTION PROJECTS

The LPS is a lean construction technique developed by construction industry practitioners for managing Architecture and Engineering Construction since the early 90's (Daniel *et al*, 2015; Ballard and Howell, 1998). A review of published papers on LPS implementation between 1993 and 2014, obtained from the international group for lean construction (IGLC) database reveals that the LPS has been implemented on over 56 construction projects across the major continents of the world (Daniel et al, 2015). These include building construction, heavy civil engineering construction, highway infrastructure projects, ship building, and pit mining. This indicates that the implementation of the LPS in construction is on the increase.

Fernandez-Solis *et al* (2012); Porwal *et al*, (2010) summarised the benefits and challenges associated with the implementation across the projects studied. Their studies identified barriers and challenges to LPS implementation on construction projects. Some of the challenges includes; lack of commitment to LPS implementation, partial implementation, contracting and legal structure, lack of management support, and resistance to change among others. The identification of contracting structure as barrier to LPS implementation cannot be overlooked, considering the crucial role contract plays in the execution of construction projects. In recent times, collaborative or relational contracting structures are now incorporated into the implementation of lean principles. These include: Integrated Project Delivery, Lean Project Delivery System, Integrated Form of Agreement, and Target Value Design among others (Cheng *et al*; 2012; Yong-Woo, 2009). Evidence from literature shows that the LPS has been implemented under various contracting structures; while some are collaborative, some are not. Little or no study has explored and reported how LPS works on JV highways infrastructure projects.

JV AND LPS IMPLEMENTATION ON INFRASTRUCTURE IN THE UK

There is a global increase in demand for infrastructure projects across the globe. McNichol, (2014) reported that the current global demand for infrastructure is $4 trillion annually. JV is among the current approaches used in the delivery of infrastructure projects. This could be due to the complex and critical nature of infrastructure projects. Ideally, the purpose of a JV is to enable the companies involved to achieve the common goal of the project, with all having shared ownership and control, while utilising the strengths of one another (Smith, 1994). However, this is not always the situation, as there are several reported cases of failed JV projects. For example, EC Harris' report, in 2013 reveals that one in five JV projects in the UK resulted in formal disputes between the parties in the JV (Allen *et al*, 2013). Mason, (2013) conclude that this is due to lack of clear communication among the parties in the JV.

Again, this shows that JV itself would not naturally bring about collaboration among the team at the project level. It further magnifies the need to deploy a system that has the potential to support the development of collaborative relationship such as the LPS, in managing the project production system with such contracting structure. The LPS implementation on JV projects has the potential to improve collaborative relationship at the project level, and could also influence the behaviour at the organisational level. In the UK, it could be argued that the push from public sector clients on their supply chains to adopt LPS in the delivery of infrastructure project could be due to this understanding.

RESEARCH METHOD

An interpretive case study approach was adopted for the study. Yin, (2014) identified conditions that should inform the choice of a case study approach. These include: when the goal of the study is not to have full control over the phenomenon being investigated and when the goal of the study is to focus on real life situations in a given context. Thus, case study approach was adopted to explore and understand the factors that influence the implementation of the LPS on highways infrastructure projects under JV contracting structure. To overcome the issue of lack of rigour in case study approach, multiple techniques were used in collecting data from the two case studies investigated as suggested in Yin (2014). The techniques used include; semi-structured interview, document analysis and unstructured observation.

The study commenced with literature review. The purpose of this was to understand the implementation of LPS in construction and its underlying principles. In selecting the case study projects, various factors associated with case study design as suggested in Yin, (2014); Bryman, (2014) were adhered to. Two case projects were selected from top 10 UK construction companies. Purposive sampling was used in selecting the case projects; this was done to enable the study answer the questions sufficiently (Bryman, 2014). The case studies were conducted over a 12 months period. On each of the projects, data was collected using three major approaches for deepening and authenticating the results (Yin, 2014). These enabled further clarification on findings from the unstructured observation and documents analysis. The physical environment observed include: production planning and control meetings sessions and production planning and control centres. On each case study, senior manager (SM), middle manager (MM), operational managers (OP), and subcontractors (SC) were interviewed. A total of 21 interviews were conducted and production planning and control documents were also analysed.

The interviews were transcribed verbatim and cross checked with findings from documents analysis and observation. In doing this, the data was categorised based on qualitative data analysis techniques as suggested by Bryman (2014). The data analysis process was supported using computer aided qualitative data analysis software known as 'NVivo'. According to Bryman, (2012) 'NVivo' software does not only manage large data sets, it also supports transparency, replicability, and validation of qualitative data. The 'model' tool in NVivo 10 was used to analyse and present the emerging themes and sub-themes from the study. The findings are presented and discussed hereafter.

• ANALYSIS, RESULT AND DISCUSSION

• CASE STUDY ATTRIBUTES

Table 1 reveals the case studies attributes. CSP01 is an upgrade to replace a dual carriageway with a three lane motorway. The project is segmented into three sections (north, south, and central). CSP01 comprises of two top UK contractors in a JV

Table 1: Case Study Project Attributes

Project Attributes	CSP01	CSP02
Nature of project	Highways and Infrastructure	Highways and Infrastructure
Nature of works	Upgrade to replace existing dual carriage way with three new lanes	Improvement of motorway to Smart motorway
Mode of contractor selection	Framework agreement and ECI	Framework agreement
Proposed project duration	30 months	24 months
Project delivery structure	Joint venture (D&B)	Joint Venture (Design bid and build
Contract sum	£380 million	£120 million
LPS facilitation process	Internally facilitated	Internally facilitated

Both contractors have a long history and expertise in the delivery of construction and engineering projects. However, one of the contractors has a strong record in the delivery of mega highways infrastructure projects with sustainable approaches. The JV was formed to benefit from this, due to the scale and critical nature of the project.
Similarly, CSP02 JV comprises two top UK contractors. The project is an improvement of an existing motorway to a smart motorway. One of the contractors on CSP02 has expertise in transforming roads into intelligent network using technology. The second

contractor has good record of successful delivery of highways infrastructure projects. The JV was formed to build on this skills and expertise from the different organisations.

- **DEMOGRAPHIC INFORMATION OF RESEARCH PARTICIPANTS**

The interviewees comprise of 8 SMs, 4 MMs, 5 OMs, and 4 SCs. These shows all the key stakeholders were involved in the interviews; however, the number interviewed varied across the projects. The least response is from the subcontractors. Some of the subcontractors were reluctant to participate in the study, although they were also constrained by their work schedule. This is part of the limitation of this study. All the respondents have some level of experience and knowledge on the application of LPS principles in construction. This means their responses could be relied on.

- **SUCCESS FACTORS FOR LPS IMPLEMENTATION ON JOINT VENTURE**

The factors for successful implementation of LPS on JV infrastructure identified below are from the analysis of the semi-structured interviews, the document analysis, and the observation of the physical environments.

#1 Reduced Batch Size

The study reveals that the batching of the projects into segments supports the implementation of the LPS on the highways infrastructure project. This was observed on both projects. On CSP01, the project was batched into three segments: the north section, south section and central section. While CSP02 was batched into two sections: north bound and south bound. The division could be due to the linear and extended nature of the road network. However, it supported the implementation of the LPS on the project. For instance, on CSP01, a production planning and control centre was created for each section, with each running meetings with support from the central facilitating team. It is worth noting that problems inbetween sections are centrally addressed at the weekly senior management meeting. On CSP02, though the project was also batched into segments, only one production planning and control centre was provided. It is worth noting that the length of the road network on CSP02 is shorter compared to that of CSP01.

- **#2 Inclusion of LPS practice in the Contract**

On the projects investigated, LPS practice was formally included in the contract agreement between the main contractor, client, and subcontractors. A senior manager on CSP01 stated that: “We have agreed with the client and our supply chains that LPS will be used on this project and we use it on our other project too” [Operational Manager]. Similarly, a subcontractor on CSP02 stated that: “It is part of the main contractor’s policy, so if we do not want to do it, we can’t go away with it. My signing into it in the contract, supports my commitment to it, and it benefits us as subcontractors” [Subcontractor’s, Senior Site Manager]. Most of the respondents identified the role of the inclusion of the LPS approach in the delivery of the project. Doing this is essential, as it would make it a formal process on the project, thus encouraging more commitment to the process. It would also encourage the required stakeholders to get engaged in the process. This is important, as it was observed in a previous study, that subcontractors were not involved in production planning meetings on a project that claimed to be managed with LPS (Pasquire *et al*., 2015). Furthermore, construction is filled with many formal processes (Kadefors, 2004), which sometime may not even support the goal of the project. However, the goal of LPS is to engender collaboration among the project team, while focusing the team to achieve the common goal of the project (Ballard and Howell, 2004). According to Kadefors (2004), formalisation of construction process should not be in relation to cost alone, but should include other practices that would support the actualisation of the project goal. The LPS could be considered to be among such practices or processes.

- **#3 Use of Collaborative Form of Contract and Long Term Relationship Focus**

Empirical evidence from observation and document analysis in this study reveals that collaborative form of contract was used on the projects. This includes, Framework agreement, ECI and D&B. The study reveals that even when DBB (e.g. CSP02) is used on a project, and the supply chains have a framework agreement, collaborative relationship still develops. The contractual behaviour that occurs here could be better explained with relational contracting theory. According to Macneil, (1980) as parties to the contract have more and frequent conversations on the project, improved relationship begins to develop. Also, the clear assurance of the possibility of securing a future job, for example, in framework agreement, could motivate the team to get committed on the project. Harper, (2014) asserts that when there is shared expectation between teams on a project, it influences their behaviour on the project. This suggests that contractual behaviour has the potential of supporting collaboration on a project. Also, the two main contractors on CSP02 and the supply chains have delivered similar projects using LPS; this contributed to the implementation of LPS on the JV project.

- **#4 Training and Creation of Awareness**

Majority of the respondents, including subcontractors and main contractors, identified the need for provision of training. For instance, some respondents stated that: “There is need for guidance on LPS right from conception by the management; we do receive some training on LPS” [CSP02SC01, Project Manager] and “training is very essential, without it, the facilitation would not have worked on this project” [CSP02SM01, Programme Manager]. A senior manager suggested that the nature of training on the LPS to be provided should be tailored for each stakeholder on the project. For instance, it was argued that the initial training for the smaller subcontractor should be to explain the benefits of the process in order to get their buy-in before full implementation. Also, a senior manager stated that “for an organisation that is venturing into it, trainings and demonstration of tangible benefits from previous implementation is important” [CSP01SM01, Planning Manager]. Previous studies (such as Porwal *et al*, 2010; Hamzeh *et al*, 2009) have also identified the importance of training in the implementation of LPS. LPS awareness on CSP01 was through training workshops and monthly project briefing by the JV project director. This show there was also top management support.

- **#5 Appointment of Facilitators and Lean Champions**

The study reveals that the appointment of facilitators and lean champions contributes to LPS implementation on the JV project. A respondent stated that: “The appointment of lean champion and facilitators, promotes the practice across the business” [CSP02SM01, Programme Manager]. Also, on CSP01, the respondents believe that a facilitator supports the implementation process. One respondent said "A facilitator is needed to coordinate the process for the initial start; this is an early stage support" [CSP01MM02, Section Engineer]. This is because the process cannot really progress if not duly facilitated, as observed in the South section on CSP01. This is crucial as the process would not progress if there are no capable and experienced personnel to man the process. On both case study projects, the process was internally facilitated. Although on CSP01, it was argued that after the initial facilitation, the process should be left with the team. As good as this may seem, it could lead to the abandonment of the entire process as each member of the team has a specific role to perform on the project. On both projects, LPS facilitation was the primary responsibility of the facilitators which yielded better results. Leaving the process to the team will make no one accountable. The role of LPS facilitators and lean champions in implementing a new process has been identified (Mossman, 2015).

- **#6 Provision of Physical Space and Co-location of the Team**

The study reveals that the provision of designated space for production planning and control and co-location of the team supports the implementation of the LPS. A contractor stated that: "Allow for a suitable rooms/facility on site for production planning and control" [CSP01SC02, Project Manager]. It was observed on both case studies that designated spaces provided for production planning and control were also close to the work station. The physical space created includes those for working and visual production planning and control centre. This is essential, as the board located in the room has the potential of communicating information visually to the team during and out of meeting times. However, such locations should be readily accessible to all the required stakeholders on the project including the subcontractors. It should also be located close to work station to prevent non-value adding activities that could come from unnecessary movement. The team were co-located in the physical space provided on CSP01 and CSP02 which further improves the level of communication among them, including the subcontractors. It has been observed that face to face communication is one of the most active ways to communicate on construction projects (Dainty, 2007). However, a co-located team without a mind-set change would not contribute to the development of collaborative relationship as demonstrated by the design team on CSP01.

#7 **Team Integration and Less Parent Company Identity**

The study reveals that various practical approaches were adopted on both CSP01 and CSP02 that supported the integration of the team. The teams on the JV projects viewed themselves as a single entity. This implies that all members of staff on the project have to ignore their original company culture or identity in performing their responsibility on the project and create a shared culture. However, whether the target was achieved on CSP01 and CSP02 still remain unanswered. One of the strategies adopted to reduce parent company culture and integration of the team was; the recruitment of some staff directly on the JV, hence, such staff only had one identity at the time. For instance, the LPS facilitator on CSP02 was employed on the JV project. Other strategies used include, shared spaces and offices, email addresses, and every facilities used were purpose made in the name of the JV. All this could reduce the influence of the parent company culture, which could support the integration of the team in the LPS implementation. According to Smith, (1994) for a JV to work successfully, there is a need to make provision for cultural compatibility, shared ownership, and joint control.

- **BLOCKERS TO LAST PLANNER SYSTEM IMPLEMENTATION ON JV**

The study reveals various blockers to the LPS implementation on the JV projects. These include: (1) poor promising (2) culture of old thinking and attitude among middle managers (3) lack of discipline and trust (4) resistance through procurement. While most of the barriers identified in this study are similar to those identified from previous studies (Fernandez-Solis *et al*, 2012; Porwal *et al*, 2010), the issue of poor promising seems to be obvious in this study. "Poor promising" here entails making commitments that are not sound, it could be under or over commitment. This issue was raised on CSP01 and CSP02. One respondent stated that: "one of the biggest things during the production planning meeting is people not telling the truth, you got to be honest with yourself and members of the team, it is no use to say, I will finish the work today while you know you still need 3 or more days. It is no good to say I will do it next week and you know you have not got the men to do" [CSP02SM01, Programme Manager]. Also, on CSP02 some of the subcontractors stated that: "Some subcontractors agree dates knowing they cannot achieve it!!!" [Subcontractor's, Senior Site Manager]. "The process is fine; one of the barriers is people committing to things they cannot do and also unrealistic expectation from the main contractor" [Subcontractor's, Contract Manager].

The statements above highlight why stakeholders at the project level should not be pressurised into making promises or commitments as it could turn out to be unrealistic sometimes. In the LPS, workflow reliability is achieved via reliable promising (Macomber and Howell, 2001). Macomber and Howell, (2001) identified five elements in making a reliable promise among project stakeholders. These are: (1) understanding the condition for satisfaction (2) competency to perform the task (3) capacity to perform the task (4) sincerity (trust among team) and (5) commitment to clean the mess, if failing. This clearly suggests that in making promises during LPS implementation, the team must be transparent and sincere that the needed capacity is available.

- **CONCLUSIONS**

The aim of this study is to understand the factors that influence the implementation of the LPS on highways infrastructure projects under JV contracting structure. The study identified seven factors that support the implementations of the LPS. The study found that the use of JV platform on the projects support the implementation of LPS and the implementation of the LPS equally supports the activities of the team members in the JV. While the JV created the initial collaborative platform and the framing of the LPS into the contract which supports team members' commitment to the implementation; the implementation of the LPS components improved the level of communication among the different stakeholders in the JV.This shows that the JV platform and the LPS implementation synergise each other on the project. The study established that the use of some form of collaborative contract such as; early contractor involvement, framework agreement that supports long term relationships and the framing of LPS into the contract were among the major aspects of the JV that enabled LPS implementation.

The study identified four major blockers to LPS implementations on JV infrastructure projects. These blockers include: poor promising, culture of old thinking and attitude, lack of discipline and trust, and resistance through procurement. A closer look at the above barriers shows that they are behaviour related rather than process. This shows that people and human behaviour still remain the major barriers to LPS implementation irrespective of the contracting structure. Although the blockers to LPS implementation on the JV highways infrastructure project are not entirely different from those identified in previous studies, the issue of poor promising seem to be very prominent in this study. To overcome the problem, the study suggests that the five key elements of reliable promising identified in Macomber and Howell, (2001) should be adopted. This study is limited to the two case studies in the UK

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THE FIRST EXTENSIVE IMPLEMENTATION OF LEAN AND LPS IN LEBANON: RESULTS AND REFLECTIONS

Farook Hamzeh[1], Jessica Kallassy[2], Marvin Lahoud[3], and Ralph Azar[4]

ABSTRACT

Lean construction as a philosophy and set of tools has been successfully implemented in construction to reduce waste and improve customer value. The Last Planner System (LPS) has enriched the construction industry with a production and planning system that aims at improving the reliability of construction planning and workflow. However, several developing countries have not started implementing lean construction or LPS. This paper presents a reflection on the first implementation of lean principles in general and the LPS in particular on a large scale project in Lebanon. The study employs case-study analysis to investigate the implementation process by the General Contractor's team as well as the various subcontractors. Results highlight the team's satisfaction despite the several challenges faced. Improvements to the reliability of planning and project's progress are clearly presented through a longitudinal cross section of the main key performance indicators measured on the project. The paper also highlights the major barriers faced during implementation. This study serves as a reflection process for the general contracting company implementing lean and LPS while forming a basis for future implementations in Lebanon and the Middle East.

KEYWORDS

Lean Construction, implementation, Last Planner System, production planning and control.

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INTRODUCTION AND LITERATURE REVIEW

Lean construction (LC) as a philosophy and a set of principles was introduced in construction to maximize customers' value through waste reduction and continuous improvement (Koskela, 1992). The literature is rich in case studies describing the successful implementation of LC on real projects. Garnett et al. (1998) reported a 25% reduction in construction time, an increase in client satisfaction, and a decrease in the overall project cost. Conte (2001) showed that the project construction time was reduced by 20% to 30% and cost was reduced by 5% to 12%.

The Last Planner System (LPS) is one of the tools used in LC to increase reliability of planning and workflow (Ballard & Howell, 2004). It is a production planning and control system used to reduce variability and uncertainty in construction. (Ballard & Howell, 1994). The LPS includes four levels of planning steps: master scheduling, phase scheduling, lookahead planning, and commitment planning. The main goals of LPS are: (1) planning the tasks in detail as soon as they near execution, (2) involving the people who are going to perform the work in the planning, (3) identifying and removing constraints ahead of time in order to clear the path for the execution team, (4) coordinating between team parties and trade partners in order to make reliable promises to execute the planned work, and (5) identifying the root causes of the problems and learning from failures to continuously improve (Ballard et al., 2007, Hamzeh et al. 2015)

Despite the benefits displayed, several companies struggle to successfully implement LC and face a number of barriers during implementation (Wandahl, 2014). Organizations need to address several change management issues related to their current processes as well as their cultural realities when implementing LC. Starting the shift towards lean thinking, the organization must first create a sense of urgency (Hamzeh, 2011). An urgency to change, whether through continuous improvement or a sense of competition. People, in general, do not like to change and prefer to stick to old habits by maintaining routine and stability (Zammuto & Krackower, 1991).

A successful implementation requires lean champions who understand lean principles and the philosophy behind them. Those leaders need to motivate people to adopt lean principles, to redirect them from the safety of traditional methods, and to resist any attempts to dilute lean principles (Raghvan et. al, 2014; Howell and Ballard, 1998). On top of that, the champions themselves need to be fully engaged with the system and taking part in implementation for the system to succeed. (Garnett et al., 1998)

Wandahl (2014) studied the major barriers behind implementing LC by surveying several papers published in the IGLC conference and found out that the major barriers are: lack of communication, lack of top management commitment, lack of knowledge, lack of leadership, lack of training, and most importantly cultural resistance to change. Kenny and Florida (1993) confirm that lean success is heavily reliant on culture

An important cultural change is having a 'no blame' environment. This is crucial when teams start learning from failures to continuously improve. Moreover, people must trust each other to start exercising reliable promises (Seymour, 1998). Therefore, companies must focus on changing the behaviors of people rather than just focusing on implementing the tools (Liker, 2004; Kalsaas et al., 2009).

There has been a slow adoption of LC in the Middle East (ME). AlSehaimi et al. (2009) present an LPS implementation in the ME and Rached et al. (2014) discuss barriers for implementing integrated project delivery in the ME. Both studies report a variety of barriers related to culture, lack of teamwork, short term vision, and lack of knowledge in LC as implementation barriers. Some aspects of lean and LPS were investigated in Lebanon where Jazzar & Hamzeh (2015) present LPS metrics in shelter rehabilitation projects, Hamzeh et al. (2012) study improvisation in planning, and Yassine et al. (2014) tackle takt-time planning in construction to improve work flow. However, none of these studies address a formal implementation of lean and LPS. In this context, this paper presents a reflection on the first implementation of lean principles and LPS in Lebanon. The paper describes the journey towards the first LC implementation, research methods used, results from case study research, discussion of the results, and conclusions.

THE JOURNEY TOWARDS LEAN

This paper describes the journey of a leading construction company in Lebanon and the Middle East region as it is implementing, for the first time, LC and the Last Planner System on a large and prestigious construction project in Lebanon.

Since its founding date in 1971, the company delivered a wide variety of projects in the residential, commercial, educational, and industrial sectors in Lebanon and around the Middle East region. Prior to implementing LC and LPS in the company, projects' planning was handled by the planning department as a silo cell and was considered a specialty that doesn't concern much other departments. Planners would send out emails or print out schedules on a weekly or fortnightly basis indicating the dates that they want other departments or projects to adhere to. The planning process was not collaborative.

The planning cycle in the construction company would start by performing work on site for a given week based on what each team believes they can do, given the available resources and the cleared activities at that point in time. A schedule update is performed by the planning department after incorporating the actual progress. The updated results and floats are then sent back to the site and to the client as an after-the fact reporting. For a number of employees, scheduling had only one purpose, which is to satisfy the contract requirements. To most, it wasn't essential to plan the work on site; doing the best they can do considering the current constraints seemed like the wisest course of action to them.

Realizing the shortcomings of this planning method and recognizing that no project was delivered as promised in the past 10 years, the company established a team of operation engineers to map the current processes, critique them and identify adequate operational improvements to implement on construction sites. Before researching any new system, the newly-founded team agreed that the desired system needs to meet two main goals: 1) involve every employee in active planning, and 2) create a culture of making and meeting promises. Once the company's planning goals were defined, the team came across LPS in their research and realized that this new system will meet their requirements and reach the desired goals if implemented correctly.

The project in which the implementation took place is a shopping mall located in Beirut, Lebanon, with a total built up area of 150,000 square meters. The project began in 2015 and is expected to finish in 2017. Results of this study will highlight the improvements seen on site as well as the major barriers faced during implementation.

METHODOLOGY

The paper employs case-study analysis as it allows strong evidence collection, description and observation. It also answers questions related to "how" and "why" where no control for behavioral events is required (Yin, 2003).

The lean champions were recording on a weekly basis the outputs of safety, time, cost, productivity, and quality. The causes of delays were monitored as well. Several key performance indicators related to LPS were recorded as a longitudinal section (through time) including: Percent Plan Complete (PPC), target productivity attainment, target quality attainment, and safety adherence score. Other indicators were also tabulated such as: PPC by each Last Planner, root cause of delays, constraint identification, and constraint resolution. Results are presented in the next section along with a discussion of the improvements seen, the challenges faced, as well as suggestions for further improvements.

RESULTS AND DISCUSSIONS

Implementation started with communicating a new philosophy; creating a sense of urgency, presenting a viable solution, and inspiring a buy-in into the local team. The lean champions introduced LPS concepts as well as the key performance indicators that will be measured on site. The lean principles were printed and posted in the meeting room, relabeled as "the war room", for the teams to get familiar with the new system. Although teams were hesitant and resisting the change at first, they started to see improvements after several meetings and got more motivated to implement the LPS. This is confirmed by the feedback of the implementing team. A section engineer comments: "This system is very useful … I believe that the most important part is how we are dealing with constraints, planning their resolution and learning from the historical records". The project director said: "This new system ensures proper and continual communication between all project team members and therefore improves teamwork, which represents the biggest challenge on large construction projects; it also increases transparency."

Starting from a master schedule, the company developed an internal excel program that enabled every employee to develop their own lookahead (LA) plans. Weekly work plans are based on LA schedules and daily huddles are conducted to review, plan and adjust the plan for the day. During the weekly meetings held on site, key performance indicators related to LPS were measured and posted on a dashboard accessible to all. These include: Percent Plan Complete (PPC), individual Last Planner's PPC, productivity, quality, safety, root cause of delays, and constraint resolution. Figure 1 shows a photo of a weekly meeting held on site and the "War Room" setup. Figure 2 shows some of the indicators mentioned. Although the LPS was introduced one year into the construction phase, several improvements ensued soon after introducing the new system.

First, visualization has increased since the key performance indicators were posted on the dashboard. The site team was glad to see their weekly updated results and liked the transparency of the system. Second, all the engineers and foremen agreed that the communication has enhanced. In a typical weekly meeting, the team members review last week's performance, discuss the constraints faced, plan work for the coming week, and collaboratively work on eliminating constraints beforehand. Hence, they are able to visualize where they stand and what they are willing to achieve in the coming week. Moreover, the last planners were heavily involved in the planning process by collaborating with the responsible engineers for each zone to agree on the tasks they are willing to achieve for the coming week

Figure 1: Onsite weekly meeting and the “War Room” Setup

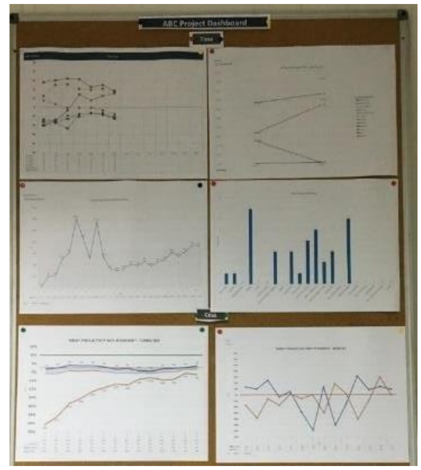

Figure 2: Weekly key performance indicators posted on dashboard

A site foreman said: “This new system created in us a sense of empowerment and accountability which significantly boosted our motivation”. PPC for each last planner was recorded to track reliable promising. Figure 3 shows the weekly PPC for the whole project and Figure 4 shows the last planners’ PPC for a specific week. Third, the team aimed to relate safety, quality, time and cost similar to the objectives of the Toyota Production System (TPS). Quality management indicators were measured to track quality related results. Figure 5 shows the quality inspection approval rate on the project, as one of the quality management indicators employed.

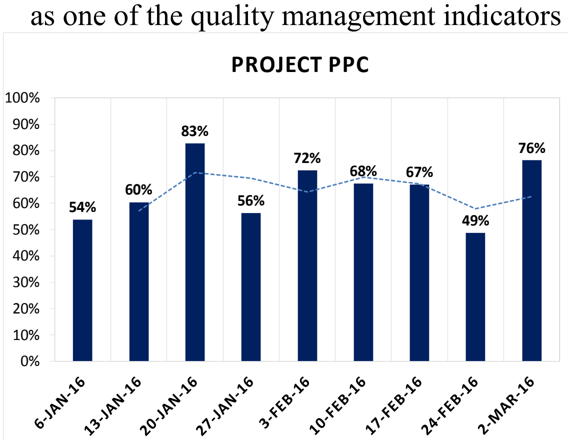

Figure 3: PPC calculations for the project as a whole

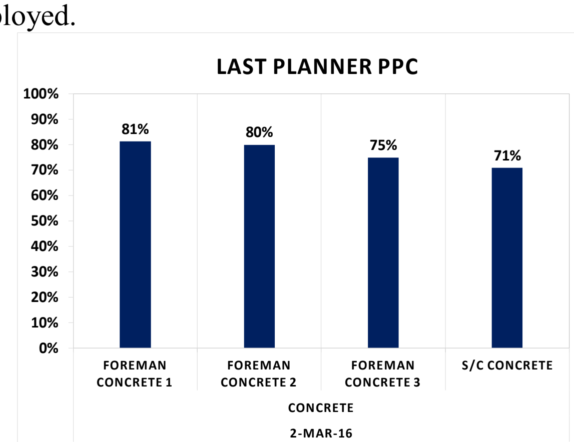

Figure 4: Weekly PPC attainment by last planner

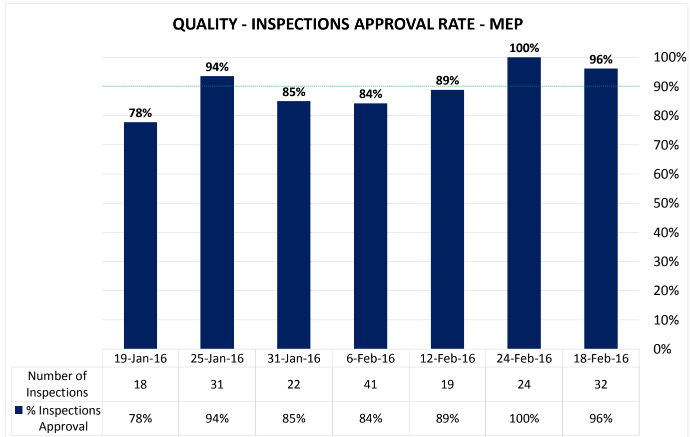

Figure 5: Quality - Inspections Approval Rate

Despite the improvements shown on site, the company encountered several challenges during implementation. Table 1 summarizes the major improvements, challenges and suggestions for various LC related methods employed on the project. One of the challenges faced was eliminating the root causes of delays or planning failures. Although the teams were aware of the root causes of the problems, most of them were recurring. Figure 6 shows the cumulative root causes of delays within various categories since the kick-off of the new system. It is recommended that the teams apply the 5 why's process, learn from failures, and try to avoid their reoccurrence in order to continuously improve.

As for constraints analysis, Figure 7 shows the weekly number of constraints identified and their resolution status. It clearly shows that most constraints were not removed. For better implementation, constraints should be identified with a certain lead time beforehand so they can be removed in time prior to execution. Furthermore, some employees felt that this new implementation brings extra work and hence they were resisting the shift to the new system. Additional training on the benefits of LC and LPS may help since practitioners are implementing the tools without fully understanding the philosophy behind them.

The company should focus on cultivating lean behaviors in its people company-wide and not just focusing on implementing the tools (Liker, 2004; Kalsaas et al., 2009). Moreover, an incomplete implementation of LC and the LPS will not reap the full benefits of an improved planning and control system (Wandahl, 2014). Since the LPS was implemented one year into the construction phase, the master schedule had been already developed by the planning department. This resulted in finding tasks with wrong time estimates or even wrong predecessors during the weekly meetings. That's why collaborative planning should have been implemented prior to commencing the project execution. Last planners and subcontractors have more experience in methods to perform work on site and can find better ways for execution reducing time and cost.

Table 1: Areas of implementation including improvements, challenges and suggestions

Areas	Improvements	Challenges	Suggestions
Planning	● Lower level players are involved in planning ● Teams discuss and coordinate their weekly work plans ● The Last Planners are responsible for their promises	● Uneven levels of involvement of engineers and foremen in the LPS planning process	● Involve all foremen in the planning process
Percent Plan Complete (PPC)	● Communication is enhanced between team members. The teams discuss the tasks completed versus those planned, and plan the work for the coming week(s) ● The teams analyze the constraints and try to find solution to improve the PPC	● The original master schedule was not developed collaboratively	● Apply LPS from project outset ● Develop all plans collaboratively ● Involve the client in the collaborative planning process
Root Causes of delays	● Causes of delay are investigated ● Teams are aware of them	● Failures are repeated ● Slow learnings from failures	● Apply the “five why’s” process ● Remove the causes collaboratively
Quality	● Quality management indices are tracked	● Client representatives are not involved	● Involve the client representatives in the process
Safety	● Improved compliance to safety guidelines ● Enhanced site safety performance ● Teams with high safety performance are recognized	● Ownership of safety performance is mostly given to team leaders	● Task hazard analysis to be part of the LPS ● Developing a risk assessment manual ● Involving workers in hazard identification & mitigation
Cost	● Productivity indices are tracked, reviewed and discussed with all supervisory levels on a weekly basis ● Root causes are investigated, and lessons learnt are communicated	● Cost / Productivity rates for the subcontracted finishing activities is harder to impact	● Improving the Involvement of the Subcontractors in the Cost/Productivity monitoring process
The project as a whole	● An increased transparency, visualization and collaboration ● Key Performance Indicators are updated, posted on the dashboard, and discussed on a weekly basis	● The philosophy behind LC tools is not yet clear to all ● There are uneven levels of understanding of the LC tools	● Train all employees on LC and LPS ● Employ location based management ● Increase the involvement of stakeholders

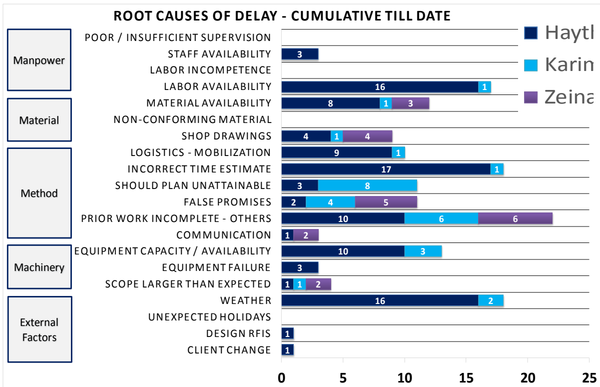

Figure 6: Root Causes of Delay – Cumulative till date

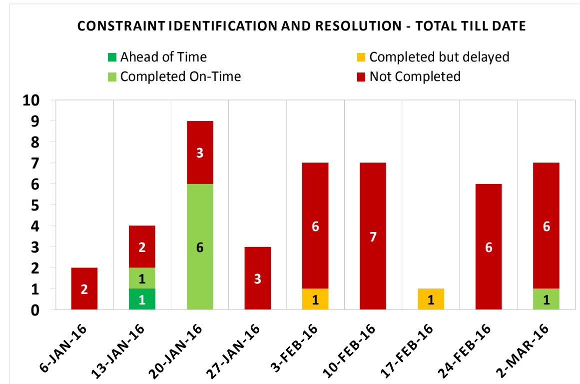

Figure 7: Number of Constraints Identified per week and their Resolution Status

Furthermore, location based management can be used in conjunction with the LPS to improve construction workflow and reduce task conflicts. The project team have heavily used precast concrete elements to speed-up the construction process. And since the project covers around 18,000 square meters of foot print area with several zones, lay down areas, cranes coverages, and precast unit sizes, employing location based management along with the LPS would have improved the overall workflow and reduced process waste.

Safety was given a huge focus by the team. Team leaders were in charge of enhancing their safety performance metrics within their zones. Recognition for teams accomplishing high safety performance figures had a positive impact on compliance with safety guidelines. However, several improvements are possible including: adding task hazard analysis to the LPS as suggested by (Wehbe and Hamzeh, 2013), developing a risk assessment manual for construction tasks, and involving all workers in hazard identification and mitigation.

CONCLUSIONS

This paper highlights the first implementation of LPS on a large scale project in Lebanon. Several improvements have been realized: visualization is improved, collaboration and coordination between team players are enhanced, the root causes of delays are identified, lower level players are involved in upper level decisions and the key indicators regarding safety, quality, time and cost are updated and discussed on a weekly basis to get optimal results. All of those improvements wouldn't have been present without the encouragement and motivation of the top management and lean champions. Despite all those improvements, many challenges were faced during implementation. The root causes of the problems were identified but not resolved. Furthermore, some employees resist shifting to the new system which is why more training is needed so that the people are more motivated to change. The teams are following a master schedule prepared by the planning engineer which is somehow not in line with the actual facts/problems. Moreover, foreman and engineers prefer to improvise on the job without being obliged to solve all issues beforehand.

Despite the implementation challenges encountered on the project, the overall implementation goals were achieved. However, various improvement opportunities were identified. Training for all employees on LC and LPS and relating them to the Lean philosophy, will help in building a lean culture. Involving subcontractors and the client's representatives in the process will create a chance for reaping more benefits from implementing LC methods.

Moreover, the introduction of novel planning methods such as location based management, as a complimentary system to the LPS, can help in improving workflow and reducing waiting times across project areas. This study was performed on the initial stages of the construction phase where few subcontractors were involved. The activities till date were mainly related to concrete works which are self-performed by the Contractor. The challenge would be to integrate the subcontractors in the new system during the finishing phase. The construction company is willing to implement LPS on all its projects and has already begun this initiative with two other projects in two different countries in the Middle East. So far, it seems that the second and third attempts are more effective than the first, since the system is better defined and elaborated before its initial introduction. This created a higher buy-in compared to the first project. A later study will be conducted to see improvements and barriers faced on the other projects and compare them to the first implementation.

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LAST PLANNER SYSTEM, SOCIAL NETWORKS AND PERFORMANCE OF CONSTRUCTION PROJECTS

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• ABSTRACT

Last Planner System (LPS) has made significant improvements in project performance worldwide. It is assumed that LPS implementation improves communication among members of the organization. However, the way that LPS management practices and organization's social networks are related to project performance is still unknown. The purpose of this study is to analyse the relations between LPS implementation, social networks metrics and performance in construction projects. A correlation analysis was applied to implementation levels of LPS, social network metrics and Key Performance Indicators (KPIs) in construction projects. The implementation levels of LPS practices were measured during LPS meetings. Social network data was collected by an on-site survey. The participant companies agreed to a KPIs report, encompassing nine projects over three months. This paper presents significant correlations tying project performance to social network metrics and to LPS implementation levels, in nine projects from two Chilean construction firms. Implementation level of LPS appears related to network average degree and density but that does not always mean better projects performance. The relations found are a tool that could be used to implement improvements in management practices and organizations. Identification of social networks' optimum metrics related to project performance still requires further research.

• KEYWORDS

Management practices, Last Planner System; Social networks; Key performance indicators; Project performance.

• INTRODUCTION

Construction has been defined as a complex system consisting of many diverse connected and interrelated elements acting in an adaptive way. Despite this reality, construction managers tend towards simplification to a one-dimensional form more conducive to decision making (Bertelsen 2003). In consequence, frequently the

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measures taken by project managers affect project costs, duration, safety and quality and increase project risk (Pons A. 2014). Many studies on pairs of variables involved in the construction projects have been conducted; one example is the effect of management practices on the results of the projects in construction (AlSehaimi et al. 2014). Also, the effect of the temporary organizations acting in the projects has been analysed to establish their influence in construction project results (Bertelsen and Koskela 2005). Influence of lean management practices, such as Last Planner System (LPS), on organizations implementing projects has won recent attention in an approach that involves people, from a lean construction perspective (Priven and Sacks 2015).

It has been established that the implementation of the LPS, that is applied to produce predictable work flow and rapid learning in programming construction of projects, has positive effects on project performance (Alarcón et al. 2008). Also, LPS has shown important improvements in project organizations connectivity measured by social network metrics like density and average degree of actors (Priven and Sacks 2015). Connectivity is important for construction management because it eases information flow and production is conceived as materials and information flow (Koskela 2000). Still, no conclusions have been drawn concerning the relationships between social network strength and work or workflow outcomes (Priven and Sacks 2015).

Project management system is mainly affected by people and production management practices (Aramo-Immonen and Vanharanta 2009). A holistic analysis of construction projects including those factors is needed. However, there are few analyses on how LPS management practices and characteristics of temporary organizations, in conjunction, are related to project performance. Construction management needs to be aware of these factors as they make decisions which affect the construction teams (Radosavljevic and Bennett 2012).

The purpose of this study is to analyse the relations between LPS implementation levels and project social networks metrics related to performance in construction projects. The information generated constitutes a management tool in order to understand project organization and reinforce best management practices for better project performance.

• BACKGROUND

LPS is a production management practice regularly applied in construction projects. Production is defined as the set of actions which convert materials and components into a new facility (Radosavljevic and Bennett 2012). It has been highlighted the effects of using LPS in improving production in construction projects as well as their positive influence on the organization in charge.

The interest in analyzing organizational social networks has grown in recent years since that structures depict organizations better than charts (Krackhardt and Hanson 1993). At the same time, Social Network Analysis (SNA) techniques have developed a vocabulary and set of measures for relational analysis (Scott 2013). SNA have been applied in construction projects in order to make visible information flow inside organizations (Alarcón et al. 2013). Information flow is a critical issue from the point of view of lean production (Koskela 2000).

A common approach to evaluate performance in construction industry relies on achievement of client objectives like cost, time and quality (Kagioglou et al. 2001). Usually, KPIs are used to measure performance, or the success of an organization on achieving a particular objective, at different levels inside the firm activity: headline, operational and diagnostic. Operational KPIs are related with specific production activities and are used for continual improvement (Beatham et al. 2004).

• METHODOLOGY

• CASE SELECTION

This study was performed in nine construction projects from two construction firms operating in Chile. The participating companies were part of a benchmarking exercise led by the Center for Excellence in Production Management – GEPUC.To avoid the bias of ending or recently starting activities, projects that had advanced at least three months and/or with at least three months before ending were chosen. Each company selected a group of comparable running projects to measure similar indicators. All of the selected projects were for housing buildings. Projects managed with LPS implementation were selected. Organizational and administrative diagnoses were made relying on the staff who ran the projects, from the construction manager to foremen and subcontractors. A total of 190 people participated in surveys to establish social networks' composition and metrics.

• METRICS ELECTION

A common list of nine operational KPIs was agreed upon between the two participant construction companies, these included LPS indicators. KPIs were chosen attending to their importance for project monitoring and the availability of information to calculate them. Also, the two participating companies have implemented monitoring systems that report the nine selected indicators monthly. These systems were developed during a benchmarking exercise led by the Centre for Production Excellence Management (GEPUC). Thus construction companies took advantage of the set of indicators without causing work overload for employees. The group of KPIs included cost deviation, schedule deviation, accident frequency index, accident gravity index, planning effectiveness, constraint release, quality index, productivity and contract bid change

A metric of the degree of implementation of LPS, based on Planning Best Practice index checklist of 15 planning and control practices, was applied during LPS meetings (Viana et al. 2010). Each practice was associated with a list of steps that should be met for proper execution. A scale from zero for not implemented to four or fully implemented was associated to this list. A weighted average of these steps was awarded as a percentage of implementing the practice. Practices evaluated were: a) Formalization of the planning and control process, b) Standardization of short-term planning meetings, c) Use of visual devices to disseminate information, d) Corrective actions based on the causes non-completions of plans, e) Critical analysis of data, f) Correct definition of work packages, g) Systematic update of the master plan, when necessary, h) Standardization of the medium-term planning, i) Inclusion of only work packages without constraints in short-term plans, j) Participation of crew representatives in decision making in short-term planning meetings, k) Planning and controlling physical flows, l) Use of indicators to assess schedule accomplishment, m) Systematic removal of constraints, n) Use of an easy to understand, transparent master plan, o) Scheduling a backlog of tasks.

Although a variety of informal networks exist in the workplace. This study analysed four job-site social networks that were identified as important to describe the information flow in projects: general interaction, relevant information sharing, planning and problem solving, and personal issues. Social network metrics were used to characterize organizations: density and average degree (Abraham, Hassanien & Snášel, 2009). These metrics are used as a tool to establish the communication patterns and ease of information flow (Lin 2015; Priven & Sacks, 2015). Density is a measure of the level of connections within a network relative to the total possible value achievable. Average degree is a measure informing about the average number of connections per node in the network (Cherven 2015).

- **SOCIAL NETWORK SURVEY**

Before the application of the survey, companies were requested to supply the current list of persons having administrative roles in the project. Social network data were gathered by application of an on-site survey conducted by trained personal to improve runtime. The survey questionnaire had four questions related to interaction, which is defined as a communication act or information transaction between individuals, for: total interaction, work relevant information exchange, planning and problem solving and personal issues chat. Each member of administrative personnel in projects had to report who he/she interacted with. This approach allows the identification of the interactions patterns developed during the workday (Alarcón et al. 2013).

- **MANAGEMENT PRACTICES SURVEY**

The degree of implementation of LPS management practices in projects was measured by a trained surveyor during weekly planning meetings. Surveyor perceptions about the absence or presence, whether partial or total, of the proceedings detailed in the checklist were registered. Any aspect not reachable at first sight was asked to the LPS meeting leader after the meeting and/or verified on site. Nine meetings were attended in different dates since some projects used to meet on Friday.

- **KEY PERFORMANCE INDICATORS SURVEY**

The project performance evaluation was based on project KPIs used as leading or process indicators. Project managers of nine construction projects during three months filled out the form containing the nine KPIs and sent them to the research team by internet, attached to corporative emails.

- **SOCIAL NETWORK ANALYSIS**

In social network theory, people are considered as nodes and interaction between them is taken as ties or connections (Easley and Kleinberg 2010). Social networks can be identified by indices such as degree and density that are related to how easy information flows inside the organization. SNA was applied for finding density and average degree of each of the four networks studied (Abraham et al. 2009). Both indicators are associated with information flow and dissemination.

- **DATA ANALYSIS**

The number of projects studied admits non-parametric analysis so the Spearman correlation was applied to the series after ranking raw data. Ranking was assigned, ranging from 1 as the worst performance up to 9 as the best performances. Spearman's r is the correlation coefficient on the ranked data and varies from 0 for no correlation to 1 for full correlation. Only strong ($0.6 <= r < 0.8$) and very strong ($r => 0.8$) correlation values, according to Evans 2012, were considered relevant. The p value, or the probability value, is a statistical measure that helps determine whether correlation hypotheses are correct or not. Null correlation hypothesis is discarded when p value is equal to 0.05 or less. Statistical software R was used to obtain Spearman r and p values.

- **RESULTS**

- **GENERAL DATA.**

The percentages of implementation of each of the 15 LPS practices were calculated from data collected at weekly meetings. Results are shown in Figure 8.

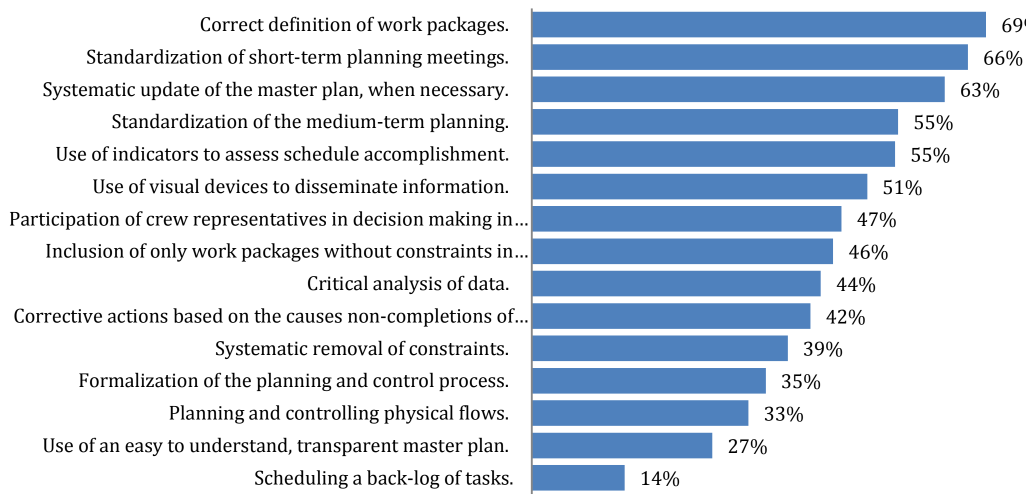

Figure 8 LPS management practices implementation percentage

Short term planning and programing activities is characteristic in all studied projects. Definition of work packages, standardization of short-term meetings and update of master plan are priorities, instead of backlog tasks or use of an easy to understand master plan. This goes with similar conditions reported in construction projects by (Viana et al. 2010)

After SNA, projects social networks density and average degree show appreciable differences and are depicted in Figure 9.

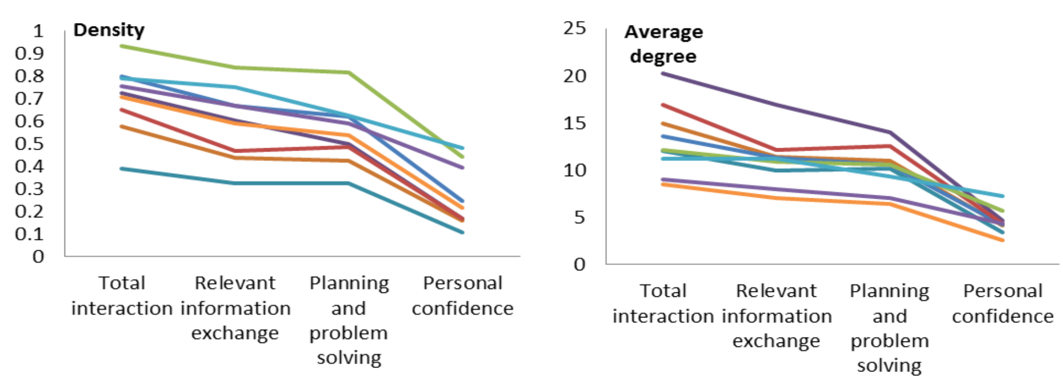

Figure 9 Projects' social networks characteristics

Personal confidence networks had the lowest density and average degree compared to the other three networks, despite its importance on teams' performance (Krackhardt and Hanson 1993). On the other hand, total interaction network had the highest values in all nine networks. Job-site networks, as relevant for information exchange and planning and problem solving, are at intermediate level. Results indicate that relevant information exchange and problem solving and planning is sometimes done among people that don't trust each other, maybe resulting in low commitment (Zeffane et al. 2011).

- **MANAGEMENT PRACTICES AND PROJECT PERFORMANCE**

Simple linear correlation was used to pair each management practice score and the median of each project's KPIs. Results are shown in Table 1.

Table 1 LPS management practices vs KPIs median

LPS management practice	KPI median	Spearman r	p-valor
Corrective actions based on the causes non-completions of plans	Contract bid change	0.729	0.040
Corrective actions based on the causes non-completions of plans	Accident frequency index	-0.759	0.029
Corrective actions based on the causes non-completions of plans	Constraint release	0.735	0.038
Critical analysis of data	Contract bid change	0.950	0.000
Correct definition of work packages	Productivity FT	0.856	0.007
Systematic removal of constraints	Accident frequency index	-0.903	0.002
Standardization of short-term planning meetings	Quality	1.000	0.000
Planning and controlling physical flows	Cost deviation	0.783	0.022
Use of visual devices to disseminate	Cost deviation	-0.786	0.021
Use of an easy to understand, transparent master plan	Accident frequency index	-0.771	0.025
Use of an easy to understand, transparent master plan	Constraint release	0.856	0.007

A high implementation of LPS management practices appears associated to better KPI values except for accident frequency index and cost deviation. Positive effect of LPS in project performance was reported by Alarcón et al. 2008. The inverse correlation between the LPS practices, accidents and cost deviation KPI requires further search of causes.

- **ORGANIZATION AND PROJECT PERFORMANCE**

The correlations found between the characteristics of social networks of each project and its performance indicators are shown below.

Table 2 Project social network average degree vs KPI median

KPI median	Social network average degree	Spearman r	p-valor
Contract bid change	Total interaction	-0.814	0.008
Contract bid change	Relevant information exchange	-0.882	0.002
Contract bid change	Planning and problem solving	-0.848	0.004
Accident frequency index	Total interaction	0.667	0.050
Accident gravity index	Total interaction	-0.679	0.044

Accident gravity index	Planning and problem solving	-0.775	0.014
Productivity FT	Planning and problem solving	-0.667	0.050

In Table 2, high social network average degree doesn't mean better results in project measured by KPIs. An exception is the accident frequency index, where a higher average degree in total social network interaction has a positive relation. Maybe this metric's increase must be explained by external factors, such as the fatality presence for example (Rivera and Kapucu 2015). Network density didn't present a significant relation with any KPI median.

- **MANAGEMENT PRACTICES AND ORGANIZATION**

Relations found between LPS management practices and network density are shown in Table 3.

Table 3 LPS management practices vs Project social network density

LPS management practices	Network density	Spearman r	p-valor
Standardization of short-term planning meetings	Personal confidence	-0.752	0.032
Standardization of short-term planning meetings	Total interaction	-0.897	0.003
Use of visual devices to disseminate information	Total interaction	-0.786	0.021
Standardization of short-term planning meetings	Relevant information exchange	-0.829	0.011
Use of visual devices to disseminate information	Relevant information exchange	-0.731	0.040
Standardization of short-term planning meetings	Planning and problem solving	-0.849	0.008
Use of visual devices to disseminate information	Planning and problem solving	-0.762	0.028

Better scores in management practices doesn't mean high density. Maybe current density is a result of poor quality communication or the unintended application of procedures as in Krackhardt and Hanson, 1993.Next, relations between LPS management practices implementation level and networks average degree are detailed in Table 4.

Table 4 LPS management practices vs Project social network average degree

LPS management practices	Network average degree	Spearman r	p-valor
Corrective actions based on the causes non-completions of plans	Total interaction	-0.988	0.000
Corrective actions based on the causes non-completions of plans	Relevant information exchange	-0.916	0.001
Corrective actions based on the causes non-completions of plans	Planning and problem solving	-0.952	0.000
Critical analysis of data	Total interaction	-0.805	0.016
Critical analysis of data	Relevant information exchange	-0.878	0.004
Critical analysis of data	Planning and problem solving	-0.854	0.007
Inclusion of only work packages without constraints in short-term plans	Total interaction	-0.819	0.013

Inclusion of only work packages without constraints in short-term plans	Planning and problem solving	-0.819	0.013
Scheduling a back-log of tasks	Total interaction	-0.846	0.008
Scheduling a back-log of tasks	Planning and problem solving	-0.846	0.008
Use of an easy to understand, transparent master plan	Total interaction	-0.735	0.038
Use of an easy to understand, transparent master plan	Planning and problem solving	-0.711	0.048

Social network average degree is inversely related to high scores on LPS practices. It is assumed that better implementation of practices leads to an increase of average degree and improves communication (Priven and Sacks 2015). But the optimal metrics of a network under normal circumstances has not yet been established. Relation between Management practices, Organization and Project performance.

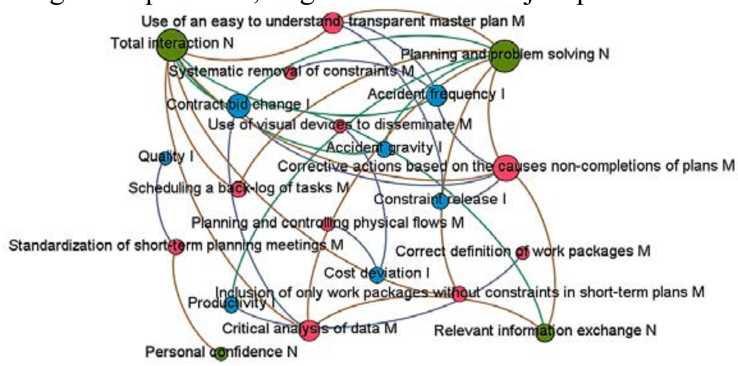

Figure 10 Relation among LPS, social networks and KPIs in construction projects.

Figure 10 shows the relevant correlations detailed above (Tables from 1 to 4). Each variable is represented as a node and the relations are ties. Pink nodes are LPS practices, the green ones are social networks and blue dots are KPIs. Node dimension represents its degree or number of connections to neighbours. LPS practices show high relation with three social networks, and maybe a high influence on their metrics (Priven and Sacks 2015). Note the prominence of total interaction networks as well as planning and problem solving. Most of the LPS management practices present relations with project KPIs, except for the Accident gravity index. Consider the relation of LPS practices on productivity, quality and the accident rate (Alarcón et al. 2008).

• CONCLUSION

The weakness shown by the networks of personal confidence, and a bias towards the use of short-term scope management practices, are the main features of the projects studied. Such conditions promote greedy relationships and construction crews' sense of no membership to the organization. This conspires against personal commitment and is needed to improve confidence, collaboration and fair share of information.

The high social network metrics of the temporary organization, conformed by project crews and management personnel, does not always mean good news. High values of network average degree or density can mean poor quality communication or reaction to adverse events. Thus a rise in those metrics cannot only be attributed to the effect of implementation of management practices as LPS.

We offer a diagram of the relation of the variables studied. However, pictures don't tell the whole history; a correlation diagram is just one tool among many others. It must be used with management criteria considering the complexity of the relations between management practices and organization characteristics that produce project performance.

This document is limited to portray the conditions of the projects investigated during the study period. Have not been considered in this study, characteristics associated with communication quality within construction projects, these factors should be taken in future research.

• ACKNOWLEDGMENTS

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METHODS FOR PRODUCTION LEVELING – TRANSFER FROM LEAN PRODUCTION TO LEAN CONTRUCTION

Marco Binninger[1], Janosch Dlouhy[2], Svenja Oprach[3], and Shervin Haghsheno[4]

ABSTRACT

Leveling of work packages is a basic requirement for production planning, and an important part of Lean Management. It offers the advantage of a steady utilization of resources and leads to a constant rhythm by using a defined sequence of work packages. Currently leveling of activities in construction processes is mainly applied by defining Takt units and by matching the required workload to the available workforce. Reasons for this are the traditional division of work into trades, interfaces regarding warranties, project based organization, outsourcing, or the lack of optimization of individual activities. Experience shows that apart from this, leveling of construction processes by currently used methods cannot adequately respond to unexpected disruptions. As a consequence resources are overloaded and project execution is delayed. In comparison to this stationary production industries are better equipped to react to disruptions with suitable tools such as the use of additional labor and supermarket delivery systems or through rotating work shifts using a qualification matrix.

This article brings together the results of a theoretical analysis, which investigated the transferability of selected tools for leveling of work processes from stationary production industries to the construction industry. It is determined that a number of tools can be transferred to the construction industry. It is shown how these tools must be adapted to be effectively implemented, and which changes to the basic framework are required in order to achieve this. In the future the results of this analysis must be validated by case studies. For this the required theoretical basis is developed in this paper. The article shows furthermore the potential for increased reliability and a higher efficiency of production systems in the construction industry through a higher degree of leveling activities.

KEYWORDS

Takt, work packages, leveling of work

INTRODUCTION

To realize construction projects in Germany construction works are usually divided between individual trades. Specialized contractors then complete the tasks of these trades. This makes the coordination of individual trades decisive in determining project

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success (Friedrich et al. 2013, 45). A lack of standardization and systemization of the construction process is complicating the planning and coordination of the project. Due to perspectives limited to their own field, the trades only seek to improve their own processes without taking considering other trades. The focus is on individualized optimization to reduce the time taken for one individual trade. In this way an overall optimization of construction projects is seldom achieved. Often a critical-path time plan is used, in which the critical works takes priority.

If construction projects are viewed from the perspective of lean management, the flow of value creation processes is usually referenced (Womack & Jones 2003, 21; Koskela 1992, 38). A continuous pull brings out the most efficient performance. This is caused by applying takting or a pull mechanism. Prior experience is no longer sufficient for planning complex and interdependent execution processes and should be supported with calculations and technical systems. However the acquisition of accurate data is difficult. This presents the challenge of calculating the required effort for small, structured and standardized work packages through which overall harmonization of the construction process can occur. This is required for the complete flow of works. The data as a basis for this must be optimized and verified to repeatedly be reliable across multiple projects.

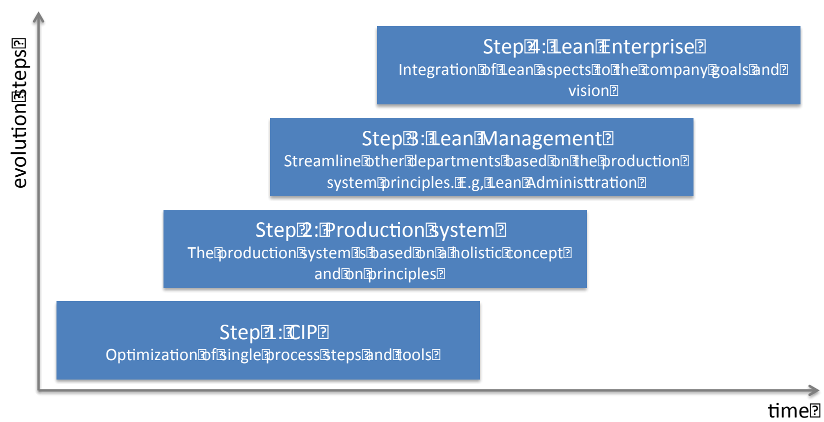

Figure 1: The four steps for "evolution" to a lean enterprise according to Peters (2009, 17)

Figure 1 shows the four steps of an "Evolution" to a lean enterprise according to Peters (2009, 16ff). Here the continuous improvement process is defined as the first step on the way to a lean enterprise. The second step is the development of a production system. On the third step lean management is introduced, where the lean principles are carried over to all divisions of the company (e.g. lean administration). The final step, and goal, is the lean enterprise, which is developed with a clear vision according to lean thinking.

A general contractor and client are mainly on the way toward the second step, the production system. A few companies even have implemented lean in other departments (step 3) without totally fulfilling step 2. Here value creation is set according to significant lean principles such as flow, Takt, pull and zero-defects. However the methods are frequently uncoordinated. Setting and following uniform rules and improving with every project processes and products as can be found in lean production systems is not consistently present in construction projects. This is evident by the variable amount of work within each trade. For example the work package for painting, or technical installations trades often requires a high level of effort, whereas door installation or plastering works have a comparatively smaller amount of effort required.

Optimization should be systematized across a complete production system. This enables all participants a coordinated understanding of the interrelationships. The overall coordination of the individual activities aims for a constant production rhythm (Jap. “heijunka”) (Liker & Meier 2004, 47).

The goal of this contribution is a process-near investigation of production leveling in construction to achieve a constant production rhythm. The results will serve as a basis for development of a complete production system for construction contractors. Production leveling is widely used in stationary industries. For this reason the significance of leveling in production in the stationary industries within the framework of lean production will first be investigated. Additionally the current situation in the construction industry will be described and compared in order to derive process-near leveling for construction.

SIGNIFICANCE OF LEVELING

If a value creation process is unevenly loaded, every process step must be set out according to the peak capacity. This leads to an average under-capacity of all process steps, and an uneven loading of individual process steps compared to the peak capacity. Furthermore it reduces the capacity for production planning to react to changes to the production sequence at short notice (Oeltjenbruns 2000; Spath 2003). Within the supply chain the requirements are passed on according to production planning. Trades plan machine and equipment capacities based on peak capacities. This means on average machinery and equipment work are below capacity. In contrast human resources are often planned at short notice according to the urgency of the need to complete the project. Construction workers thereby seldom work to a consistent rhythm. Often they switch between operations that are characterized by being overloaded and in workplaces prone to disruptions. The demands of the uneven loading are passed back up the logistics chain (also known as the “bullwhip effect”) (Dyckhoff et al. 2004, 246). Reasons for this are decentralized planning, planning based on prognoses from the past, bundling of order quantities and fear of price fluctuations or supplier bottlenecks (Zäpfel & Wasner 1999, 297 pp.).

To enable uniform production Rother (et al. 2003, 51) recommend production leveling. Leveling means to adjust and smooth out inconsistencies (Dictionary 2016). Ideally this leads to uniform loading and a production rhythm taking all parts into consideration from an overall perspective. Furthermore the ability of a process-near and short notice reaction to disruptions must be achieved.

Leveled production has the following advantages: Value creation is located in a defined and recurring sequence as part of a constant rhythm, resources are evenly used and peak capacities at individual points are reduced; this achieves a higher level of overall effectiveness. Fluctuations in production volumes, stock quantities and lead times are reduced. With the help of process-near procedures, greater flexibility is possible (Oeltjenbruns 2000; Spath 2003). A leveled production program also allows continuous upstream process steps such as external production and in-house production, which minimizes the bullwhip effect. To be able to achieve a leveled production program, the process steps must be considered in detail. With small and controlled steps, feedback loops can be built into the process, so that variations can be detected and potential improvements can be incorporated into the system. This means that where uncertainties in the process increase, individual process steps must be laid out in greater detail and in a more controlled way. Thereby the potential for mistakes will be reduced and the speed of development increased (Minimax-method) (Bösenberg & Metzen 1993, 123ff).

AS-IS SITUATION OF LEVELING AND BARRIERS IN CONSTRUCTION

Some construction contractors in Germany have already introduced a takted production system. The following approaches are applied in practice:

Consolidating the separate working areas: In the framework of Takt planning the working surface areas are divided and organized so that the capacities of the trades are used equally and have sufficient work for the selected Takt. In the stationary production exists a minimal Takt and the Takt time is mostly totally filled out with work (e.g. at Mini nearly 100% of the Takt time of around 70 seconds are used (internal reference). By gaining more reliable performance factors buffers in construction projects should reduced, but at least three to five days of a weekly Takt should be filled out with work. This approach is strongly dependent on the type and form of building and can only be applied to a limited extent.

Dividing the work: If individual tasks require too much effort in relation to the time allocated, the work can be divided according to the classic boundaries between trades. An example is division of the task "finish wall surfaces". A painter completes this task. In practice this work frequently requires more time than the Takt allocated. However walls are first plastered or primed, and only painted in the next step and therefore two different and specialized teams can be used to better keep to the Takt.

Optimization of individual work steps and work content: If some work steps take longer than others, the can be optimized according to the selected Takt time. An example is the use of better machinery, optimized logistics, or reducing waste during completion of work. A further possibility is a higher level of prefabrication. Due to the conditions of turnkey contracts, this ability to implement these approaches is largely under the control of subcontractors. The potential for the general contractor to utilize these approaches is therefore limited.

Leveling of teams: To equalize the speed of individual responsibilities, the size of teams can be varied. This approach is widely used in practice. There are also limitations as some activities require a minimum number of personnel or a maximum number of personnel cannot be exceeded. An appropriate change to the size of teams is then not possible. For example only a limited number of personnel can work in a small room.

The preliminary approaches listed here offer the possibility to increase leveling and therefore the profitability of the overall system.

Contractors who use these approaches are in a stepped process of development, along which greater leveling of production systems is possible to further increase profitability. An example is shown in Figure 2. Here the utilization of the individual work packages is shown in a takted system. A work package can be made up of one trade, or a combination of multiple trades. From this it can be seen that even in leveled system the utilization of the individual work packages can still be subject to large variations.

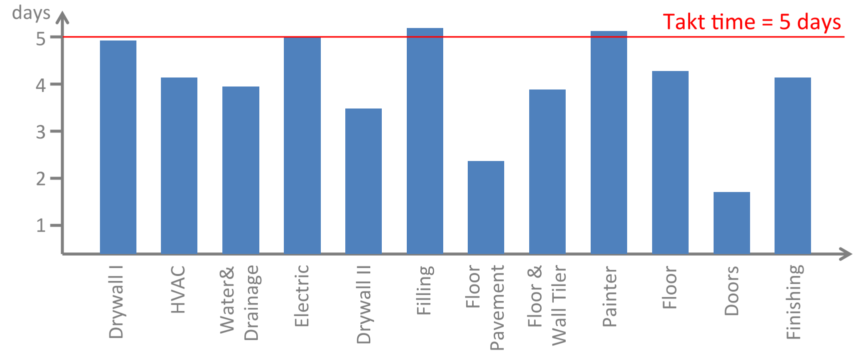

Figure 2: Capacity diagram for an example in practice

The goal is the best possible utilization of the individual work capacities. Measuring the utilization rate of a construction site can assess the quality of production planning. The utilization rate is the weighted average value of utilization of individual work packages. The size of the respective teams is used as a weighting factor to take individual working intensities into account. These figures can be used in future to empirically assess the quality of production planning for construction works.

$$RU_{\text{tot}} = \frac{\sum_1^n (RU_x \times cs_x)}{\sum_1^n cs_x}$$

x: number of work packages 1, …, n

RU_{tot}: total rate of utilization of the production system

RU_x: rate of utilization of a work package

cs_x: crew size of a work package

The calculation of the rate of utilization for each working packages:

$$RU_{\text{x}} = \frac{D_{\text{x}}}{TT} \qquad \text{with } D_{\text{x}} = \frac{V_x \times p_x}{8\left[\frac{h}{d}\right] \times cs_x}$$

D_x: Average duration of work package x [in days]

TT: Takt Time of production system [in days]

V_x: Volume of work of work package x

p_x: performance factor [in hours] of work package x

cs_x: crew size of work package x

Construction has special conditions that must be noted during execution. The following lists the significant unique qualities:

Division into trades: Construction project execution is traditionally divided into highly specialized trades. For example within the framework of takting the trade "Installation of doors" has significantly less work in comparison with other trades, and therefore is not at full capacity. However the door installer is generally not prepared to fit his logistics and services to a new system. With the main goal to improve the overall performance of the project, single trades (like the door installer) cannot be optimized within their work. Their work either can be fragmented over the total construction period or this works are added to other trades.

Warranties/Boundaries between task areas: Between the trades there are clear boundaries between task areas, which are also reflected in providing warranties. Therefore a new organization of tasks due to harmonization is only possible under certain conditions. For example it is not feasible to eliminate the boundaries between tilers and installers of sanitary fittings.

Time-limited cooperation: Due to the time limits based on a contract for works in a project-specific work phase, interest in systematic cooperation and development is limited to a tangible construction site or a tangible project. Scaling effects are rarely implemented.

Outsourcing: Outsourcing and spreading of risks favor short-term project-based thinking. Subcontractors according to the area of responsibility retain potential improvements. Narrow margins often prevent greater investment at the subcontractor level.

Global-Contracting: The integration of turnkey contracts with a functional performance specification favors poorly considered risk allocation. More in-depth consideration, and a detailed understanding of individual processes is no longer necessary from the perspective of the general contractor. On this basis subcontractors are obligated to optimize their own processes – however they lack a total overview of the project.

Optimization of Work Packages: Optimization of work packages is also left to the subcontractors. The general contractor's ability to influence this is severely limited due to the conditions of outsourcing.

Other industries have implemented standardized production systems. These take the framework relevant to the particular field into account. Enterprises have also changed parts of their frameworks to improve their own production systems. A significant part of the new production systems is newly developed methods for production leveling.

LEVELING IN LEAN PRODUCTION

In the stationary industries the goal of leveling is to introduce a uniform production rhythm aligned to customer demand. In reality customer demand is not static. Therefore it is necessary to decouple the production program from customer demand. For this demand must be identified in the first step and categorized according to type, quantity and required resources. For the demand to be met the production must be divided into work processes to be arranged in a suitable chain of production. In a second step production is smoothed out during which templates of the smallest subsets are determined. With an increase in the number of cycles the set-up time must be reduced (Bullinger 2009, 1- 23).

According to Engeström (1987, 217) output can be influenced by subjects (or work stations), objects (or products), instruments, rules, community and work performance. Based on this categorization specific tools and methods from the lean production approach for leveling will be introduced.

Subjects: By changing working capacity, throughput times and thereby also leveling can be influenced. Capacity is made up of *human, machine, and instrument resources* (Schuh & Schmidt 2014, 346).

Objects: Products can be divided between standard products and special customer requests (Glaser et al. 1992, 407). Specific product groups are required by particular customer Takts. These should be identified. Bundling products into *batches* and the length of the planning cycle (also known as "pitch") are significant influencing factors for leveling (Rother & Shook 2008, 51). Short planning cycles together with short throughput times enable the ability to react quickly.

Instruments: To reduce the effort required for control, leveling is supported by the *heijunka-board* (Rother & Shook 2008, 53). The goal of the heijunka-board is to use constant production rhythm to achieve an optimal capacity utilization and the ability to react quickly to customer demands. Using a matrix, planned-demand maps of downstream process steps are used to allocate a Takt and product variant (Brunner 2014, 107). Another instrument is restrictive dimensioning of buffers (Decker 1993, 94). This supports leveling, however is considered waste from the perspective of lean thinking. Material buffers as *product supermarkets* balance out external fluctuations (Rother & Shook 2008, 88). Finally visualization instruments (e.g. shadow-boards, signs) help identifying deviations (Dickmann 2015, 28).

Rules: To allow flexible response to customer demands, *the system (people, machinery and equipment* should be specialized for multiple product variants (Erlach 2010, 72). Furthermore by organizing small batch sizes, quick set-up times and short transport times are made possible.

Community: A team should be flexible with regard to its Takt area. With a *qualifications matrix* every employee is allocated to secondary task areas in addition to their main task area (Dickmann 2015, 62). Thereby appropriate training and up skilling can be planned for the medium to long term.

Work performance: In addition to division into working groups, flexible employees also called jumpers (Jap. "Shojinka") fill some positions (Monden 2012, 159).

A further position is termed *"Water Spider"* (Dickmann 2015, 357). They function as process manager and are responsible for maintaining material stocks to work stations. This splits value-creating and non-value-creating logistical tasks. Time spent on material handling, as well as time spent moving around and searching are reduced. (Fabrizio 2014)

TRANSFER TO THE CONSTRUCTION INDUSTRY

In the following the tools and methods for leveling described will be evaluated from the perspective of lean production and their transferability to construction practices. This qualitative evaluation is according to the subjective judgment of the authors based on experience in practice, and serves as a basis for discussion. This will take the previously discussed framework into account, particularly in reference to the construction industry. The tools and methods will be evaluated according to the criteria of social, economic and technical transferability. The criteria of social transferability include sub-criteria such as "employee acceptance" and "restrictions to working ability". The economic transferability includes the aspects of effort to implement and maintenance costs. The technical transferability is defined according to changes to working processes, contractual considerations and application of IT solutions. The evaluation will be completed on a 1 to 3 scale. If a criteria is defined as not transferrable, it will be marked "--". Table 1 gives and overview of the completed evaluation of the individual tools and methods. The final column shows the total values. This is derived from the sum of the individual evaluations assuming no criterion was evaluated as "not transferable".

Table 1: evaluation of the individual tools and methods

"3" = directly transferable "2" = transferable with minimal effort "1" = only transferable with considerable effort "--" = not transferable	Social transfer-ability	Economic transfer-ability	Technical transfer-ability	Total
Rapid setup/reduction of the resources on hand	1	2	3	6

Small Takt areas (cf. small batches)	2	3	3	8
Implement the Heijunka-Board for takting	2	2	2	6
Partial hand overs as supermarket system	2	1	2	5
Wide spectrum of tasks for workers (qualifications matrix)	3	1	3	7
Fast transfer between Takt areas (cf. fast setup times)	2	2	1	5
Short transport times to construction sites through supermarkets or using local suppliers	2	1	2	5
Involving employees in CIP	3	2	2	7
Implementation of jumpers	2	3	3	8
Implementation of the "Water Spider"	3	2	1	6

As can be seen from Table 1, the tools and methods often cannot be directly transferred, but rather must be adapted. Transferability was not ruled out for any tools. This suggests that that possible transferability should never be ruled out. The following will describe the transferability of the approaches of "implementation of jumpers" and "smaller Takt areas" in greater detail, these being the two approaches, which were scored the highest.

The implementation and use of jumpers is a valuable element of risk minimization and resource leveling in lean production. This approach is easily transferable to construction production however there are some drawbacks in terms of contractual considerations. These will be discussed terms determining contract conditions in the construction industry. There are two possibilities for implementing jumpers. Interdisciplinary/external flexible employees can be deployed at each construction site, and provide assistance to various trades. The second approach is to have jumpers for each trade, which allow leveling of one trade across multiple construction sites. These jumpers are highly specialized in their trade. A drawback is the higher logistical requirements and coordination needed between construction sites. For example one team whose task is door installation, and whose work at one site would be completed in one day would instead be required to work simultaneously across five sites for one week.

As previously mentioned, the requirements for the implementation of smaller Takt areas in the construction industry will be stated. The authors' experience from practice can provide the following purposeful Takt area sizes to fill a weekly Takt: Residential construction approx. 200 m^2, office construction approx. 300-500 m^2 and hotel construction approx. six to eight rooms per week. If a weeklong Takt is selected the waiting times of the individual trades is relatively high. To address this smaller Takt areas and Takt times could be aimed for. The smaller the Takt area, the more short-cycled the inspection points regarding the completion status, quality and security topics are and therefore production areas are completed more efficiently. Examples from practice with short-cycled daily Takts have clearly shown this. This approach is however not transferable to all projects as it is strongly dependent on building geometry. Further advantages are the higher level of control due to the higher number of standardized task interfaces. Finally this form of short-cycled Takt allows a very stable process of supply.

CONCLUSIONS

The analysis of the tools and methods for leveling from lean production show that transfer of various approaches from the production industry is also possible within the conditions of the construction industry. Some tools are directly transferable and offer significant potential. As examples the transferability of two approaches were described in detail. On the way to becoming a lean enterprise the framework of a production system places a high demands on a construction contractors. For further improvements to their production systems under implementation of the methods of leveling, construction firms must have a stronger influence on their operating environment and make adjustments to their business models. Through efficient processes and a stronger competitive position these firms can also become better suited following the influences of their customers. The transfer of the tools and methods discussed here must be tested in practice and validated.

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MODELING INFORMATION FLOWS BETWEEN LAST PLANNER AND LOCATION BASED MANAGEMENT SYSTEM

Bhargav Dave[1], Olli Seppänen[2], Ralf-Uwe Modrich[3]

• ABSTRACT

Production planning and control are two of the most important aspects that contribute towards the successful completion of construction projects. The Last Planner® System (LPS) and Location Based Management System (LBMS) have emerged as two popular methods for production planning and control. Previous research has shown that by combining LPS and LBMS there is an opportunity to improve production tracking, forecasting and control and described the process of how the systems can be combined.

However the research has stopped short of developing specific information flows between the two systems. In particular, the use of LBMS forecasts in LPS lookahead planning and the use of LPS constraints in LBMS forecasting lack specific guidelines. Information can be moved in several different ways and research is needed to make sure that the integration adds value. The goal of this research is to evaluate alternative ways to integrate the information in LBMS and LPS systems. Thought experiments and simple scenarios were used to evaluate the benefits and drawbacks of different approaches. The result is an initial proof of concept that can be implemented manually or automated in LBMS and LPS software applications.

• KEYWORDS

Production Control, Last Planner System, Location Based Scheduling, Production Planning.

• INTRODUCTION

The Last Planner System (LPS) supports site based production processes, replacing ad-hoc and "push" based traditional systems (Ballard 2000). The Location Based Management System (LBMS) provides a much needed spatial element to planning and has strong optimisation and forecasting capability that can help plan and steer the project towards its goals (Kenley and Seppänen 2010). Studies over the years have highlighted that there is a risk of losing sight of the big picture if LPS is not sufficiently integrated with high level planning and tracking (Dave et al., 2015), whereas the LBMS

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system lacks the constraint screening and weekly planning processes. From this perspective, both these systems have complementary features which if combined properly – can improve the production management on site significantly (Seppänen, Modrich, and Ballard 2015; Dave et al., 2015).

While previous studies have explored synergic potential of LPS and LBMS (Seppänen, Modrich, and Ballard 2015; Seppänen, Ballard, and Pesonen 2010; Dave et al., 2015), they have yet to clearly define the workflows and integration of functions from both these systems. For example, how will forecast information be brought to help the lookahead planning function in LPS, and whether the updated plan with constraints should be taken into consideration in LBMS, or how will the updated execution statuses from LPS will be brought into LBMS each week, are some examples of questions that need addressing for field implementation of these two systems.

From the perspective of integration, Master and Phase scheduling are reasonably clear from workflow perspective. As has been proposed in previous studies, Master and Phase scheduling will be carried out in LBMS based on LPS social process. These plans provide a starting point for more detailed lookahead and weekly planning of LPS. The workflow for information exchange at Master and Phase schedule level is defined well in previous research (Seppänen, Ballard, and Pesonen 2010; Seppänen, Modrich, and Ballard 2015).

- **FUNCTIONAL INTEGRATION**

Lookahead planning involves bringing all stakeholders together, creating sub-tasks from the milestone schedule, identifying and assigning responsibility to constraints and commitment from workers in removing these constraints (Ballard 2000). While LPS tackles the collaborative planning and constraints analysis effectively, LBMS has the capability to provide a much needed "big picture" through the live forecasts. When planning their detailed execution plans, the crew should have access to time-location boxes in LBMS schedule. In LBMS the flow of work is clearly defined within locations, hence the workers can identify how much time each of them have at each location and when do they have to handover to the next trade.

On the other hand, the LBMS schedule generally does not tackle detailed task level planning or identification of constraints which could have an impact on forecasts. Figure 11 outlines the proposed workflow for a combined LPS and LBMS implementation for lookahead planning. In the weekly planning, one of the main features of LPS is commitment from the team and screening for unfit tasks and removing them from the execution schedule.

One of the biggest risks from production perspective at this stage is to lose sight of the big picture, i.e. there is not reverse feedback to inform the team of the impact the changes will have on the schedule if they remove unfit activities. This gap can be filled by i) feeding the actual task statuses from LPS to LBMS; ii) feeding the updated/live weekly plan data to LBMS and checking the forecasts. Another important aspect is that the crew will have access to the time-location boxes, i.e. each team will know when the location becomes available for them and the deadline by which they have to deliver the location to the next team. As shown in Figure 14, a time-location box is a visual notation in LBMS that shows the available time window for a particular location handover to the crew. In other words, all work related to that activity and location should be completed within the time-location box. If the weekly plan changes impact this, the LBMS schedule can raise an alarm to inform the team of potential clashes. Subsequent sections in the paper will provide in-depth explanation of the workflow and integration between the functions.

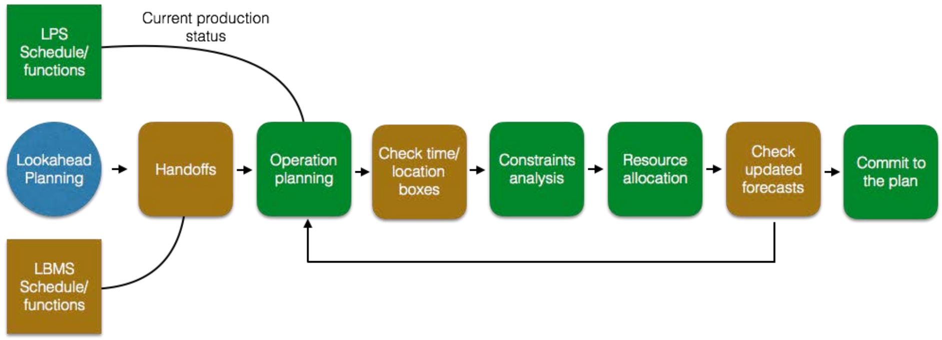

Figure 11 - LPS-LBMS Combined Lookahead workflow

- **METHODOLOGY**

The research is based on constructive research strategy, which aims to tackle a practical problem and devise experiments, which are then iterated and validated through user feedback. The typical steps in constructive research approach (Lukka 2003; von Alan et al., 2004) are, i) identification of a practically relevant problem; ii) examining the potential for research; iii) obtaining deep understanding of problem area, theoretically and practically; iv) innovate a solution idea; v) implementing the solution; vi) ponder the scope of applicability of the solution; vii) identifying and analysing the theoretical contributions. The current research stage is "innovate a solution idea". The subsequent stages of implementation to theoretical contributions will be developed in subsequent research.

- **RESULTS**

The following are recommendations to integrate LPS and LBMS at various planning and execution stages. The workflow is explained through a simple schedule of 2 tasks which are carried out in 5 locations, Figure 12 shows the LBMS schedule.

- **MASTER SCHEDULING**

Master Scheduling in LPS is considered to be equivalent to identifying major milestones for the project. Due to its strong optimisation capabilities, it is recommended that the Master plan would be developed in LBMS, where major milestones will be identified.

- **PHASE SCHEDULING**

Seppänen, Modrich, and Ballard (2015) suggested starting reverse phase scheduling using the LPS social process of carrying out a collaborative workshop where the site team works backwards from the master schedule milestone. In contrast with the LPS – only workshop, durations would not be discussed in this workshop. Rather, a "homework assignment" would be given to participants to detail their quantities and labour consumption data by location for each task. These quantities and labour consumptions would be used to create the first version of the schedule based on preferred crew sizes and then the schedule would be optimized collaboratively using LBMS in another optimization workshop.

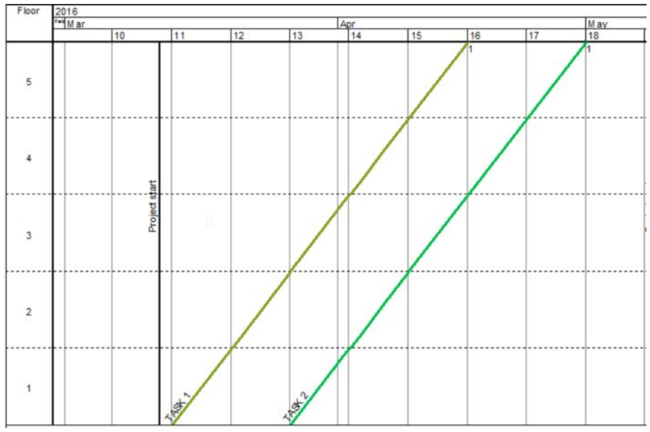

Figure 12 - Master Schedule in LBMS with 2 activities and 5 locations

After Phase Scheduling has been completed, the Phase schedule data from LBMS would be imported in LPS system. The information can then be shown in a simple Gantt view and subsequently in the timeline view (Figure 18) once the resources (workers) are allocated to tasks. Figure 13 shows the imported Phase schedule from LBMS system, with activity-location handover date shown as a milestone (red diamond). Each time-location box from the LBMS schedule (as shown in Figure 14) will also be available to the LPS crew when carrying out lookahead and weekly planning activities.

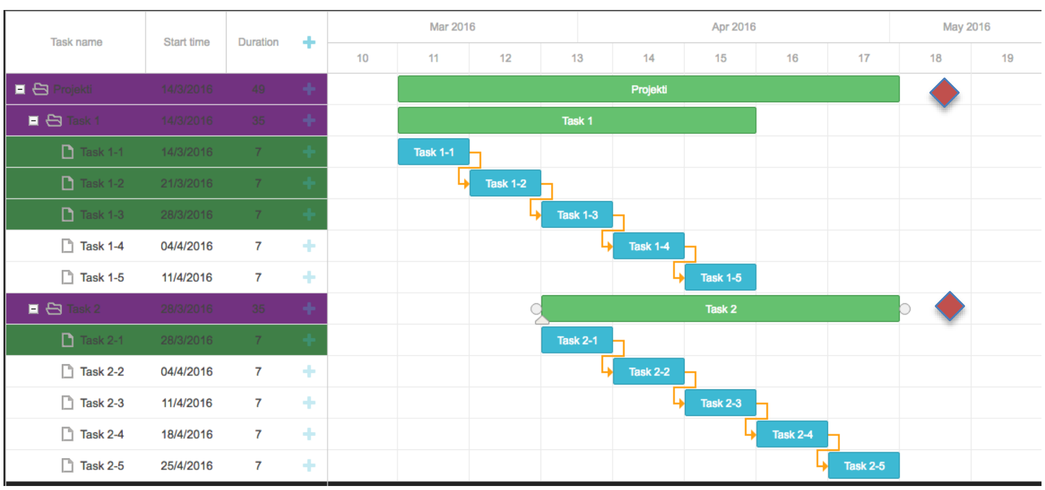

Figure 13 - LBMS Schedule imported as Master plan for LPS

- **LOOKAHEAD PLANNING**

The crew members will perform the lookahead planning using the Phase Scheduling data from LBMS. First, the tasks will be divided into operations which can then be assigned to workers. In this case (as shown in Figure 15), each activity-location is subdivided into two operations, which are to be carried out by two crews (each crew with two workers). The "exploded" schedule is shown in Figure 15.

Once the operations are created, they will be assigned to individual workers or foreman as shown in Figure 18. After the initial task allocation, the lookahead team identify task constraints and realise that activity 1 has a space constraint on location 3 which has to be rescheduled from its original date. Example of an app interface for the workers is shown in Figures 6 and 7 (where the workers will update the constraints on each selected activity).

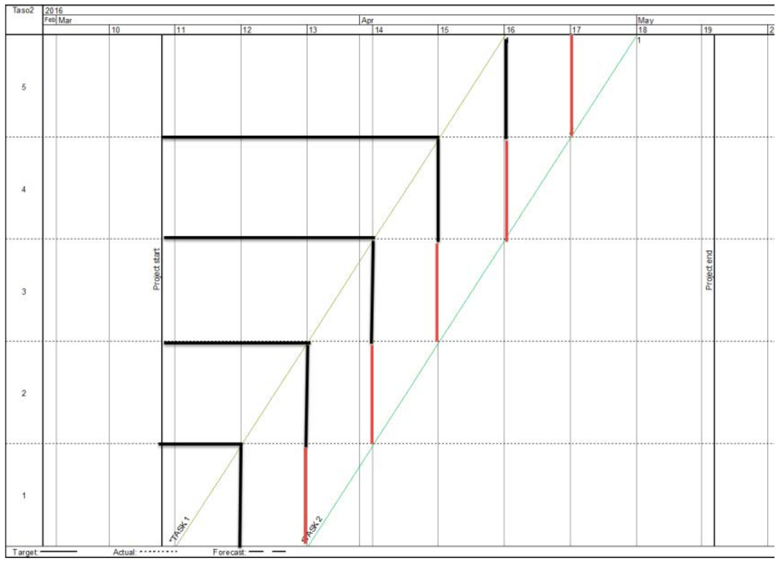

Figure 14 - Time location boxes in LBMS schedule

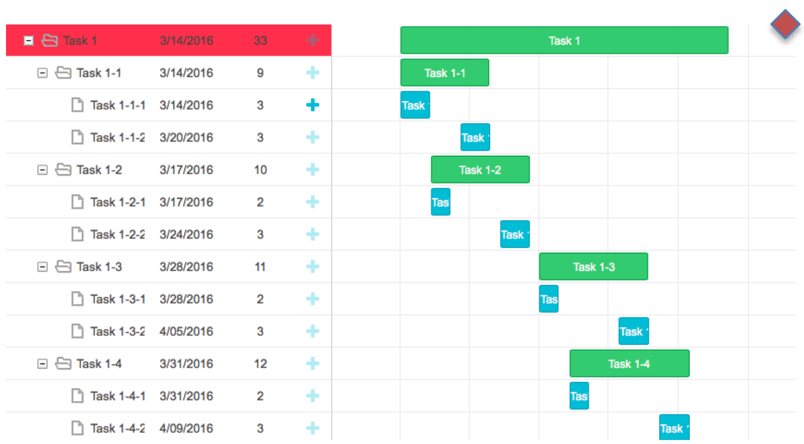

Figure 15 - Task 1 Exploded in LPS to create Lookahead schedule

The weekly subcontractor meeting has two purposes, first lookahead planning for the next 6 weeks ahead on a task level of detail. The lookahead planning is then followed by the weekly work planning for the next two weeks ahead on an operations /steps level of detail. From this perspective, during the lookahead planning meeting, the crew will have access to the forecasts from LBMS schedule, and each time/location handover date is shown as a sub-milestone for activities as shown in Figure 12. If changes to the plan impact these location milestones, an alarm would be raised in the LPS system to notify the crew. After negotiation, the crew will commit to the schedule and subsequently the LBMS forecast will be updated with this information. The lookahead and weekly planning schedules in LPS will have preserved the links to the higher level plans (phase and master) by following a Task ID -> Sub Id structure. This way the real-time feedback on task statuses will update the phase and master plan level tasks and inform the crew of potential delays or other problems during the weekly and lookahead planning sessions. Each crew/location will have their own display board showing the current weekly plan which can be used during the daily stand-up meetings where the real-time progress from the LPS plans can be discussed.

Figure 16 - Updating task constraints in LPS

Figure 17 - Task execution data from LPS

In the example discussed here, the impact from the initial re-planning of the layout tasks in LPS following the identification of the space constraint would have delayed the framing activity, and overall the activity would have been delayed by a week. However, in the new workflow the crew has access to the LBMS schedule, and they reorganise the activities in such a way that layout on floors 1-2 will be handed over 1 week earlier and framing will be brought forward one week so that following the delay by space constraint, the layout crew on floors 3-5 will be able to handover the location to framing (floors 3-5) on time. This way the overall handover of Task 1 can be carried out as planned.

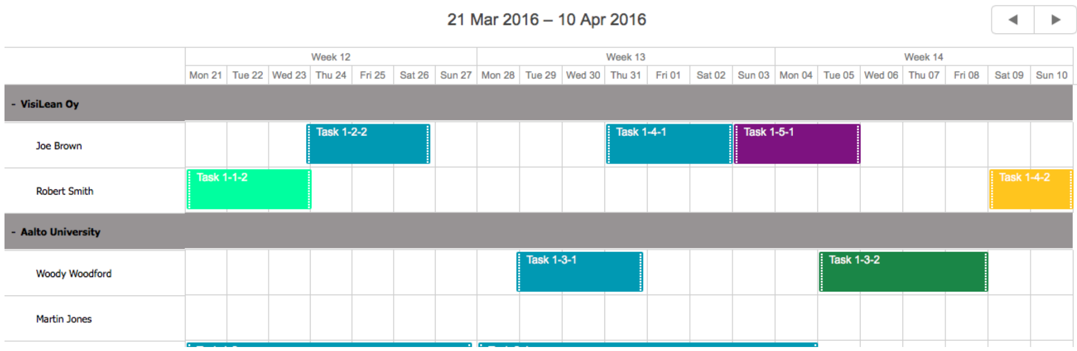

Figure 18 - Tasks allocation for the lookahead planning

Figure 19 shows the updated LBMS schedule following the Lookahead planning session, where the x-axis shows the duration in weeks and the y-axis shows the location (floors 1-5). It can be seen from the rearranged tasks that although the overall hand-off date is on time, individual locations are performed late (outside their "box") which will delay the succeeding subcontractor. This will trigger negotiation and re-planning to mitigate the impact.

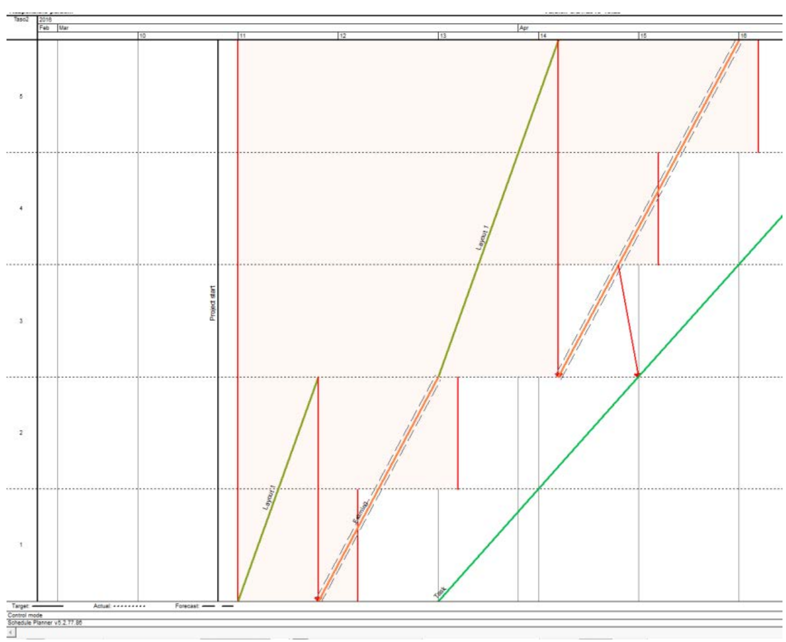
Figure 19 – Updated LBMS schedule after Lookahead session

Following the Lookahead meeting and the weekly planning session, the crew updates the commitment plan with latest task updates (execution) from the field. Figure 17 shows the interface for crew when updating the activities from the field. If a planned activity, including constraining (or predecessor) activity fails to complete on time, the system will raise and alarm and the LBMS schedule will be updated accordingly. The combined system would raise an alarm if the low productivity or a constraining task results in delay. Similarly, the actual start and finish dates from the LPS system will be used to update the LBMS to ensure the forecasts remain up-to-date and alarms raised if needed.

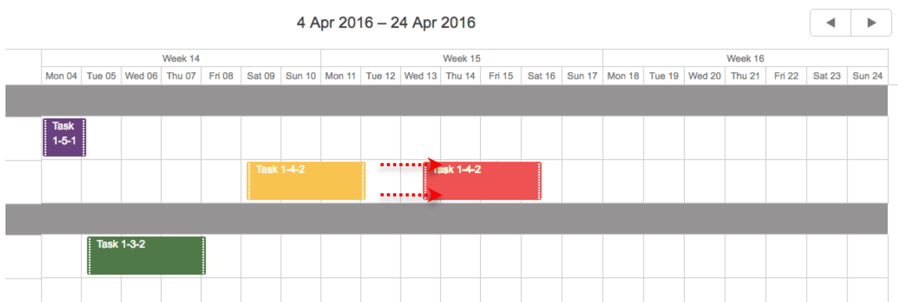

Figure 20 - LPS schedule updated with actuals from field

Figure 20 shows an example where the LPS operation 1-4-2 is delayed by four days, where each row represents a responsible person (or a team) and the x-axis depicts time in days (each box represents a single day). The corresponding task (1-4) is updated in the LBMS schedule (Figure 21) and revised forecast shown to the crew, and an alarm is raised in the LBMS schedule due to this delay. Similarly, if the crew fails to maintain a sufficient level of working backlog and/or there is low level of commitment in the weekly planning meeting, which results in delays in location handover, an alarm will be raised in both the systems.

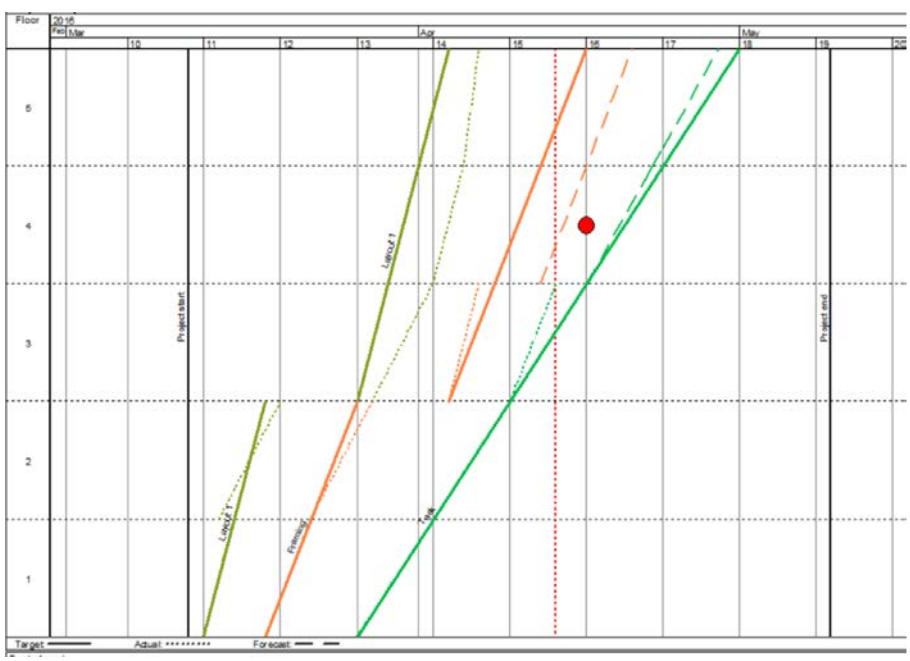

Figure 21 - Updated LBMS Schedule with actuals from the field

• Proposed Combined Data Model

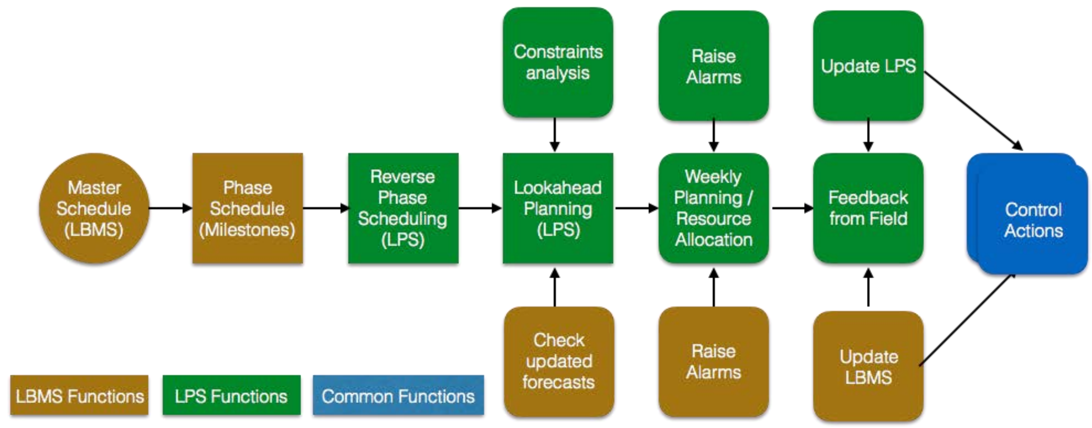

Figure 22 Proposed Combined Data Model

Figure 22 shows the proposed combined data model. The master and phase schedules are prepared in LBMS and milestones are imported in LPS. The reverse phase scheduling (in a collaborative way) is carried out in LPS and information is updated in LBMS. Subsequently, the constraints analysis and operational level planning is carried out in LPS, while the forecasts are updated in LBMS for potential delays or low-productivity. Weekly planning with resource allocations is taken care in LPS, and actuals are tracked from the field. Both the LPS and LBMS systems are updated with field updates and control actions are initiated from respective systems.

• CONCLUSIONS

This research outlines a structured approach to integrate Last Planner System with the Location Based Scheduling System. Through a simple example, the integration between these two systems is demonstrated. By integrating these functions, the workers would have access to both the short and medium term production planning and scheduling information (through LPS) and the impact of the current decisions and statuses on long-term project plan (through LBMS).

The current research is limited in scope, as it has not been validated through real-life case studies. Future research should take into consideration the coding requirements between these two systems and actual pilot implementations on construction projects, to carry out detailed analysis on effectiveness and the need for improvements in the detailed implementation methodology.

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BIM AND SEQUENCE SIMULATION IN STRUCTURAL WORK – DEVELOPMENT OF A PROCEDURE FOR AUTOMATION

Omid Haiati[1], Jakob von Heyl[2], Sarina Schmalz[3]

ABSTRACT

Sequence simulations are a very useful tool to increase the visibility of workflows, to identify potential conflicts in advance, to improve the communication between different trades and to assign tasks accurately. Hence, the entire construction process can be executed in a more efficient manner – saving time and costs. Building Information Modeling (BIM) enables the linking of schedules and 3D CAD models. This is widely understood as 4D-simulation. However, in practice the process of data entry is time-consuming, making the employment of this procedure cost-prohibitive. As consequence, it has not yet been established in practice. 4D-simulation has yet to show any noticeable simplification or improvement to the planning and scheduling process.

The goal of this paper is to support the development of a procedure which automates the generation of a construction schedule from the data of a standard BIM model. Firstly, a demarcation of research will be done, as there are already several research approaches in the field of 4D simulation. Secondly, a system analysis of structural work will be executed in order to identify requirements for the procedure. An important criterion is that the construction schedule can be formulated and adapted in all project phases.

Building on the results of the systems analysis, a process model can be formed in which the activities of a construction schedule can be constructed as a universal and project-independent template. For each of these activities, attributes are established which exactly describe the associated components of the BIM-model specific to any particular project site. The attributes of the activities from the process model must be tested for consistency with those from the BIM model. A case example is demonstrated to validate the developed procedure.

• KEYWORDS

Building Information Modeling (BIM), 4D-simulation, Scheduling, Visual Management, LPS

• INTRODUCTION

Since BIM has been applied in the construction sector for several years, positive synergies between Lean Construction and BIM have become obvious. Remarkable

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improvements are expected all across the lifecycle of a project. Therefore, the implementation of BIM in construction projects is progressing quickly. Significant benefits are expected when BIM and Lean Construction are implemented together. (Sacks et al, 2010; Dave et al, 2011; Bhatta and Leite, 2012; Hamdi and Leite, 2012; Gerber et al, 2010; Toledo et al, 2014).

One approach is the use of 4D simulation in combination with the LPS (Gonzalez 2012; Bhatla and Leite, 2012). It is important that project participants understand the construction processes and progress in order to achieve compliance with schedules and planning results. 4D simulation can ideally be used for virtual first run studies and to visualize Gemba and project content in order to improve and accelerate project understanding. Thus, 4D modeling improves coordination of the different trades and allocation of resources. The consequences are reduced waste and variability, as well as a more stable workflow.

Unfortunately, the use of 4D-models is currently often limited to basic 4D-simulation at a macro level. A project is usually only simulated with the level of detail of a master or phase schedule (Dave et al, 2011). A more detailed depiction of a project with a refined schedule requires an intensive manual linking of tasks, durations and dates with the BIM objects in order to represent all dependencies. This is very time-consuming and therefore a noticeable improvement in the planning and scheduling process has yet to be realized (Harris and Alves, 2013). Hence, 4D simulations have not yet been established for day-to-day use in construction projects. To achieve this, the use of BIM and 4D simulations has to be facilitated. Automated and standardized procedures are required in order to rapidly generate and evaluate construction plans and scheduling alternatives with 4D simulations (Bhatla and Leite, 2012).

The aim of the approach depicted in this paper is the development of a procedure to automatically create an initial construction schedule based on a BIM model in order to accelerate and facilitate 4D simulation, thus improving the scheduling process and the assignment of resources to activities. Project-independent process templates are sought based on a universal definition of the structure, components and attributes of a 4D model in the field of structural work. The aim is to replace manual work with automated procedures as far as possible.

• RESEARCH – CONSTRUCTION SIMULATION

A number of investigations has been conducted in the field of construction simulations in order to automate and facilitate scheduling. According to the approaches of many researchers, a description or formalization of construction processes is crucial to achieve a certain degree of automation.

Research on automated schedule using object data is dating back at least to the 1970s, e.g. CYCLONE (Halpin, 1977). This work as well as other early work in construction simulation has been the foundation for recent research, e.g. object-orientated process simulation, CPM-Networks or discrete-event-simulation by using object-orientated programming (Tommelein and Odeh, 1995; Zozaya-Gorostiza, 1989; Liu and Ioannou, 1992 etc.). Important research questions when applying these theories to current approaches are the automatic definition and integration of semantic information or how to extract attributes contained in the BIM-model while regarding technical and organizational dependencies.

One approach for automated scheduling is the use of process templates. In this context, the construction process is described as a sequence of activities and component status. For this purpose, the building has to be broken down into components to be assigned to categories afterwards. The basic principle here is that each category has a predefined set of status variables to describe the manufacturing process of a single component. Thus, the execution of an activity requires a specific component status, resulting in the associated component status. This approach is not CAD based (Huhnt and Enge, 2007).

The abovementioned approach has been extended to a CAD based scheduling. The method enables the creation of schedules by using the data contained in the CAD model. Furthermore, the non-geometrical information in the CAD model determines the construction method. The results are valuable for better scheduling, but not suitable for use on construction sites, due to the fact that the schedule is depicted in a table and not in a bar chart or work breakdown structure. It is also not possible to automatically verify whether all the contained components from the CAD model have been considered for the scheduling; a manual completeness check is required (Kugler, 2008).

Another approach is the constraint based scheduling, which has been specially developed for structural work and finishing. A distinction is made between hard and soft constraints. These constraints define dependencies between objects within a simulation environment. The hard constraints (e.g. technological dependencies) must be complied with in order to depict a process. Soft constraints, on the other hand, describe strategic dependencies. They don´t need to be complied with completely. This approach enables the generation of various execution strategies (König and Beißert, 2008).

A Case Based Reasoning (CBR) system presents an alternative option in model based scheduling. Here, reapplying and adapting proven solutions from similar previous projects can solve new design problems. The CBR cycle passes through its four phases: retrieve, reuse, retain and revise. The idea is to store every solved case in a case platform, separated by problem and solution. Hence, the most similar solution for a new problem can be found and applied (Hartman et al., 2012).

Another research project presents a solution for creating both schedules and 4D simulations based on the data stored in a CAD model. According to this research, 4D simulation is usually only used for the visualization of construction processes and the linking is mostly done manually. Further research is required in order to significantly speed up a 4D simulation, thus improving its cost-benefit relationship. Provided there is a logic suitable for extracting data to define processes and durations, an automated linking between the CAD model and the schedule is possible (Tulke and Hanff, 2007).

However, all approaches are difficult to handle & haven't been developed holistically in accordance with the BIM method. This prevents application and acceptance in practice.

• ANALYSIS OF FUNDAMENTALS

• STRUCTURAL WORK

In the planning and construction of buildings, the work is packetized and divided. This is done in order to facilitate the tendering and contracting of projects or parts of them. However, a uniform structure cannot be found. It is possible to differentiate between structural work, mechanical, electrical and plumbing (MEP), finishing and the building envelope. A finer structure can be expressed in trades or work sections, based on the traditional branches of industry. This paper focuses on structural work. For the procedure to be developed, it is assumed that the structural work consists of the construction of the foundation and the supporting structure. Associated trades are brickwork, concrete work and reinforcement work.

GEOMETRIC STRUCTURE

The structure is one of the first things that have to be considered in a construction project. A Work Break-Down Structure is a useful tool to define the scope of a project and to break the work down into work packages. (Berner et al, 2013) The WBS is the basis for all other plans, e.g. resource plans or schedules. Hence, a WBS enables adequate planning and management of a project. A WBS also adopts the basic structure of the BIM model. The better a model is structured in the beginning; the less effort is required to generate a 4D Simulation (Dave et al, 2013). For the work with a BIM model, a geometric-based structuring approach seems to be the best approach. Figure 1 demonstrates two possible variants to structure a project.

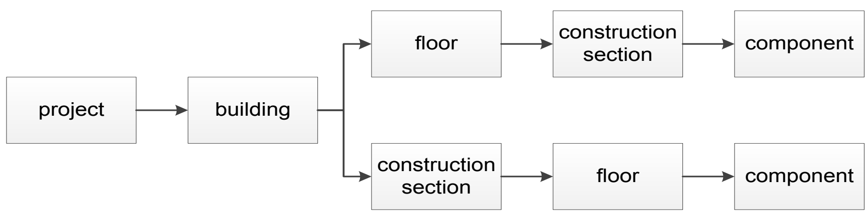

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Figure 23: Structure of a building in structural work

• TECHNICAL DEPENDENCIES

The decomposition of a building into its components is essential for a consideration of its technical dependencies. There is a manufacturing order of the components in order to erect a building. Technically, first the foundations, then the walls and finally the ceiling are built. This information can be used generally and independently from an individual building, because this order is universal. A closer look demonstrates that a single component is composed of a number of parts and crucial applications, e.g. concrete, formwork and reinforcement. The information on technical dependencies will be used in the process model.

• ORGANIZATIONAL DEPENDENCIES

Organizational dependencies are generally difficult to model, especially when formalizing these dependencies independently of a project. In practice, these decisions are made subjectively, repeatedly reconsidered, and possibly also changed over the course of a project. The main focus relating to the organizational dependencies in a construction project is the production cycle, which arranges cycle elements. A cycle element can be defined in different ways; e.g. construction section, floor, or a combination of both. The definition of a cycle element differs from project to project and depends largely on the level of detail of the schedule. The working direction of the cycle elements also needs to be defined (Fig. 2).

The variants “horizontal” and “vertical” are seldom used due to economic aspects. For instance, the abovementioned variants require more formwork elements than the “diagonal” variant. A lack of formwork elements causes waiting times and interferes with the construction process, thus causing waste. On the downside, an abundance of formwork elements leads to increased costs without improving the construction process.

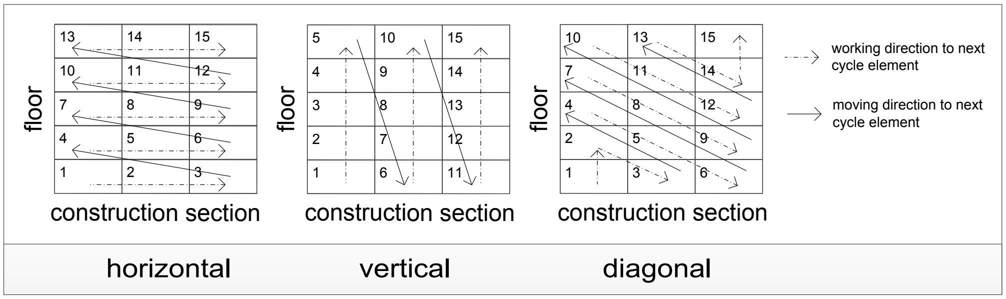

Figure 24: Working direction of cycle elements

- **REQUIREMENTS FOR THE PROCEDURE**

The procedure is developed according to the requirements described below.

1. Adaptability: In order to ensure a dynamic and flexible procedure, changes should be automatically adjusted in the 3D model and scheduling.
2. Generality: General structures and naming conventions must be considered. Project-specific construction schedules have to be generated. The automatic linkage of the construction schedule with the 3D model should be based on a general logic.
3. Usability: Existing commercial 4D software systems should be used in order to avoid unnecessary problems or interfaces caused by new or multiple systems.
4. Correctness: The mapping of components and their attributes with the individual processes of the process model has to be unambiguous and correct. This is essential for the automated generation of the schedule and for creating the 4D animation.
5. Completeness: All components contained in the 3D model have to be linked to the process model. If one or more components cannot be linked, these should be identified through a verification process.

- **PROCEDURE**

- **PROCESS MODEL**

A process model is generally used to describe and define how processes should look, and represents an anticipation of a universal valid construction process. Its elements consist mainly of processes and their relations to each other. A single process maps an activity (e.g. construction of walls) within the construction process. Its relation to other processes represents the given order (e.g. first construction of walls then construction of ceilings). Expertise in scheduling and modeling is needed to prepare a process model. It is recommended that the crucial processes be defined in close collaboration between the scheduler, the BIM manager, and experts from the corresponding trades.

By implementing the abovementioned dependencies, both technical and organizational, a procedural structure results (Fig. 3). In order to map the process model to a specific project, each process needs to be identified by a number of attributes. Thus, components of a BIM model can be addressed in order to activate the corresponding process (see "automatic generation of sequences"). To generate a schedule, it is helpful to reduce this number of attributes as much as possible. Attributes that contain information to building physics (e.g. insulation values) are not relevant, because these have no direct impact on the schedule. There must be a standardized definition of attributes for each process to ensure a successful scheduling. Attributes which represent the topological location of the component and their categorical designation are important. Regarding the topological location of a component, attribute values for “building”, “construction section” and “floor” are required. The categories “ceilings”, “foundations”, “structural columns” and “walls” must be used to describe components within structural work. At the end, the developed process model can be used as a template for scheduling. Creating the process model requires a lot of effort but only needs to be done once for a project or company. The procedural structure can also be modified and adapted, e.g. changing the working direction of the cycle elements.

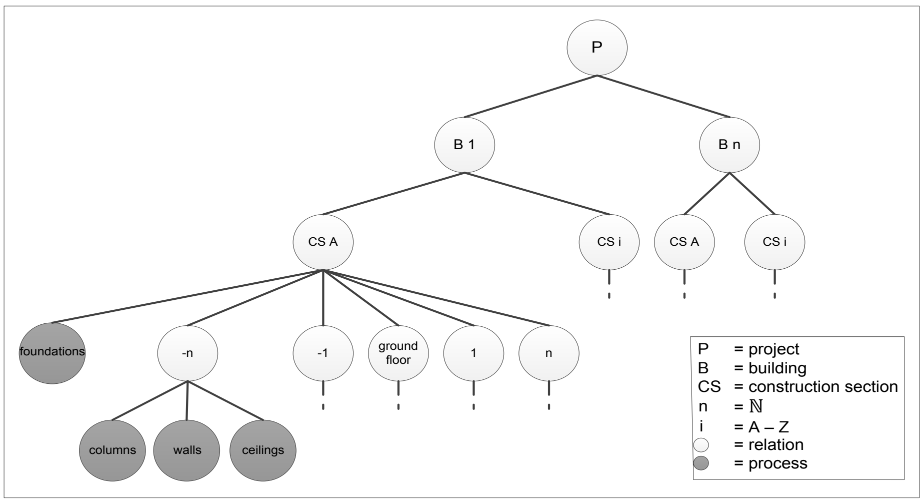

Figure 25: Process model presented as graph

- **BIM MODEL**

A BIM model is a 3D representation of a building enriched with information. In the procedure developed, project-specific information is stored via attributes in the components of the model. In contrast, the process model contains general information; the attributes of the processes are predetermined. A requirement of the procedure is that the attributes of corresponding processes and components match. Applying a standardized BIM library for a guaranteed consistency of attributes is recommended. A standard naming procedure for all components and attributes is required. The attribute names and values must be selected clearly and concisely. Table 1 illustrates that.

Table 1: Necessary attributes in a BIM model as sample

	attribute name	attribute value
topological location	building	1, 2, 3, n
	floor	-n, -1, 0, 1, n
	construction section	A, B, C, ..., Z
categorical designation	category	ceilings, foundations, structural columns, walls

- **DEPICTION OF PROCEDURE**

The Procedure, with its main components, the BIM and process model, is explained below.

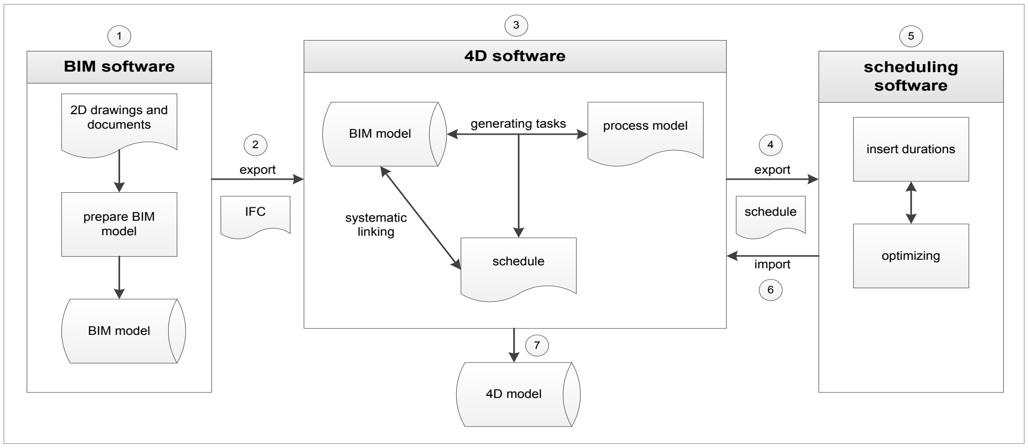

Figure 4: General workflow of the BIM based procedure

A BIM based CAD software, a 4D software and a scheduling software are required for the procedure. The procedure contains of the following steps:

1. A BIM model is created using input data, such as 2D drawings, documents and specifications.
2. Subsequently, the BIM model gets exported into the 4D Software. A neutral exchange format (Industry Foundation Classes IFC) is used. Any proprietary data format can be used alternatively if required.
3. The 4D software is mainly used for two purposes: firstly, tasks are automatically generated based on the imported BIM model using the process model. However, time durations or optimal sequences are not defined. Secondly, tasks are systematically linked with objects/components of the BIM model.
4. The incomplete schedule is then exported to a scheduling software. The required data format differs depending on the chosen scheduling software.
5. The schedule still has neither task durations nor an optimized sequence of tasks. This will be done manually in the scheduling software. The schedule can be optimized based on performance factors, available resources and experience. Any additional information known at this time may be added. Resources cannot be assigned automatically yet. Adjustments require a manual update.
6. The optimized schedule is imported back into the 4D software.
7. Even after Step 5 (optimization), the schedule has the same links to the BIM model as before. In contrast to classic scheduling, no new links are created, nor are old ones changed. In the last step, the 4D model is produced.

• AUTOMATIC GENERATION OF SEQUENCES

In this section, the automatic generation of sequences (Step 3 in Fig. 4) is shown in greater detail. The BIM based approach is based on a comparison of the attributes stored in the process template with the attributes in the BIM model. The order of processes is based on the organizational and technical dependencies of a construction process. For each process, attributes are defined to ensure an assignment to the corresponding components. Attributes (geometric and non-geometric attributes) are a prerequisite for the identification of and matching processes and components.

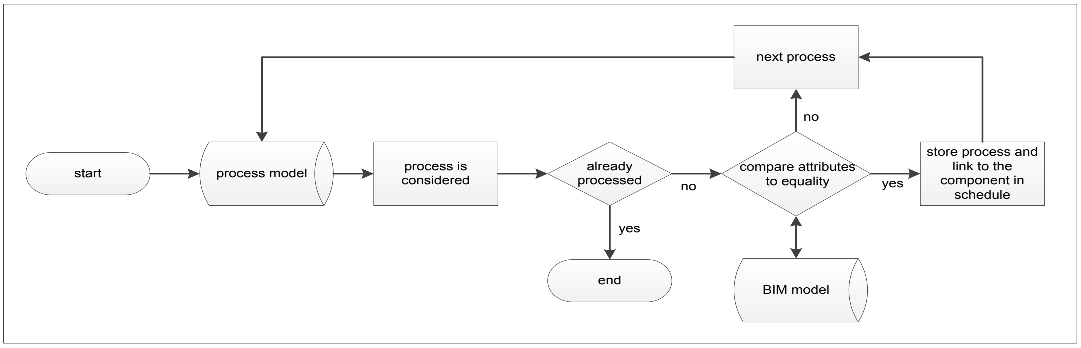

Figure 5: Workflow of automatic generation of sequences

The attributes in the process model are compared and checked for equality with the BIM model task for task. This is done in a numerical or alphanumerical order. If there is a match, the task is stored in the schedule, and a dynamic and adaptable link between component and task is created. Tasks and components are linked via a unique identification number. If a task has no corresponding component, the next process gets checked. The processes in the process model are checked sequentially until all processes have been checked. Processes with no corresponding component in the BIM model will be ignored. In this case, the processes are either not needed, or the attributes are missing or false in the BIM model. Then these attributes need to be edited in the BIM software manually. Only tasks with a link are displayed in the schedule.

• EVALUATION

An industrial project which comprises the structural work of three buildings, each with three floors and a total of six construction sections, was selected for testing. The aim was to get both an initial schedule and an automated linking in the 4D model. It was necessary to emulate the abovementioned automation to generate sequences, because this functionality is not yet part of common 4Dsoftware. This could also be implemented as an add-on in a 4D software solution. Existing functionalities of the software solution used enable the search for components according to defined attributes. Like that a single process within the process model was mapped. This step was repeated for any process to map the process model successively. As a result, a selection of processes and their corresponding components was displayed. Afterwards, the outcome was transferred into scheduling software for optimization. As a result, an initial schedule was generated, linking the schedule and the BIM model. The schedule was checked for correctness and completeness. All tasks were correctly identified and placed in the correct order. All components from the BIM model were included. The demand for adaptation was examined by modifying the structure of the construction sections – the modifications were automatically displayed in the BIM model. A schedule and its related dynamic links could be automatically generated and updated.

• CONCLUSIONS & LIMITATIONS

A simultaneous implementation of BIM and Lean Construction can improve construction processes significantly. The use of 4D simulation in combination with classical lean tools such as LPS is very promising. The draft depicts a procedure to automatically create an initial construction schedule based on a BIM-model in order to facilitate 4D simulation. Process templates are required based on a universal definition of the structure, components and attributes. It is possible to automatically link and update the process- and BIM-model. 4D simulations can be generated more easily, although specific dates, durations or adjustments still have to be addressed individually. An automated quantity take off as well as calculation of durations and resources is not part of the procedure. The focus was structural work from the perspective of a general contractor - other trades and project participants need to be regarded as well. Furthermore, a deeper consideration of details and processes below the current level of detail of the developed procedure is required. The BIM-method requires very structured and disciplined work. First projects show that more effort is required in early phases of a project in terms of accurate modelling, decision taking and providing required procedures and databases (e.g. a process model and its attributes). New professions emerge, and the project participants collaborate in a different way – new processes and roles are required. Thus, the implementation of the BIM-method requires a lot of effort in the beginning. That might be a barrier to adopting the BIM method and the proposed procedure depicted in this paper. More research is needed to address the abovementioned limitations and to demonstrate the expected efficiency gains.

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IMPLEMENTING LAST PLANNER IN THE CONTEXT OF SOCIAL HOUSING RETROFIT

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ABSTRACT

The paper aims to investigate the implementation issues and benefits of utilising the Last Planner and 4D modelling in the context of retrofit of social housing. It presents initial results of an on-going research project carried out in Northern Ireland, which focuses on the retrofit of solid wall homes. The research project involves the proposal of a process in which BIM is used to evaluate what-if scenarios for the retrofit of social housing with a focus on reducing user's disruption throughout the construction process. Both 4D and the Last Planner are used to ensure the retrofit works with the minimum disruption.

A case study on the retrofit of a set of houses was carried out, which is part of a bigger research project entitled S-IMPLER. Data was collected via semi-structured interviews, participant observation in planning meetings, site visits and documental analysis. The study sheds light on a particular type of project that has not been well explored by the lean community, i.e. retrofits. It is argued that the results can be applicable to support the retrofit of a number of solid wall homes throughout the UK.

KEYWORDS

Retrofit, disruptions, production, last planner system.

INTRODUCTION

Retrofits, or sustainable retrofits, refer to the refurbishment of buildings with the purpose to improve their energy performance (Swan & Brow 2013). This type of refurbishment has been gaining importance within the construction sector as it plays a vital role in the achievement of sustainable targets (Kelly 2009).

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The retrofit process presents many challenges for managers and decision makers, particularly when the users remain in the building over the period that the works are carried out (CIRIA, 2004). The retrofit works cause disruptions for building users, which need to be treated as an additional variable in managing retrofits and considered as part of the strategic objectives in such projects (Kelsey 2003).

This scenario offers an interesting opportunity to investigate the applicability of lean principles in order to tackle the issues inherent to retrofit projects. Despite being well tested in new build projects, the implementation of lean methods in retrofits has been scarce (Kemmer & Koskela 2012). This study contributes to fill this void by exploring the potential of using Last Planner System (Ballard 2000) with the support of Building Information Modelling (BIM) to ensure the retrofit works with the minimum disruption.

LEAN IN RETROFIT PROJECTS

There are around 4.95 million of dwellings in the UK's social housing stock (DCLG 2015). A significant part of these homes do not meet the minimum requisites of insulation and energy conservation and, therefore, require retrofit activities to improve the thermal comfort and to replace building components at the end of its useful life (Itard et al. 2008). The problem is that the majority of those homes are owner-occupied which enhance the difficulty of retrofit works and the possibility of users' disruptions. Lean principles might be an interesting option to tackle the issues inherent to retrofit projects.

Several authors have highlighted the need and opportunity for investigating the applicability of lean principles in retrofit projects (Smith & Owen 2011; Brayshaw et al. 2012; Swan 2013). However, there is still limited evidence of practical applications of the lean theory in the refurbishment sector as a whole, including retrofits, especially when compared to what is found regarding new builds (Kemmer & Koskela 2012).

Despite the lack of research on the application of lean in retrofit projects, it is worth mentioning that there are few examples available in the literature demonstrating the usefulness of lean initiatives in such projects. For example, Tuholski and Tommelein (2008) and Tuholski et al. (2009) show the potential of lean tools such as design structure matrix methodology and cross-functional process charts for optimizing the design process on complex seismic retrofit projects. Ladhad and Parrish (2013) contend that lean practices such as learning from previous projects, shared understanding, early integration of design and construction teams are also useful for promoting energy savings during the building's lifecycle. Last Planner System (Ballard 2000), the well-known lean method of production planning and control, is also mentioned as a useful tool for improving coordination and integration among project participants (Ladhad & Parrish 2013).

Although providing inspiring results, those studies have not addressed the context of social housing retrofit. It is argued that such project context has particular characteristics and management challenges that might demand specific lean approaches. This study contributes to the existing literature by discussing the implementation issues and potential benefits of applying Last Planner with the support of BIM in a social housing retrofit.

BIM IN RETROFIT PROJECTS

According to Hammond et al. (2014), BIM has potential to be used in retrofits in the following areas: (a) determine the level of green building certification systems can be achieved (e.g. LEED); (b) perform building analyses, such as, orientation, massing, envelope, daylight to enhance design; (c) perform analyses on building functions, as energy and water use, ventilation and lighting. In addition, BIM model created for retrofit works can be also used in a cost estimating software to calculate the cost of retrofit and in others software for further building maintenance and operation (Ilter & Ergen, 2015).

Despite the potential of BIM for retrofit projects, there are no studies about its use to analyse end user's disruption. Therefore, this study is focused on filling the gap about the benefits and challenges in use BIM tools to reduce the user's disruptions, as it is a common problem faced in retrofit works.

THE S-IMPLER PROJECT

The work presented in this paper is part of a wider research project entitled Solid Wall Innovative Insulation and Monitoring Processes using Lean Energy Efficient Retrofit (S-IMPLER), funded by the Innovate UK (http://www.s-impler.com). This project aims to develop a retrofit solution for social housing, which were built with solid walls, to achieve 60% reduction in monitored energy costs, at least 10% faster than conventional installations, with less disruption for end users, without reductions in quality and safety.

This research initiative involves a housing association, two academic institutions, an independent research organisation, an energy service supplier, a building contractor, a consultant on continuous improvement, an architectural practice, a company specialised on energy management solutions, a software company, and material suppliers. The application of lean and BIM practices are part of the elements investigated in the project. The retrofit work consists of:

- Replacing the old external windows and doors made of wood and single glass by openings made of PVC and double glass;
- Strengthening of the existing loft insulation layer;
- Insulation of external walls using insulation dynamic boards and rendering;
- Switching the existing oil boiler with natural gas boiler heating system;
- Switching the ventilation system with a more efficient one.

The retrofit work will be carried out in five different phases to enable analysis, learning and improvements between phases. This paper specifically reports on the use of Last Planner and 4D modelling with the purpose to reduce user's disruptions.

RESEARCH METHOD

A case study was carried out to evaluate the implementation issues and benefits of utilising the Last Planner System and 4D BIM modelling in the retrofit of a set of houses. This study is part of an on-going research project conducted in Northern Ireland, which involves the refurbishment of eight houses in five phases (see details below). This paper reports findings from the first three phases (Table 1). The objectives set for each phase along with the methods used in this investigation is presented in the following table.

Table 1: Research process.

Items	Phase 1A	Phase 1B	Phase 2
Objectives	(a) understanding of project's current status, (b) problem identification along with root cause analysis, (c) identification of opportunities for improvement	(a) introduction of Last Planner with the support of 4D BIM modelling, (b) identification of opportunities for improvement	(a) use of BIM for what-if scenarios simulations and use of line of balance for assessing disruptions, (b) identification of opportunities for improvement
Research methods	Semi-structure interviews, direct observation of works on site, documental analysis	Participant-observation in planning meetings, direct observation of works on site, documental analysis	Participant-observation in planning meeting, documental analysis

As illustrated in the table above, the first phase of the study was exploratory. In order to achieve the goals set for this initial stage, it was conducted semi-structured interviews with project participants (e.g. project manager, site manager, consultant, architect, etc.), direct observation of works on site, participant observation in planning meetings, and documental analysis (e.g. production plans, scope of works, design drawings). As the main goal of this phase was just to understand the current planning system, the researchers made no intervention in the process of production planning and control.

In the phase's 1B and 2 the researchers collaborated closely with project participants. This refers to a pro-active participation in the implementation of Last Planner and 4D BIM modelling, i.e. facilitating planning meetings, devising plan options, making direct observations on site, and analysing documents related to production planning and control.

RESEARCH FINDINGS

PHASE 1A – EXISTING PRODUCTION PLANNING AND CONTROL SYSTEM

The first phase of the project involved the retrofit of one house, which was void during the construction. The team assembled for the delivery phase was led by a project manager who was responsible for managing a group of material's suppliers, an architect responsible for the retrofit design, and the subcontractor assigned for carrying out the works on site. Such team will be referred in this paper as "the delivery team".

In order to get ready for the retrofit, the delivery team met four weeks prior works were due to start on site. The main goals of this meeting were to devise the construction programme and phase sequencing as well as checking the prerequisites for the retrofits such as design information, material and labour supply. Such tasks were facilitated by the project consultant and performed by the delivery team in a collaborative fashion through the use of post-its notes for setting deadlines for removing the project's constraints and milestones for the main construction processes. Four weeks later the retrofit began as planned. The lead time planned for the retrofit in this phase was four weeks.

During the construction phase, the production planning and control process was carried out in an informal basis. There was no formalisation of plans, apart from the construction programme generated at the outset. Such plan, which served as a master plan for this first phase, become out-dated quickly as the sequence of works agreed initially changed during construction. Likewise, the problems on site were not systematically registered since there was no formal document for that purpose.

Several problems were identified during the construction phase such as disruptions in the workflow (main problem), downtime, and rework. The lack of materials (e.g. windows and insulation components) and design information (e.g. detailed drawings) caused such problems. However, the analysis of the root causes, carried out by the delivery team during an improvement meeting after the completion of the retrofit, revealed that such problems were mostly due to inefficient communication amongst the team, as neither the communication structure within the project nor the roles and responsibilities of each participant were clear, and also due to the compressed time for developing the design, which resulted in the lack of information for carrying out the works on site as planned. The actual lead time for retrofitting the house was eleven weeks.

In terms of opportunities for improvement, the delivery team decided that no works on site should get started until all uncertainties were resolved. This decision was made in order to prevent disruptions in the workflow and downtime, therefore enabling the compression of the lead time for the next retrofit phase. Also, a web-based project management platform was set up and a meeting was organised by the project consultant in order to streamline the communication and foster collaboration amongst the team. Besides, it was decided that a formal production planning and control approach should be adopted so better results could be achieved (e.g. less disruptions, compressed lead time).

PHASE 1B – INTRODUCTION OF LAST PLANNER AND 4D BIM MODELLING

The second phase of the project involved the retrofit of two houses, both occupied during the construction. In order to produce a predictable workflow and rapid learning as well as reducing disruptions on site, the Last Planner System (LPS) of production control was adopted. 4D BIM modelling simulations were also used as a visual aid to support decision-making within the LPS framework. They aimed at contributing to the development of the master plan by showing the implications of different production strategies in terms of disruptions for the residents. The target lead time set for this second phase of the project was four weeks for the retrofit of both houses.

In order to implement the LPS in such specific project context, some adaptations had to be made. These are summarised in the following table.

Table 2: Last Planner's adaptations to suit the retrofit context.

LPS elements	Phase 1B
Long-term (master plan) Phase planning	Devised in a collaborative fashion by the delivery team through the use of post-it notes and a location-based chart
Medium-term (lookahead plan)	Constraints were listed for the entire project duration
Short-term (commitment plan)	Devised on a daily basis to register the assignment of tasks to crews on site
Learning	Daily measurements of Percent of Plan Complete (PPC) along with root cause analysis

As illustrated in the table above, the master plan and phase planning were devised simultaneously due to the characteristics of the project, namely, a retrofit of small houses planned to be executed in short amount of time. In this paper, such plan will be referred as "master plan". It was devised by the delivery team through the use of post-it notes fixed on a chart at the site office as showed in the following figure.

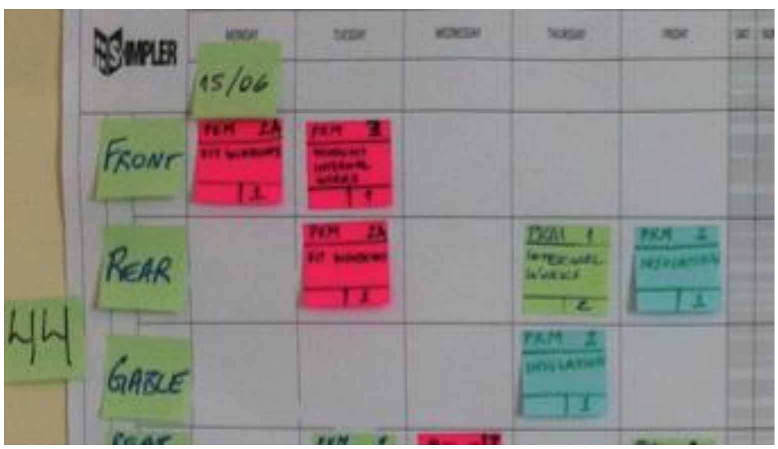


Figure 1: Post-it notes fixed on a location-based chart at the site office (master plan).

The number 44 in Figure 1 represents the house number and the locations (e.g. front, rear) refer to the facades of the house. The selection of facades as programming batches is due to the main retrofit processes (e.g. windows and doors, external wall insulation, and rendering) being executed in such areas. The different post-it colours indicate distinct retrofit processes. The post-it information was standardised and included the crew size, the task and its duration.

The lookahead planning was carried out for the entire project duration, i.e. four weeks. A list of constraints was generated and circulated via the web-based platform in order to communicate the deadlines and necessary actions to the delivery team. The short-term plan was carried out on a daily basis as well as the PPC measurements and root cause analysis. The actual lead time for retrofitting both houses was 6 weeks.

In terms of problems, there were still disruptions in the workflow due to the lack of materials. However, the root cause analysis indicated that the problem was actually linked to a failure in checking the quantity of material available for carrying out the insulation works. It is worth mentioning that such disruptions were considered as a minor problem and not a major issue as noted in phase 1A. Another problem faced was the lack of subcontractor's collaboration in the planning meetings as the foreman showed resistance to formalise the plans as well as analysing the problems and their root causes.

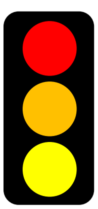
In terms of improvements, it was realized that the 4D BIM simulations were too detailed to enable the visualisation of the sequence of activities with clarity. As a result, it was agreed that the models should be redeveloped with a lower level of detail. Furthermore, collaboration was deemed as critical for the success of the next phases of the project so a meeting was organised with a representative from the subcontractor in order to tackle that issue.

PHASE 2 – WHAT-IF SCENARIO SIMULATIONS TO EVALUATE DISRUPTIONS

Phase 2 comprises the retrofit of two houses, both occupied during the construction. 4D BIM models were used in this phase as a means to evaluate what-if scenarios for the retrofit with a focus on reducing user's disruptions throughout the construction process.

This phase started with the definition of production scenarios and their activities sequence and work packages. For each scenario, different capacities of production resources were used, which caused different durations for the retrofit works. Also, three lines of balance were developed to enable the analysis of the number of disruption days in each house and the number of planned workers. This analysis was done on the basis of a classification of the work packages that could cause more disruptions for the end users (Table 3). The lead time planned for the retrofit in this phase was four weeks.

Table 3: Levels of disruptions of work packages.

Disruption level	Work packages
	Windows, External door, Internal Works, Loft insulation, Building services
	Lobby, Render, Facades elements
	Mobilisation, External Wall Insulation, Eaves, Demobilisation

The most disruptive activities for users, classed in red in the table above, are the ones that cause interruption of everyday life due to the need to access the houses inside and/or suspend the provision of building services. This information was essential to adjust the line of balance in order to reduce the number of overall disruptive days. Each period in which the disruptive activities (red and orange categories) took place in the house was counted. The parameters for each production scenario created for phase 2 are described in Table 4.

Table 4: Production scenarios developed for phase 2.

Scenarios	House number	Total duration (days)	Period disruptions Red (days)	Period disruptions Orange (days)	Total disruptions / house (days)	Total disruptions / scenario (days)	Total workers
Scenario 1	46	19	6	16	22	41	9
	47	20	7	12	19		
Scenario 2	46	21	9	14	23	41	7
	47	21	8	10	18		
Scenario 3	46	21	7	15	22	42	8
	47	22	7	13	20		

Scenario 1 is considered as the best option since it presents the shorter duration and less disruptive days than the other scenario. However, an evaluation of this result is needed with the project team, as this option requires more workers. This evaluation is planned to happen in the near future as the project is still on going.

DISCUSSION

The compression of the lead time noted between phase 1A (11 weeks) and phase 1B (6 weeks) can be seen as a benefit of utilising the Last Planner System (LPS). Principles associated to the LPS such as focusing on removing constraints before starting works on site and learning from mistakes were certainly factors that contributed to reduce disruptions in the workflow as well as compressing the retrofit lead time. The learning effect, evidently, cannot be ruled out as an additional cause of such improvements.

Another benefit of using LPS is the improvement in the project coordination and communication. For instance, the formalisation of the list of constraints fostered the interaction amongst project participants and assisted the project manager in coordinating the issues required for enabling the start of works on site. Also, it created a baseline of potential issues that can be used from phase to phase to avoid unnecessary disruptions in the workflow.

In terms of the LPS implementation issues, two aspects deserve attention. First, there was a need to promote adaptations in the way the LPS basic elements were applied in order to suit the retrofit context (Table 2). As the project referred to a retrofit of small houses to be executed within a short amount of time, it was decided to list constraints for the entire retrofit duration so uncertainties could be anticipated and disruptions avoided, besides daily, not weekly, plans were put in place in order to enable the creation of basic stability and establishment of short learning cycles. Also, the use of a visual management tools such as the location-based chart along with post-it notes for displaying the master plan helped to improve the understanding of project participants regarding the production strategies. Second, poor collaboration was considered as a major issue faced during the study as it precluded the appropriate formalisation of daily production plans and, as a result, it impeded the evaluation of daily production performance as planned. Such issue, addressed during phase 2, highlights the need of gaining top management support prior the implementation of LPS on site.

Regarding the use of 4D BIM simulations as a visual aid during the development of the master plan, an important lesson was learned, namely, the 4D model must correspond to the level of detail of the plan analysed. The use of a detailed model in phase 1B did not produce the expected results since the participants could not see clearly the sequence of activities as well as the potential disruptions associated to each production scenario.

Another important finding was the need of combining different tools to enable a better assessment of disruptions. The 4D BIM models should be used along with the Line of Balance (LOB) since the latter is better in analysing the disruptions according to the categorization devised in the study. The identification and counting of number of disruptions in the LOB proved to be easier than what was found when using the 4D BIM models. In fact, without the LOB, the creation of what-if scenarios as presented in Table 4 would not have been possible. The 4D BIM models are helpful for communicating the construction programme to clients and also valuable to enable the visualisation of aspects related to site logistics such as material storage, scaffolding position, and users' access.

CONCLUSIONS

The aim of the paper is to discuss the implementation issues and benefits of utilising Last Planner with the support of BIM 4D modelling in the context of retrofit of social housing. It focuses on reducing user's disruption throughout the construction process.

Regarding the benefits of utilising Last Planner, the research findings indicated that there is a potential, especially with regards to reducing the disruptions on site and compressing retrofit lead time. Improvements in project communication and coordination were also noted as a result of the LPS adoption. In terms of implementation issues, the need for adapting the basic elements of LPS in order to suit the retrofit context as well as getting buy-in from top management staff prior to start works on site were deemed as vital factors towards a successful practical application.

The use of 4D BIM simulations was also assessed during the development of the master plan as a supporting tool for stressing potential disruptions resulting from distinct retrofit strategies. The main finding on this matter is that the assessment of disruptions in such projects should consider the use of additional tools, e.g. the line of balance method, as the 4D BIM models are incapable to provide information about disruption in a suitable way, i.e. they do not allow comparison of scenarios as easy as the line of balance does.

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WORK STRUCTURING AT THE BOUNDARY OF REALIZATION: A CASE STUDY ANALYSIS

Laurie Spitler[1] and Nathan Wood[2]

ABSTRACT

Work structuring as a method of managing handoffs has been extensively investigated as it applies to supply chains within a project. Work structuring techniques help teams manage the supply chain and improve project delivery. Existing case study research, however, tends to focus on particular silos within a project, such as curtain wall or doors, frames, and hardware. The authors hypothesize that work structuring techniques can also be effectively applied at a project-scale to improve overall project delivery. In every project, there is Boundary of Realization, or transition from completion of design intent to "make ready" for construction. This Boundary of Realization period is characterized by a multitude of formal informational hand-offs between design and construction stakeholders, dictated by contract obligations and ingrained behaviours. The authors use case studies to examine the implementation of work structuring techniques at a project scale, the set-up of contractual requirements, and the patterns and methods of communication. With an understanding of contractual relationships and work structuring techniques used to manage a project's informational supply chain, the authors diagram methods for structuring informational hand-offs at the Boundary of Realization.

KEYWORDS

Boundary of Realization, Work Structuring, Work Chunk, Production Unit, Hand-off.

LITERATURE REVIEW

It is important to situate the discussion in the context and vocabulary of current research. Christian, et al (2014) provide a four phase project delivery framework based on the "V" model. The first two phases, Value Definition and Representation of Solutions, are separated from the last two phases, Realization of the Solution and Value Capture, by the Boundary of Realization (BOR). The BOR is point at which the project moves from representation to realization, and is the "point at which the quantity and rate of resource consumption typically accelerates by the greatest margin" (Christian et al 2014).

Christian et al (2015) define the ideal state of the realization phase to have "zero risk of failure because the representation was perfect and was analyzed to confirm with

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certainty that the value defined was intact and that the constructability was flawless." The BoR shown in the ideal state is a single moment.

Figure 1: Four Phase Project Delivery from Christian et al 2014

Work structuring is the process of analysing project supply chains and defining the work required to bring value to the customer; or simply put it "determines what work must be done on a project, who would be best-suited to execute it, and when they should be doing it." (Tsao 2005) Work Structuring consists of three basic components:

- **Production Unit:** The direct production of workers that share responsibility for similar work (Ballard 2004).
- **Work Chunk:** The unit of work that is handed off from one production unit to the next (Tsao 2005).
- **Hand-off:** The combination of (a) completion, (b) release and (c) acceptance of a work chunk between production units (Tsao 2005).

In her 2005 thesis, Tsao researches a framework for studying the concept of work structuring through in-depth analysis of case studies with the following findings.

Table 1: Tsao Work Structuring Cross Case Study Findings

Cross-Case Similarities	Cross-Case Differences
• Product design often defines 'means and methods' • Moving work upstream improves project delivery • Contracts impact feasibility of system-level thinking • A broader view can reveal high-impact changes • Tolerance management is a work structuring objective • Received traditions prevent innovation in work structuring • Successful projects still have room for improvement	• Product supply approach impacts degree of integration • Owner type influences degree of integration • Push for integration can come from any project participant

To understand how project teams create project-specific work structures, a baseline understanding of industry standard contract language is needed. The American Institute of Architects (AIA) provides that standard, having published sample contracts since 1911 with decennial updates. Series A of the AIA contracts represents the owner/contractor agreements and series B represents the owner/architect agreements. A study of the language describing hand offs between design and construction stakeholders in the most the prevalent AIA documents, A201 and B101, is summarized in Table 2 (AIA 2016)

Table 2: Study of AIA Language regarding Handoffs at the BOR

Handoff	A201-2007 (General Conditions of the Contract for Construction)	B101-2007 (Standard Form of Agreement: Owner and Architect)
Contract Documents	• The Contract Documents shall not be construed to create a contractual relationship of any kind between the Contractor and the Architect or the Architect's consultants, Subcontractor, or between any persons or entities other than the Owner and the Contractor. • The Architect will provide administration as described in the Contract Documents	• The Architect shall provide administration of the Contract between the Owner and the Contractor as set forth in AIA A201–2007, • Architect shall not have control over or responsibility for construction means, methods • Drawing deliverables defined - Prelim Design, Schematic Design, Design Development, Construction Documents
Submittals	• Shop Drawings are drawings, diagrams, schedules and other data specially prepared • Shop Drawings, Product Data, Samples and similar submittals are not Contract Documents. Their purpose is to demonstrate the way by which the Contractor proposes to conform to the information given and the design concept .. • The Contractor shall perform no portion of the Work for which the Contract Documents require submittal and review of Shop Drawings, Product Data, Samples or similar submittals until the respective submittal has been approved.	• "The Owner and Architect acknowledge that in order to construct the Work the Contractor will provide additional information, including Shop Drawings, Product Data, Samples.. • "The Architect shall review and approve or take other appropriate action upon the Contractor's submittals such as Shop Drawings, Product Data and Samples, but only for the limited purpose of checking for conformance with information given and the design concept expressed in the Contract Documents.
RFIs	• The Contractor shall promptly report to the Architect any errors, inconsistencies or omissions discovered by or made known to the Contractor as a request for information in such form as the Architect may require. • The Architect will review and respond to RFIs about the Contract Documents.	• RFIs shall include, at a minimum, a detailed written statement that indicates the specific Drawings or Specifications in need of clarification and the nature of the clarification requested. The Architect's response to such requests shall be made in writing within any time limits agreed upon.

INTRODUCTION

The Boundary of Realization is described as the moment that "drawings of stone blocks become the stone blocks themselves" (Christian et al. 2014). Two important implications of this statement must be examined.

First, it becomes apparent that the Boundary of Realization is indicative of a shift of control in the project. In the representation phase, the architect is responsible for nurturing and developing the design intent; once the vision becomes real, or the "stone blocks themselves", the contractor has become responsible for the execution of the design intent. In traditional contracting, the architect and contractor are not contractually linked. The result is that the progression and hand off of the project vision happens between two parties with no direct relationship and differing contractual motivations.

Second, is should be recognized that the project does not cross the Boundary of Realization as a unit, but in phases. Early work, such as structure, is released and installed before design is complete on later work such as finishes. During the project-wide transition over the the BOR, coordination of building details is a negotiation between scope that has materialized, and scope that is still in the representation phase.

The hand off process between contractor and architect in the traditional Guaranteed Maximum Price (GMP) contract is largely prescriptive[3]. Upon receipt of contract drawings, the contractor shall complete submittals to demonstrate compliance with design intent, and submit RFIs to clarify the drawings. In this way the project moves, scope by scope, past the Boundary of Realization. To comply with a prescriptive contract, a party merely needs to comply with the outlined processes. Collaboration for the purpose of bringing additional value to the owner is not incentivized.

As lean construction has gained popularity, the AIA published the *C195–2008 - Standard Form Single Purpose Entity Agreement for Integrated Project Delivery (IPD)* (AIA 2016). By tying all major participants to on contract with shared risk and reward, IPD defines the relationships between project stakeholders while avoiding prescriptive means and methods. Figure 2 contrasts the bifurcated contact structure of GMP with collective structure of IPD.

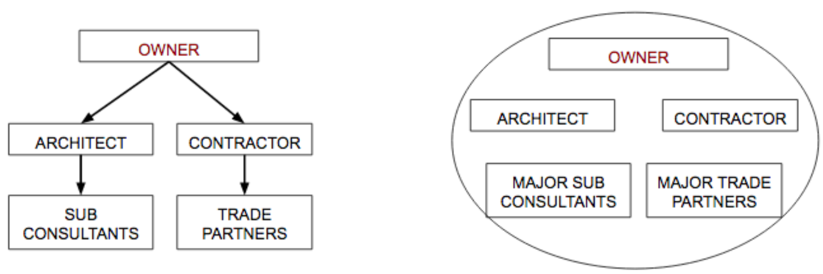

Figure 2: Relationship Structure for GMP (left) vs. IPD (right) Contract Delivery Type

CASE STUDIES

Five projects were identified whose project teams were actively analysing and questioning traditional hand offs. All projects were new vertical construction, with a value greater than 50MM USD. The methodology employed involved surveying project teams via a cloud-based worksheet including process questions and relationship diagrams, interviews with

[3] Throughout this paper, the term "prescriptive" is used to describe contractual requirements that include specific steps to reach a desired outcome. The term "perfomative" is used to describe contractual requirements that define the desired outcome, but not the specific steps.

key contacts from general contractors and design teams, and verification of findings via cloud collaboration. No owners participated in the in direct interviews. Follow up research to validate the benefits of the research findings to the owner would be beneficial. During the interview process, three topics were discussed.

- The Project's formal contractual relationship and how it differed from the self-described relationships
- Informal communication channels which occur outside contract requirements
- The handoffs and processes at the Boundary of Realization: Drawings, Specifications, RFIs, and Shop Drawings

Teams were asked to describe their relationships and processes in detail, and process deviations from AIA contracts were analysed through work structuring process mapping. Table 3 presents the communication findings. "Formal" indicates the team followed contractual guidelines; "Informal" indicates that there was communication outside of the contractual guidelines; and "Open" indicates that the team co-located in a Big Room environment.

Table 3: Case Study Contracts and Communication

	Contracts		Communication				
Case Study	Actual	Self Describe	Owner / Architect	Owner /GC	Architect / GC	Sub Trade / Engineer	GC Self Perform Scopes
CS-1	GMP	GMP	Formal	Formal	Informal	Informal	Limited
CS-2	GMP	"IPDish"	Formal	Informal	Informal	Informal	Structure, Framing
CS-3	GMP	"IPDish"	Open	Informal	Informal	Informal	Structure, Framing
CS-4	IPD	IPD	Open	Open	Open	Open	Concrete, Interiors
CS-5	IPD	IPD	Open	Open	Open	Open	Limited

SPECIFICATIONS AND SUBMITTALS

Specifications are developed as a written description of project requirements not shown in the drawings. Among other things, they outline product data, and what is required for submittal by the contractor. The purpose of Submittals is, according to the AIA, to "demonstrate the way by which the Contractor proposes to conform to the information given and the design concept expressed" (AIA 2016).

All case study teams modified the specifications to align with construction execution. CS-1 had its design-assist MEP trade partners review and mark up the specification to conform with their negotiated scope of work. CS-4 developed a mostly prescriptive specification, but invited the general contractor and trade partners to comment and provide substitution requests prior to the final submission of the Specifications to the state review agency.

CS-2 and CS-3 placed emphasis on the performative specification over the prescriptive specification. For example, when specifying concrete, the specifications would provide performance requirements (3,000 PSI strength) rather than prescriptive requirements (specific mix design). The contractor in CS-3 went so far as to provide the architect with specific language for inclusion in the specifications.

CS-5 questioned the need for specifications at all. Acknowledging the conventional construction wisdom that "no one reads the specs, anyway", they asked the IPD stakeholders which parts of the specifications were important:

- Architect: To define product data and establish QA/QC requirements
- Structural Engineer: To include "or approved equal" language
- Mechanical Engineer: To determine which equipment to buy
- Contractor: To force trade partners to submit required submittals
- Owner: To define requirements for record handover to operations and closeout

After realizing the true value of the specifications to the project, the team was able to reduce the size of the specifications by approximately three quarters.

A major finding in the case studies, mapped in Figure 3, is the separation of performative and prescriptive elements of the specifications. By identifying the material on the project that only has performative requirements and soliciting input from suppliers, the project team can reduce variablity in lead times and cost. The teams have restructured the work package "create specification" into two smaller packages – performative and prescriptive, and then assigned the work to the entity with the most incentive for creating project value. In this way, teams avoid having the designers inadvertantly determining means and methods, and reduce outcome variability.

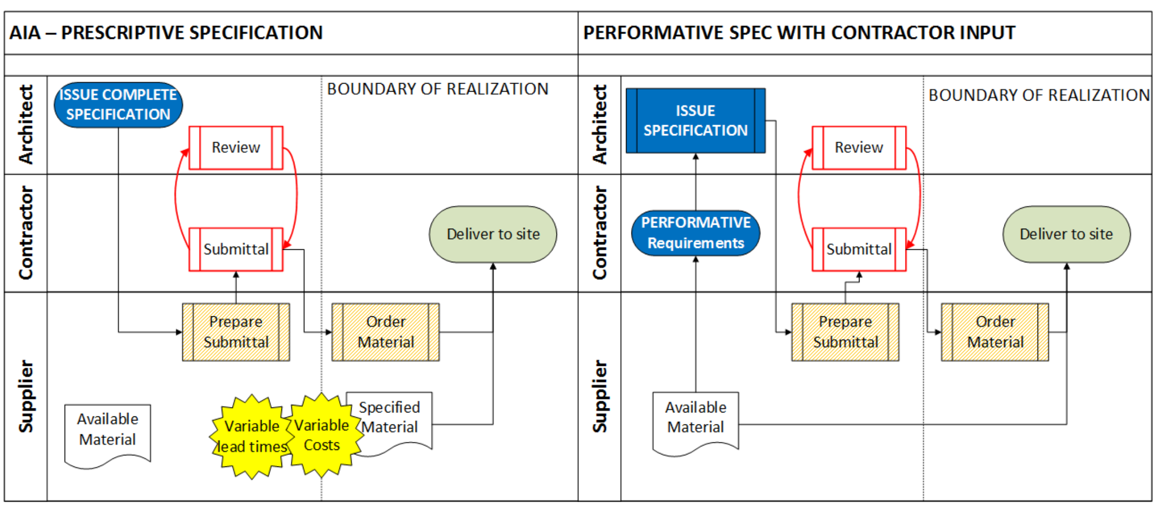

Figure 3: Specification - Submittal Process Map: Traditional (L) vs. Restructured (R)

DRAWINGS AND REQUESTS FOR INFORMATION (RFIS)

The modifications to the process of drawing issuance and RFI response are sufficiently unique as to warrant individual summary.

CS-1, the most self-described traditional project, adhered to the drawing issuance model described by the AIA contracts. Periodic sets of drawings were issued, and prior to construction, contractor constructability input was solicited. Post bid, periodic bulletins were issued to capture design changes, owner requests, and RFI clarifications. To mitigate RFIs, the team kept a log of design issues and maintained a policy of only submitting confirming RFIs. Basically, whether through the logs or direct communication, the issue at hand was thoroughly understood by all parties prior to submission. To this end, the RFI acted only to document the change that affects code, aesthetics, or performance of the building. By separating the solving of the issue from the documentation of the solution, the team reduced the variability of outcome of the work hand off.

CS-2 radically changed the pace of drawing issuance. Throughout the realization phase, informal progress sets of drawing were issued and processed on a weekly basis according to the following cycle:

- **Friday:** Drawing of new work issued by design team.
- **Monday:** Historical Drawing Overlays sent to affected trades for pricing.
- **Tuesday:** Rough order of magnitude pricing due to contractor by end of day.
- **Thursday:** Pricing meeting with owner to review and release new work.

Official sets of drawings were produced and submitted to the Authorities Having Jurisdiction (AHJ) on a monthly basis. RFIs were only submitted if a substantial change needed to be executed prior to the official drawing issuance. If an RFI was issued, it was a full sheet RFI. It should be noted that this cycle lasted well into construction, and occasionally required the removal of installed work. While this seems like waste, the owner on this project valued the ability to modify the design over the cost of modifying installed work, and therefore, this process did deliver maximum value to the owner.

The contractor in CS-3 was able to avoid many potential RFIs by moving the constructability review upstream. The contractor relied heavily on building information modelling (BIM) to develop field work packages that used model-based layout in lieu of 2D contract documents. When issues arose during creation of the work package, the team started a “BIM Con”, or tracking log. When creating work packages for a scope, the BIM con responses were included.

CS-4 worked closely with the state review agency to structure the approval process using a combination of confirming RFIs that were captured periodically into a full sheet drawing change order. The Boundary of Realization on this project was almost exclusively controlled by the AHJ and their on-site inspector of record.

CS-5 also issued drawings on a weekly basis. Due to the specific jurisdiction, it was possible to capture changes retroactively through the as-built process, making RFI approval by the AHJ unnecessary. In fact, CS-5 did not use formal RFIs at all on the project. If a large issue arose, the project would hold a “swarm”, or gathering of all entities needed to resolve the issue. The issue was discussed, a plan was formed, and the solution was represented in the next drawing issuance. This ‘no-RFI’ policy extended to sub trades that were outside of the IPD risk pool. All companies were required to complete an on-boarding process to introduce them to lean philosophy prior to construction start.

The drawing-RFI process is shown in Figure 4. The Process Map on the left shows the process as described by the AIA; characterized by inconsistently batched releases of information. The information needed to build is contained in ***both*** project drawings and individual RFIs. The Process Map on the right shows the restructured work packages. By issuing and reviewing drawings every week, the team have eliminated RFIs. Additional benefits gained are reducing the variability of drawing updates to the field and the collection of all information needed to build into ***one*** document.

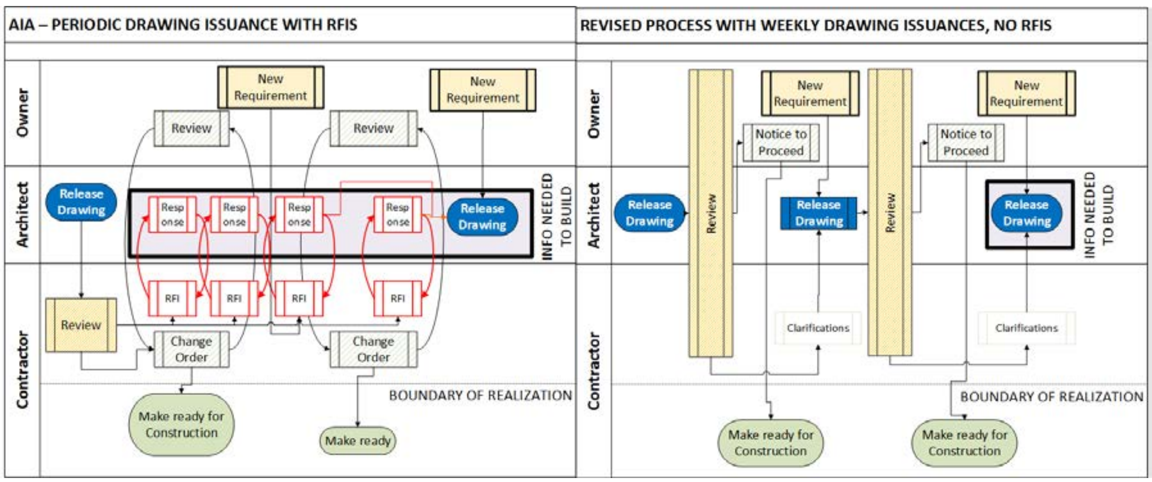

Figure 4: Drawing - RFI Process Map: Traditional (L) Vs Restructured (R)

DISCUSSION

To structure the discussion, the authors reference the cross project findings in Tsao's 2005 thesis and discusses the conclusions which the case study research supports.

Product design often defines 'means and methods'.

The specification and submittal workflow, as described by the AIA, tasks the architect with complete performative and prescriptive descriptions of project components. Recognizing that the architect's primary contractual motivation is to produce code-compliant drawings, the contractor in CS-2 provided the balance of information related to constructability. Multiple case studies had contractors providing significant input into specification and drawing creation.

Moving work upstream improves project delivery.

In changing the specifications of the project to align more closely with the needs of the respective customer, the teams are influencing the supply chain of information on their project. By having the parties involved with construction execution provide input into the specifications, the teams avoid inadvertently having the design team set the means and methods for construction. As a result of the performative specifications, CS-2 and CS-3 indicated that the response time on specifications was reduced. The teams effectively reduced the size of the work package to be reviewed to that which was necessary for performance. The team divided the work package and aligned the work with the entity who most benefited by correct execution

Contracts impact feasibility of systems level thinking.

The case study finding demonstrated that IPD contracts allow for more comprehensive revisions earlier than with GMP contracts. CS-5 modified the submittal review process to eliminate waste. The steel supplier modelled and detailed the steel in three dimensions. Rather than abstracting the information into a two dimensional submittal, the team reviewed and commented on the shop drawings from within the native authoring program. However, CS-2 and CS-3 demonstrated that despite formal contract requirements, the contractor was able to use informal communication through relationship management to significantly alter work structures.

Received traditions prevent innovation in work structuring.

The RFI process was originally put in place by the AIA to allow the architect to issue a simple drawing clarification, however, this process leads to dispersed information. Clarifications through BIM collaboration or automated drawing can be less of a burden on the architect than responding to an RFI, as demonstrated by CS-3 and CS-5. The need for RFIs as the specific vehicle for clarification is driven almost exclusively by legacy contract or AHJ requirements, as shown by CS-4. If teams can free themselves from contractual RFIs, they open the possibility a more streamlined single source of truth.

ADDITIONAL FINDINGS

Contractors who self-perform take more responsibly for the project supply chain

The team on CS-3 expanded the idea of a shop drawing as conformance to design intent and created "work package drawings" based on the coordinated model. In the field, work packages are used in lieu of construction documents. In traditional contracting this would be perceived as taking on more risk. CS-3 realizes that the greatest risk is not completing the scope correctly. CS-3 added an additional hand off in the shop drawing process, but they tailored the hand off to the needs of the customer - the installation crew.

Project supply chains should be restructured to reduce the variability of information released for construction

CS-3 and CS-5 dramatically reduced the size of the drawing issuance work package from several months' worth of work to one week. By issuing full sheet RFIs, CS-3 approached one-piece flow. This restructuring has many benefits, including a reduced cycle time for constructability and cost feedback. RFIs, as clarifications of the contract documents, become nearly obsolete if changes are picked up in a weekly drawing cycle. Eliminating RFIs removes a whole documentation cycle and consequent waste. In this process, the drawings become the single source of truth for construction execution.

CONCLUSION

The case study findings have demonstrated that that work structuring is an appropriate lens through which to study and restructure project scale informational supply chains. By using process maps to study the flow of information in the Boundary of Realization period, it is possible to understand and restructure handoffs to improve project delivery.

The case study findings have demonstrated that collaborative contracts enable complete restructuring of informational supply chains. The research has also demonstrated that with informal collaborative relationships, projects with traditional contracts can also successfully restructure informational supply chains. In both cases, constraints often remain external in the tolerance of the Authority Having Jurisdiction.

The findings of the case studies demonstrate that the teams have restructured their informational supply chains to (1) incorporate constructability input into the contractual documents and (2) structured information flow to reduce variability of information to the field. Projects seeking to streamline handoffs at the Boundary of Realization should consider the concrete case study examples of process improvement, and then map and analyse their process with these principles in mind.

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GUIDELINES FOR INTEGRATED PRODUCTION CONTROL IN ENGINEER-TO-ORDER PREFABRICATED CONCRETE BUILDING SYSTEMS: PRELIMINARY RESULTS

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• ABSTRACT

The use of prefabricated building systems has grown in several segments of the construction industry, especially in emerging economies, due to the need of reducing project duration and costs, improving safety, and dealing with the shortage of skilled labor. Most companies that operate in this market are engineer-to-order (ETO) organizations, in which there is a need to integrate the planning control processes concerned with design, manufacturing and site assembly. One of the approaches used to address these issues is to adopt hierarchical levels for planning and control, in which there are order confirmation points considering the lead-time of some tasks. The aim of this research project is to propose guidelines for integrated production planning and control in ETO prefabricated concrete building systems. It is based on two case studies carried out a leading company in this segment in Brazil. The research method involved interviews with different stakeholders, participant observation in planning meetings, and direct observations in two construction sites. The main contributions in this study are related to enhance the integration between plant and site assembly. Also, use of 4D BIM simulations for analysis of physical flows and evaluate and control the assembly process.

• KEYWORDS

integrated production control, prefabrication, lean construction.

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• INTRODUCTION

The use of prefabricated building systems has grown in several segments of the construction industry, especially in emerging economies, such as Brazil. This type of production system requires close coordination and synchronization between the design, manufacturing plant and construction sites, so that the assembly process is not interrupted and the level of inventories is kept low. Usually, prefabricated building systems faces a high level of uncertainty, due to the lack of predictability of the design process, long transportation distances between the manufacturing plant and construction sites, interference from previous construction stages, unreliable site installation plan, among other factors.

This production system can be defined as engineer-to-order (ETO) in which the "Customer order decoupling point" (CODP) lies in the design phase, that is, the customer order is made early in the design phase of a product (Gosling; Naim 2009). In this kind of production environment there is a strong dependence of the production system on client decisions, which might interfere even in the product specification during the fabrication process. Therefore, a major difficulty in managing engineer-to-order prefabricated building systems is to integrate planning and control of different processes, such as design, fabrication and assembly on site. ETO is characterized by low volume production, uncertainties, mix fluctuations and volume of non-standard product route, demand forecasting with low stock, high level customization, complexity, changing requirements, long lead times, flexibility and dynamism (Berkel 2010). The dynamism of the market requires flexibility of the ETO system to cope with demand fluctuations. Gosling and Naim (2009) and Little et al. (2000) mention the flexibility as a crucial factor for ETO companies. Commonly, managers set goals previously to the start of the project and controlling is limited to monitoring the progress of activities against a plan. In a highly uncertain environment, like ETO, Johnston and Brennan (1996) suggest another form of management in which managers need to learn from production to precisely define the following goals, called management-as-organising.

The potential benefits from prefabricated building systems are many and diverse (Blismas et al., 2006). For example, Zabihi et al. (2013) argued that with prefabrication, capacity and quality could be increased, while simultaneously offering more complex building components at a lower cost. Other potential improvements involve the reduction of construction waste (Lachimpadi et al., 2012) and a lower environmental impact and higher sustainability performance (Chen et al., 2010). Also, the delivery of prefabricated building systems has been seen as a means for additional productivity advancement (Jansson et al., 2013; Thuesen and Hvam, 2011). However, most implementations of Lean concepts on prefabricated systems have not explored opportunities for improving the overall system. An existing common problem is that the improvements are implemented in a specific subsystem or in a particular stage of the construction process, such as design, prefabrication or assembly.

The focus of this paper is on planning and controlling ETO prefabricated systems, in which a company is responsible for design, prefabricate and assemble components on site. The company is engaged on the implementation of some lean concepts, such as reducing batch-size, improving flows through pull production and 4D BIM simulations, increasing the product flexibility of the fabrication process to deal with uncertainties. This paper discusses the preliminary results of a research project of an on-going research project that aims to integrate design, prefabrication and assembly. This study has been developed in collaboration with a prefabricated concrete company in Brazil. A set of guidelines for devising integrated planning and control systems for ETO prefabricated concrete systems has been proposed in this paper.

• RESEARCH METHOD

Design Science Research (DSR), also known as constructive research, was the methodological approach adopted in this study. It is a way of producing scientific knowledge that involves the development of an innovative artifact to solve a practical problem, and simultaneously makes a kind of prescriptive scientific contribution (Holmstrom et al., 2009).

The research process was divided into two phases. The first consists of identifying and understanding a practical problem in the company, while the second is concerned with devising and implementing a solution. Finally, the applicability of the solution will be analyzed, and the relations to existing theoretical knowledge will be examined. There was participation and involvement of various sectors of the company. The sources of evidence used in this study was semi structured interviews with the different stakeholders, document analysis, participant observations in planning meetings with members of the construction company and the prefabricate contractor, direct observations in two construction sites, analysis of existing databases and workshops. Five semi structured interviews were carried out in Porto Alegre, where the construction sites were located. The interviewees were engineers responsible for the construction, assembly responsible and safety technician. Another seven semi structured interviews were realized in the company headquarters in Curitiba, and there were interviewed responsible from different sectors such as planning, design, expedition, quality, occupational safety and health, budget and research and development . The interviews were recorded and lasted an average of one hour.

Direct observations and case studies were carried out in Porto Alegre. Along a month were made six visits in a construction site in which the partner company was responsible for the design, production and assembly of structural components of a shopping mall. Three researchers collected data such as cycle time of piles, slabs and beams, work daily information, schedule and reports of security. The purpose of these visits was to carry out an exploratory diagnosis to understand the processes between plant and assembly as well as the problems and constraints that arose at the construction site. After diagnosis four researchers were involved from the beginning in a construction site where the partner company was responsible of the design, production and assembly of structural components of a university building. From August 2015 until February 2016 weekly meetings were carried out with the engineer responsible for the assembly on site. In this case efforts were performed to implement improvements.

Also, three workshops involving the research team and company's representatives were carried out to create a discussion group in order to provide a common understanding of concepts and practices. It was discussed some key lean concepts such as work in progress, size batch and continuous flow as well as diagnosis carried out in the visited construction site and some improvement opportunities were suggested.

• DESCRIPTION OF THE COMPANY

The company is a large fabricator and assembler of precast concrete in Brazil. It has more than 1.500 employees and four manufacturing plants. The businesses are basically carried out in two main business units: (i) commercial sales, which are sold standard products that always exist in the stock such as slabs, piles, tiles and panels; and (ii) global enterprise, when a whole new project, with customized components is requested. Those projects can be from different segments such as shopping malls, supermarkets, shops, sheds, vertical buildings and special constructions. This latter business is focused on engineer-to-order (ETO) products, while commercial sales on make-to-stock (MTS) products. This study is focused on the operations of the global enterprise business unit, in which projects are unique, designed with the client in order to meet specific requests.

Besides the fabrication of the structural components, the company also develops the structural design of the project, and makes the assembly on the site, as required by the client. The organizational structure is hierarchically organized, so for each unit there is a manager who leads a team and keeps constant feedback to the headquarters in Curitiba. Currently, the company intends to improve its methods and concepts for managing the production system as whole. For this reason, a new department called Integrated Planning has been created in order to achieve better integration among design, fabrication, and assembly on site. One of the first improvement efforts was to divide the delivery of the project in smaller batches. In this idea, the different production phases should deliver part of the project to the next phase, according to this batch. After the outline design, the project should be detailed in batches according to the needs of the construction site. However, until this moment this idea has not been fully implemented.

The purpose of this division was not only for controlling the assembly process, but also for controlling the design and fabrication processes, based on the benefits of reducing batch size. The challenge of this implementation process is explained in the next section.

• DESCRIPTION OF THE EXISTING PLANNING AND CONTROL SYSTEM

By dividing projects into stages, it is assumed that the company would not produce all the products at once, emphasizing the importance finalizing a batch, or stage, before moving to the next. Though the company's intention is to base design, production and assembly control on those stages, each unit had a different focus.

In design, the implementation of controls based on stages is still a challenge. Firstly, the project outline has to be designed as a whole. After customer approval, the project is divided into batches for detailing of parts according to the assembly sequence. In many cases the project combines construction technologies, such as metallic or molded in place structure which need to be defined by others. This process is often time consuming, making it common for the detailing to start the project by the easiest parts, which has no critical interdependencies with other technologies, or that has been already defined by the customer. This implies in production out of sequence, generating inventories in the plant yard.

The focus of the manufacturing plant is to use the maximum capacity, producing in large batches to better utilize the molds. The disadvantage of this process is the programming and production of parts belonging to subsequent stages and often undefined by the customer. As a result they end up generating a lot of stock in the plant yard.

At the construction site, the assembly process needs to fit into the requirement of the construction site. The division in stages in this case helped in controlling the parts for assembly, but the division in large batches do not allowed to give flexibility for some challenges that are presented, such as uncertainties or changes in the project by the customer, change of sequence assembly due to problems in the production or at the request of the contracting company, and was difficult to be able to view a particular sequence.

• RESULTS

After the assessing the existing system, the main focus of the implementation process was to develop and propose improvements in the planning and control system of the company. The lack of synchronization between planning department, production and logistics units, and assembly in site construction lead to a preliminary set of guidelines that was established for guiding this implementation process. Those guidelines aim to integrate and promote collaboration between sectors in order to generate stability in the workflow and enhanced the feedback. These are presented below.

• ALIGNING FABRICATION AND SITE ASSEMBLY RHYTHMS

The prefabrication process is often desynchronized from the assembly process on the site. In the analyzed company, each component would take around three to four weeks to be fabricated. The scheduling of the plant is set two weeks in advance, which means that throughput time inside the plant is one week.

The time required for erecting a pillar on the site, for example, takes less than an hour, which is one of the longest site processes. This uneven peculiarity of the production process is often workaround through the use of high levels of inventory after fabrication. Inventory means longer throughput times, and, in this kind of environment in which there is uncertainty in design specification, is very risky to produce in advance. In both of the analyzed cases, the overlapping between detailing design and the assembly process was common. Those components under discussion were left aside while the ones with no issues were produced regardless the assembly sequence. This was one of the difficulties for implementing the control in batches.

In order to better synchronize the production, the plant needs to fabricate components at the last responsible moment to deliver to the site, giving enough time for the detailing decisions to be taken, and still delivering on time at the site. The mismatch between fabrication and assembly has to be considered together with the plant capacity and the amount of construction sites carried out at the same time. The discrepancy in rhythms, or the production takt time, is what will reveal the need for inventory or not.

The second case had a long process of design compatibility, which delayed the detailing and hence the fabrication process, affecting the site assembly. However, during the second stage of production, a decrease in the demand for components from other sites enabled the scheduling department to dedicate one of the plants for the site under analysis. At that moment, most of the components were produced, but still before it was really required by the site. The scheduling department was planning the plant based on the predicted site demands from the master schedule. The event revealed that fabrication and site assembly could be better connected, but there was a need to understand the real demand from the site, so that the plant could be flexible to attend site needs and still having a good utilization of capacity. The need of this confirmed demand leads to the second guideline.

- **ENHANCE THE INTEGRATION BETWEEN PLANT AND SITE ASSEMBLY THROUGH A LOOK AHEAD OF THE DELIVERY SEQUENCE**

The use of an ETO approach in the construction leads to an important constraint: the logistic process. The precast concrete has some peculiar characteristics as a product. It is configured by heavy components and a relative small number of components: a four-pavement pillar is one component, a beam is one component. For this reason, an important tool for integrating plant and site assembly is the transportation batches, which were defined by the site manager through a loading plan. The loading plan describes what should go in the truck, and when it should arrive in the site. It was related to the sequence of components required, and to the truck capacity. This tool was already been used by the company when the study started. However, during the first case, the site manager would send the loading plans only to the expedition department, two days before it was required. It means that the loading plans had to be based on the produced components and had no impact on the production sequence. This problem was leading to a high level of work-in-progress, as shown in Figure 26.

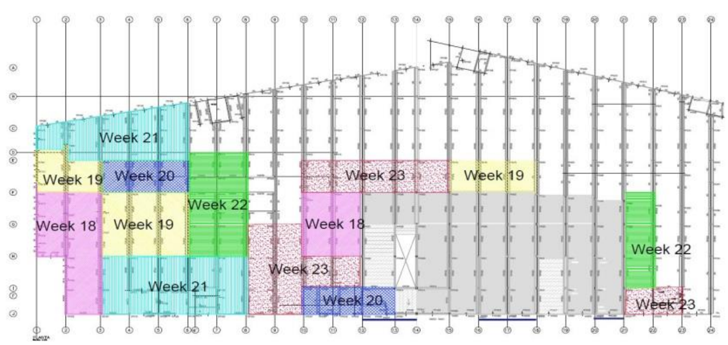

Figure 26: Execution sequence of the first case

During the second case, the researchers suggested a longer horizon of loading plans, which should be sent to the scheduling department, instead of going directly to the expedition. The scheduling department could make the plans according to a confirmed demand from the construction sites, rather than the early-defined master schedule. Figure 27 shows the amount of components already produced by the plant in a 7-weeks look ahead of loading plans, from the construction site.

Figure 27: Percentage of already produced components in the loading plans

According to the coordinator of the scheduling department , this practice was adopted by five different construction sites and was helping them to be aware of the construction site demands, decreasing the time components were waiting in the plant yard before going to the site. It is important to configure the look ahead horizon in the construction site larger than the time lead time required by the scheduling department to produce the component. In the case of the company analyzed, this lead time was around three weeks, so the minimum horizon for the site look ahead was four weeks. It is worth acknowledging that there was still a need for confirming the delivery of the components with the expedition, as shown in Figure 28. As there are a large number of interactions between the structure and the other services in the construction site, there is a high level of variability. Therefore, the site manager would keep the practice of confirming the deliveries two days before, in order to expedite or delay critical deliveries.

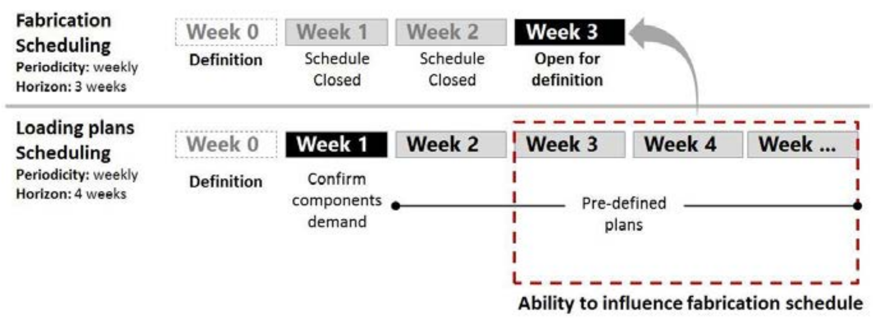

Figure 28: Relation between short-term planning horizons

The benefit of this practice is more than having a confirmation of the demand; it provides a means for decentralizing the planning process from the company headquarters. Before this implementation, the master schedule of the company was the only source for the plant scheduling. Considering that this type of schedule is developed at the very beginning of the project and that there are contractual barriers for making changes, it was not a reliable source of information.

In order to develop a more reliable look ahead, the site manager of the prefabricated system needs to deeply understand how the construction as a whole should work. It requires a well-defined production system design of the site. Although this task will be often under the scope of the construction company or the general contractor, the contractor responsible for each system should be aware of the different possibilities they are able to produce the building, this leads to the third guideline.

- **FOCUS THE LOOK AHEAD PLANNING IN THE ANALYSIS OF PHYSICAL FLOWS WITH 4D SIMULATION SUPPORT**

The environment of construction is considered very dynamic. Changes happen quickly over time and end up requiring a more systematic review of management system. This system should make the integration of all construction stages and their various stakeholders. Still, agility in receiving information and the fastest possible identification of errors or poorly designed solutions, help decision making.

The use of Building Information Modelling (BIM), particularly the 4D simulations, has become an important ally to managers. The simulations allow improvements in communication, visualization and serve as a tool for evaluation and control of physical flows. In this study, the simulation BIM 4D was used for the simulation of different assembly scenarios with realization of execution plans of activities and use of available resources. Resources include here prefabricated components, equipment and manpower.

The simulation BIM 4D helps to understand the construction components and the schedule progress that, in turn, results in a better construction planning. The analysis of execution plans assists in optimizing the assembly of the elements and control of idleness work teams and equipment used in the assembly. Figure 29 shows the similarities of 4D simulation model with the executed work in this area.

Figure 29: Comparison between 4D simulation and real executed work

In the second case, in which some assembly scenarios were tested, there were some important constraints in the site. The precast concrete was allocated to an enclosed area, four pavements underground, restricting the area for trucks and cranes. The uses of two different teams at the same time were, at some moments, not possible because of space constraints. The completion of the structure was especially critical because of the lack of space for the main equipment: truck, crane, and elevating work platform.

The evaluation of 4D model with the physical flow analysis was made during the weekly planning meetings. These planning meetings were carried out with members of the construction company and the prefabricate contractor. The use of 4D simulation in those meetings enabled a better understanding of the assembly process and execution sequence by the parties involved. Information was updated in the model from the discussions in the meetings. Figure 30 illustrates an assembly sequence from 4D simulation screenshots.

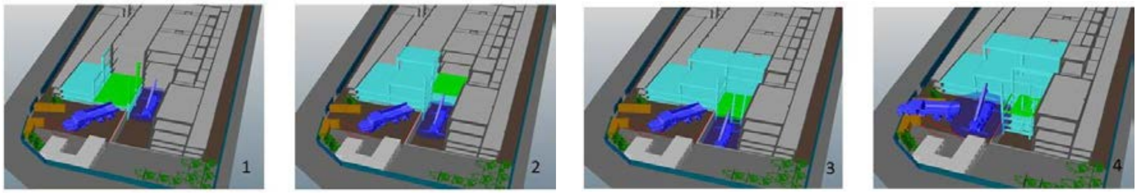

Figure 30: Screenshots of 4D simulation

Although the use of 4D simulation was not yet adopted by the company, the study revealed that the use of the BIM model for developing the 4D could affect more than the physical flow analysis. The control tools that the site manager had to deal with required a lot of paperwork, while the simulation provided a platform in which the semantic information of the components, mainly their names, was related to the location of these components in the project. This simple realization revealed how complicated and time consuming were the control tools, leading to the fourth and last guideline.

- **FACILITATE THE EVALUATION AND CONTROL OF ASSEMBLY PROCESS WITH 4D SIMULATION SUPPORT**

In both cases, it was observed the time spent by the site manager for making the production control. More than controlling their teams, the site manager should also respond to the construction company of the site and to the integrated planning department from the company headquarters. The first control was carried out in a visual manner, by painting the project floor plans, the marked components were then converted into report for the headquarters and were also used to measure productivity. The construction company used a control system based on the Last Planner System, so the control was based on the committed work packages.

Although the study still does not have final results over the implementation of new control tools, some attempts have been made in order to make the control process easier and more reliable. The first attempt was to facilitate the development of the loading plans using the information from the 4D simulation model, linking names and locations together with updated information of the fabrication process. Until this moment, it was possible to see a strong decrease in the time spent by the site manager to develop the loading plans.

• CONCLUSIONS

The basis for the discussion and establishment of the guidelines emerged from the process which aims to integrate planning and control in a complex engineer-to-order environment. Some important contributions such as understanding the real demand from construction site enables the plant to be flexible to attend site needs and still having a good utilization of capacity, as well as decreasing the time components were waiting in the plant yard before going to the site. Another contribution was related to configure a look-ahead horizon for the loading plans. The development of the loading plans was facilitated by 4D simulation model that helped to understand the construction components and the schedule progress resulting in an accurate construction planning. Information from the 4D simulation model enabled to understand how the construction as a whole should work and the trends to optimize the assembly of components and control of work teams idleness and equipment used. The guidelines suggested here were a useful starting point for enabling more reliable information of the construction site. This paper is part of an on-going research which intends further deepening of the topics developed.

• ACKNOWLEDGMENTS

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LAST PLANNER & BIM INTEGRATION: LESSONS FROM A CONTINUOUS IMPROVEMENT EFFORT

Patricia Tillmann[1] and Zach Sargent[2]

ABSTRACT

This paper discusses the benefits of adopting the last planner system and Building Information Modelling (BIM) from a Mechanical, Electrical, Plumbing and Fire Protection (MEPF) perspective. The main objective of this research was to understand how to advance the integration of such practices as means to improve workflow in complex and fast-pace projects. The paper presents the anticipated benefits from such integration and the barriers identified to realize those benefits. The discussion is based on findings of an in depth empirical study in which the learning component of last planner was used to initiate a continuous improvement effort. A comparison is drawn between a desired state on BIM and last planner integration to a real case, followed by reflections on potential solutions to bridge the observed gap. The main contribution of this paper to practice is to understand how to advance the integration of BIM and last planner to improve MEPF coordination and workflow in any kind of construction project, independently from the method of delivery. Expected contributions to theory are related to further understanding how lean processes and technology can be used together as catalysts to increase collaboration in construction projects.

KEYWORDS

BIM, Last Planner System, Production Flow, MEPF coordination

INTRODUCTION

Mechanical, Electrical, Plumbing and Fire Protection (MEPF) systems on modern projects account for about 40% to 60% of total construction costs (Khanzode, 2010). In complex projects like hospitals, these systems have to be well designed and coordinated to avoid conflicts. Failure to identify the spatial dimensions of the MEPF systems and checking for potential clashes between the different MEPF systems before construction can result in a lot of rework which can further lead to time and cost overrun (Khanzode, Reed and Fischer, 2008).

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One of the biggest areas of improvement in the design and coordination of MEPF systems is the use of Virtual Design and Construction (VDC). Studies report that projects adopting VDC were able to solve virtually all conflicts between these systems, dramatically reduce rework in the field and achieve zero change orders related to field conflicts (Khanzode, Reed and Fischer, 2008).

In addition to gains in productivity and efficiency due to the resolution of potential field conflicts, Spitler et al. (2015) demonstrates that the lessons learned from weekly plan failures can also be valuable source for understanding how to improve modelling efforts.

Within this context, this paper reports on the adoption of Last Planner® System (LPS) and Building Information Modelling (BIM) from a mechanical contractor's perspective. Thus, the aim of this study was to compare the desired benefits of integrating BIM and LPS (Last Planner® System) for MEPF into an actual construction project, and to identify opportunities that can be used to advance such integration in the industry.

In order to do so, an in depth case study was carried out. The case was a critical care healthcare facility project in which the mechanical contractor was performing in a design-assist role with a fixed price contract. BIM was a contractual requirement and the level of detail and project requirements were defined and established under a BIM execution plan. The last planner system was not utilized to its full extent in the project. Data for this research was collected during the implementation of lookahead planning and weekly work plans by the mechanical contractor's team.

ADOPTING LAST PLANNER AS A SUBCONTRACTOR

The development of the Last Planner System was motivated by the observation of a mismatch between master schedules and the progress of work performed on construction sites (Ballard, n.d.). Project management traditionally focuses on enforcing conformance of activities performed in the field based on a Critical Path Milestone (CPM) schedule. This CPM schedule is used to inform the individual crews on the activities that they should be performing. Studies conducted by Ballard and Howell in 1997 indicated that frequently there is a big discrepancy between the actual activities as performed on the jobsite versus the activities scheduled to be performed in the CPM schedule.

One of the main purposes of the Last Planner® System is to improve reliability and to increase the accuracy of planning by creating matches between *can* and *should*. This is done by carefully screening the activities in a lookahead plan and making sure they are ready to be performed. This process is also known as make ready planning and involves identifying any potential constraints, or things that are in the way of executing the planned work and removing them. Constraints can be of various types: material & equipment availability, necessary tools to perform the work, incomplete predecessor activities, access to space temporarily blocked or limited, etc.

The desired outcome of the lookahead planning process is to obtain a list of workable backlog, or a list of activities that are ready to be performed. These activities may need the predecessor completed but all other constraints are removed. Activities for the weekly work plan are then pulled from this list, once all constraints have been removed and the work is scheduled to be performed. Ballard and Howell (1997) suggest that activities included in the WWP should meet four quality criteria:

- Definition: if assignments are specific enough that the right type and amount of materials can be collected, work can be coordinated with other trades, and it is possible to tell at the end of the week if the assignment was completed;
- Soundness: if all assignments are sound, that is: Are all design documents and materials on hand or in control, if necessary equipment is available;
- Sequence: if assignments are selected from those that are sound in the constructability order, if prerequisite work is going to be done in time for the assignment to be carried out; and
- Size: if assignments are sized to the productive capability of each crew, while still being achievable within the plan period.

Once this criteria has been met, the last planners can commit to performing the work and there should be no reason for not getting 100% of it accomplished. However, quite frequently something unexpected happens and they are unable to get 100%, which results in a mismatch between *Will* and *Did*. In that case, Ballard (n.d) suggests identifying the reasons for plan failure, revising the plan and learning from them.

The Last Planner System is generally adopted by multiple companies working together on a construction project to achieve gains in efficiency together. However, in the authors' experience, the LPS can also bring the following benefits when implemented by individual companies (i.e. subcontractors):

- Matching *can* and *should*:
  - Better identification and removal of constraints that can be controlled internally, i.e. materials, tools, equipment rental, drawings, etc.
  - Better communication within a project team to facilitate the identification and removal of constraints that are preventing the crews from performing their work. This allows the team to generate reliable commitments in coordination and planning meetings (even when projects do not use last planner, there are generally planning and control systems in place, sometimes an updated master schedule is used to coordinate the work of subcontractors or sometimes phase schedules are used)
  - Improving productivity rates by improving production flow.
- Matching *will* and *did*:
  - Better preparation of work assignments for crews: optimization of crew sizing, task sequencing and improving forecasts for the work that is coming up and soon to be available;
  - Increased productivity (reduced costs) related to a reduction in rework and minimization of non-value added activities
  - Learning from common plan failures and continuously improving, especially aspects that are under the company's control.

CONTRIBUTIONS OF BIM TO LAST PLANNER

Sacks et al. (2009) emphasize the benefits of computer aided visualization of the construction process and how it can provide a unique service to support decision making to achieve stable flows and to communicate pull flow signals, while also facilitating the understanding of project status. The same authors argue that the use of 4D CAD modeling can help to plan for stable work flow and to communicate standardized processes to workers. BIM models can be pulled up any time to look up detailed information on work packages. Regarding the integration of BIM and Last Planner, Sacks et al. (2009) argue that BIM when combined with the Last Planner System can help in filtering work packages for maturity to ensure stability. BIM can provide visual status charts that show the readiness of equipment, materials, space, information, etc.

Additionally, Bhatla and Leite (2012) prescribe three steps to integrate BIM and last planner to better match *can* and *should*:

- Step 1: BIM coordination meeting and 4D scheduling to select, sequence and size what we think can be done.
- Step 2: Make work ready by screening and pulling using MEPF clash resolution
- Step 3: Verifying there are no clashes between MEPF systems

Although studies do not explicitly talk about the contributions of integrating BIM and LPS for matching *will* and *did*, Spitler et al. (2015) presented an interesting contribution by correlating weekly work plan failures to clash detection. The study allowed the visualization of clusters by location and by trade, supporting an understanding of how the BIM model could be improved in terms of constructability.

CASE STUDY

LEARNING FROM PLAN FAILURES

The starting point of this continuous improvement effort was the analysis of plan failures in the weekly work plans. It was observed that the main reasons for not completing planned assignments seemed to be related and were recurrent (see Figure 1). Those reasons were: design changes, no access to area due to out of sequence work, trade stacking, trade clashing, scheduling and coordination problems and pre-requisite work incomplete. Combined, they accounted for 77% of reasons for failing to complete work assignments.

Figure 1: Reasons for failing to complete work assignments

One of the reasons for failing to complete 100% of the plan for the week is the ability to foresee and remove constraints before they effect work. As a result of this the mechanical team decided to focus on improving the communication related to constraints. The initial goal was to identify and resolve the constraints before they effect the weekly work plan (field supervisors using the model to identify and communicate constraints in the field so they can be resolved on a timely manner).

THE CONSTRAINT LOG

The mechanical team had five General Foreman. Each one of them had a tablet and access to the model in the field. While screening the near future activities in the field, they would use the tablets to communicate if constraints were observed. Every time they identified a discrepancy between the model and the actual physical conditions in the field that would affect their installation, they would document it and notify the project team. Figure 2 shows an example, in which sheetrock opening was missing to for ductwork installation.

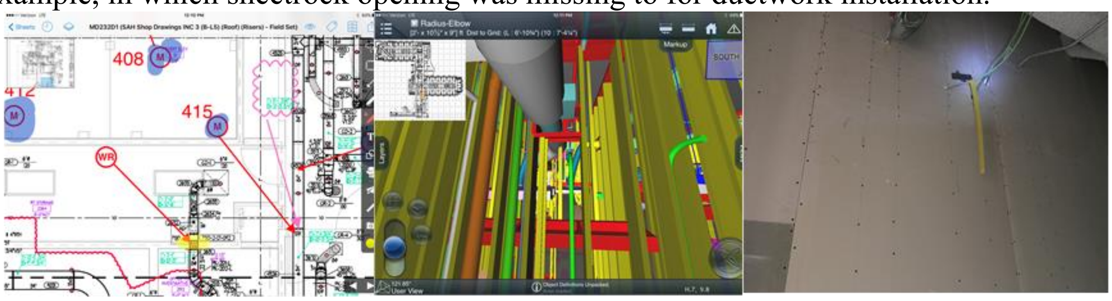

Figure 2: Example of constraint documentation using the tablets

When this paper was written, the log contained 120 weeks of collected data, during that period, 904 constraints were documented (the log included both open and closed constraints). Through an analysis of the log, it was possible to identify six types of constraints (Figure 3).

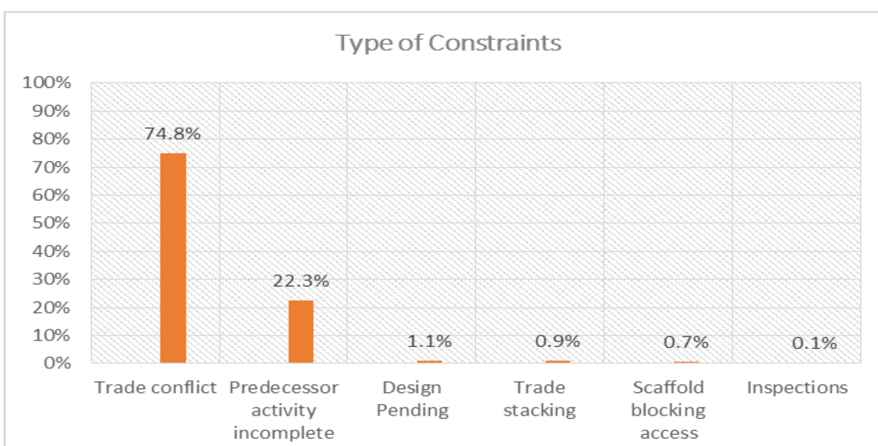

Figure 3:Types of constraints

The constraints were classified as follows:

- **Trade conflict (74.8%):** Physical conflicts observed in the field that were either not identified in the coordinated BIM model or differ from what is shown in the model. Also includes items that were installed out of sequence which prevented the crews from accessing or installing the work in the correct location.
- **Predecessor activity incomplete (22.6%):** Incomplete predecessor activities required for the installation of ductwork. Most of them were related to framing activities that required completion.
- **Design Pending (1.1%):** Changes to the design documents that effected other systems and were still pending resolution.
- **Trade stacking (0.9%):** Limited access to do the installation due to the presence of other trades working in the area or material stacking.
- **Inspections (0.1%):** Unclear directive between inspectors and seismic engineers.

Since physical 'conflicts between trades' and 'predecessor incomplete' accounted for 97.4% of documented constraints, an analysis was carried out to identify the building systems associated with them (Figure 4).

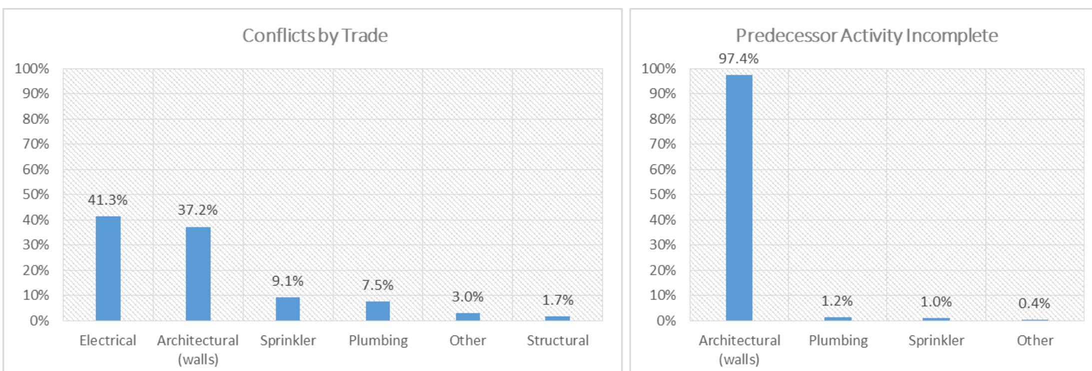

Figure 4: Constraints by building system

Conflicts with Electrical and Architectural systems accounted for 79.3% of total issues found. Conflicts with electrical system were mainly due to the placement of electrical components without observing the required clearance (defined in the model) for the installation of ductwork. Conflicts with Architectural systems were related to wall openings for duct penetration being on wrong locations, shape or wrong sizes. Predecessor activity incomplete, the second largest constraint identified, was also related to walls or wall openings being incomplete (97.4%).

Using the tablets to document, organize and distribute information about constraints allowed the project team to improve the speed of constraint resolution over the weeks (Figure 6). The use of tablets and availability of the model for the last planners allowed them to increase communication about constraints, resulting in increased velocity to inform and solve issues in the field. Figure 6 shows the increase in documentation throughout the research, both in the number of documented constraints and constraints solved.

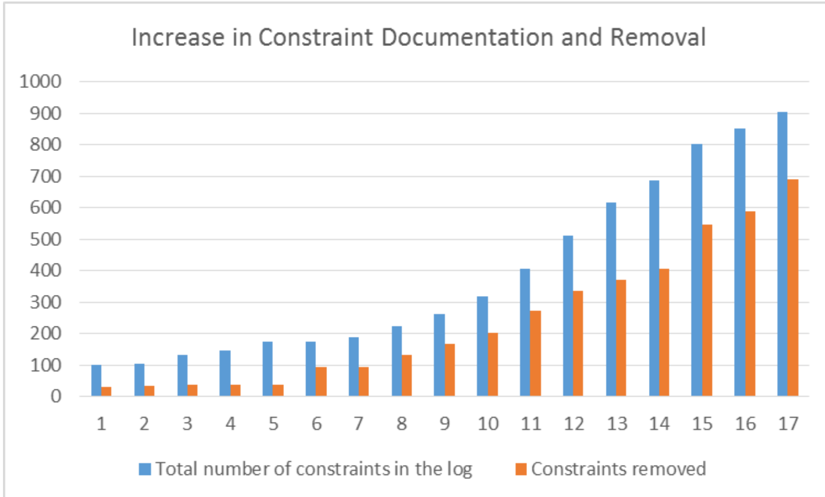

Figure 6: Constraint documentation and removal on a timeline

UNDERSTANDING THE ROOT CAUSE OF CONSTRAINTS

This continuous improvement effort also allowed for a further discussion of the root cause of constraints and opportunities for improvement. During the discussion, five causes were identified:

1. Negative impact of late design changes/clarifications on clash detection
2. Changes made in the field and not updated in the model
3. BIM model not being the only resource to support installation (use of 2d drawings as well)
4. Installation occurring out of agreed sequence (defined in model)
5. Seismic elements included or changed after model has been coordinated

Late design changes or clarifications seem to have indeed a negative impact of the identification of impacts upfront. Figure 5 shows the distribution of design changes issued in the project during the construction phase.

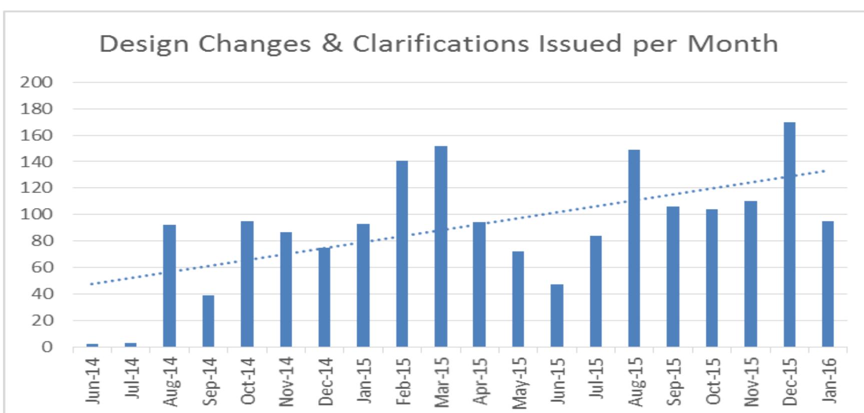

Figure 5: Design changes/clarifications issued per month

It is important to notice that "design changes" here refer to: (a) Owner driven changes; (b) Request for information; (c) Supplemental Instructions from A/E team; and (d) Alternate

Compliance Document. That means changes were associated not only with program modification by the owner but also with clarifications of the design intent before execution. When a change is issued, each subcontractor evaluates and estimates if the change will have an impact (cost and schedule) on their systems. In this project, the estimate was that 50% of the changes analyzed, could potentially impact the mechanical systems (Figure 6).

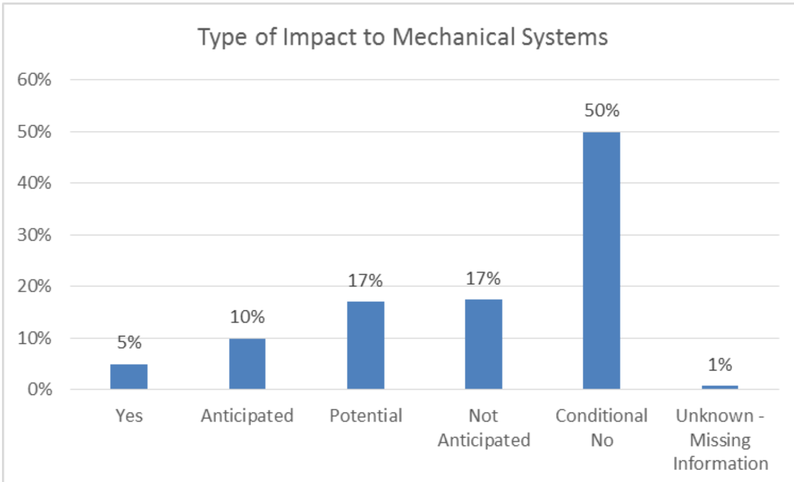

Figure 6: Classification of changes by type of impact to mechanical systems

These changes are then included in the model for clash detection to solve constructability issues prior to installation. However, due to time compression between the release of a change and time of installation, elements are added to the BIM model causing conflicts that are not fully resolved prior to installation.

The way the mechanical team dealt with those changes was by identifying upfront where design changes would affect installation, so those areas could be avoided (detailers developed map of areas where design changes are still occurring, so field supervisors can better plan the work assignments.)

Another problem observed, which is less related with design changes is the installation of systems in a sequence that was different from the one agreed during the modelling process. In a fast pace construction project, with high pressure to meet a certain deadline, there must be a strong alignment between those making commitments during planning sessions and those executing the work in the field.

DISCUSSION

This case study enabled the identification of opportunities to improve not only the integration between BIM and Last Planner to better support production flow, but also discuss opportunities to improve the constructability of BIM elements.

INTEGRATION BETWEEN BIM AND LAST PLANNER

As previously proposed by Sacks et al. (2009) and Bhatla and Leite (2012), the model can be used in to visualize and review the construction sequence by different last planners, identifying any misalignment that still might exist between them prior to executing the work. A major contribution to the installation of MEPF systems is the simultaneous visualization of different scopes of work. This allows the observation of interdependency between the systems and helps last planners improving the quality of work assignments. In this sense, BIM can offer great support to last planners in understanding what *should* be done, helping them to make decisions accordingly.

In this study, the major benefit of BIM to last planners during the lookahead planning (or the process of matching *should* and *can*) was the ability to access the model in the field, compare, document discrepancies when observed and quickly inform the project team about them. This allowed last planners to increase communication and facilitate (or speed up) problem solving during the process of screening activities and making them ready to be performed.

In regards to matching *will* and *did*, BIM contributed for improving the quality of work assignments, as mentioned earlier, but also the analysis of plan failures and data generated through the last planner system (i.e. constraints) allowed for the identification of gaps in the model that can be improved.

IMPROVING THE CONSTRUCTABILITY OF BIM ELEMENTS

Similarly to the work presented by Spitler et al. (2015), this case study allowed the identification of opportunities to improve BIM efforts based on the analysis of data generated through the last planner system. Such information, i.e. plan failures on weekly work plans and documented constraints during the lookahead planning can be valuable sources of information to further improve the constructability of BIM elements.

In this study, similarly to what have been found by Spitler et al. (2015), there is opportunity for improving the constructability of elements in the architectural model (the authors also found a larger number of clashes related with wall framing activities, when compared to other building systems). However, further analysis of the root cause of this problem in this study allowed us to understand the negative impact of late design changes/clarifications to modelling and clash detection process. Therefore, improving constructability of BIM elements seems to be more related with: (a) managing late design changes and their incorporation in the model and (b) making sure there is alignment among project participants that are making commitments during planning process and execution in the field. In this sense, some recommendations can be drawn from the observations of this case study:

CONCLUSIONS

The main objective of this research was to understand how to advance the integration of BIM and last planner as means to improve workflow in complex and fast-pace projects. The paper presented the benefits expected from such integration based on the literature and compared with the implementation and lessons learned from a case study. The study contributed for confirming and revising expected outcomes of such integration for MEPF coordination from a mechanical contractor perspective. It also enabled the identification of opportunities for improvement and further understanding the practical challenges of using BIM to support production flow. This paper provided some insights to advance the integrated use of BIM and last planner in the practice of construction, although much further research is necessary to achieve the desired state described by one of the foreman participating in this research:

"In the future, there will be no more blueprints/field drawings and most journeymen will be assigned tablets, all will be wondering how construction workers ever got anything done in the past (our present)." – Foreman in the Project

ACKNOWLEDGEMENTS

The authors of this paper would like to thank the Last Planners who initiated and led this continuous improvement effort for the opportunity to participate, support, document and now discuss in the lean community the lessons learned from this experience.

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BENEFITS OF VISUAL MANAGEMENT IN THE TRANSPORTATION SECTOR

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• ABSTRACT

This paper explores the benefits of Visual Management (VM), a fundamental sensory information management strategy in the lean production system, in the transportation sector in England. Lean construction and VM have recently gained momentum in England's transportation construction supply chain with high efficiency targets.

VM in construction is a scarcely researched topic, particularly outside the building construction context with its quantitative and qualitative benefits. The recorded benefits of four different visual tools/systems (visual workplace structuring or the 5S, visual performance system, visual specification/indicator and visual control) from one highways construction and one metro station upgrade project in England were presented through an action and case study research effort.

The findings show that VM systems can contribute to (i) increased self-management, (ii) increased coordination, (iii) increased PPC through better promises, (iv) easier control and (v) improved site conditions in transportation projects. Although both qualitative and quantitative data were collected to triangulate the findings, the main limitation of the research is in abstracting the benefits or contributions of a particular VM tool from an overall improvement in the projects' performance. Some future research opportunities for VM in the transportation sector were also discussed in the paper.

• KEYWORDS

Visual Management, benefits, lean construction, transportation sector, England

• INTRODUCTION

Lean construction has increasingly been finding a place on the agendas of the transportation sector in England with ambitious operational efficiency targets (Network Rail 2010; Drysdale 2013). One of the fundamental elements of lean construction is Visual Management (VM), which is a visual (sensory) information management strategy. There are some specific characteristics of VM (Greif 1991); (i) the information in VM is presented to create information fields, from which people can freely pull information in a

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self-service fashion, (ii) the information need is determined ahead of time to prevent information deficiencies (pre-emptive approach), (iii) the information display is integrated into process elements (space, machinery, equipment, components, materials, tools, gadgets etc.) and (iv) the communication is simple and relies little or not at all on verbal or textual information. VM increases the communication ability of process elements or process transparency (Formoso et al. 2002), which translates into simplification in decision making and control, increased coordination through stimulation of informal contacts, broadened employee engagement and autonomy (self-management), and a rapid understanding of problems (Moser and Dos Santos 2003).

Galsworth (2005) proposed a general classification of VM tools, i.e.: (i) information giving; (ii) signaling; (iii) response limiting /controlling and (iv) response guaranteeing. In practice, a visual workplace, in which VM is realized, can be created by sequentially adopting the 5S workplace structuring, visual standards (e.g. standard operating sheets), visual measures/indicators (e.g. performance boards), visual controls and visual guarantees (Galsworth 2005).

Although the literature on VM in construction has been accumulating, the VM discussions have been predominantly conducted for the building sector to date (Formoso et al. 2002; Alves et al. 2009; Tezel et al. 2015). Moreover, the discussions still mainly revolve around VM's conceptual benefits and the applicability of some conventional and IT based VM tools in construction, particularly in building construction projects (Alves et al. 2009; Barbosa et al. 2013; Sacks et al. 2013). However, apart from some generic VM systems, such as the 5S, VM solutions can be highly context-specific (Liff and Posey 2004). Therefore, this paper aims at exploring the benefits of VM, as per the theoretical propositions by Formoso et al. (2002) and Moser and Dos Santos (2003) on the benefits of VM, in the transportation sector in England over four different types of VM tools/systems identified by Galsworth (2005) (i.e. the 5S, visual performance systems, visual specification/indication systems and visual control systems).

• RESEARCH METHODOLOGY

A mixed research approach, including action and case study research, was adopted to explore the benefits of VM in the transportation sector. Action research is used in real situations, rather than in contrived, experimental studies, since its primary focus is on obtaining knowledge while solving real-life problems (Brydon-Miller et al. 2003). Case studies, on the other hand, are suitable for studying phenomena in their real-life contexts (Yin 2003). The visual systems illustrated in this paper were investigated within two construction projects from the transportation sector in England; Project 1 and Project 2.

Project 1 has been executed in northern England. It is one of the major improvement projects in England's strategic highways network to be delivered by 2020. The project is comprised of 3 individual sections and it will cover an approximately 27 kilometers long corridor with 11 junctions and 2, 3 and 4 lane carriageways along the route. A number of cameras, information signs, signals on gantries and additional lighting columns have been installed in a live traffic situation on the route as part of the project to relieve the congestion. The estimated cost of the project is 289 million US$. The works commenced in July 2014 with a planned completion in September 2017.

Project 2 was completed in southern England as a part of an ambitious plan for upgrading 72 underground metro stations over a 7-year period from 2013 within an estimated budget of 501 million US $. Project 2's scope covered the upgrade of 5 metro stations of the total 72 with a cost of circa 36 million US$. The site works included replacement of the life expired mechanical, electrical, fire and communication systems as well as failing roofs, walls and floor finishes and defective staircases. This had to be done at night when the stations were closed, in confined areas and with constrained access. The actual site works were executed between February 2014 and January 2015.

The investigated VM tools/systems include one visual workplace order or the 5S effort, one visual performance system, two visual specification/indicator systems and one visual control system. The 5S was implemented as an action research effort by the authors at Project 1. The 5S is the name of a systematic workplace organization method that uses five steps: sorting, setting-in-order, sweeping, standardizing and sustaining. The benefits of the remaining VM tools were studied as separate implementation cases at Project 1 (i.e. the visual performance system and the visual specifications/indicators) and Project 2 (i.e. the visual control). The benefits were recorded using both qualitative (i.e. semi-structured questionnaires, interviews or informal discussions) and quantitative (i.e. time-motion study, trend analysis and calculating the percentage of non-value adding activities in traffic management etc.) data collection methods. The following sections briefly describe the benefits and implementation characteristics of the VM tools.

• RESEARCH FINDINGS

• 5S IMPLEMENTATION PILOT

A 5S implementation pilot project was executed in the storehouse of Project 1 as per the requests by Project 1's management. The benefit measurement parameters were chosen as comparing the item transaction times of the most demanded items (the time was measured from the demand of a storehouse item from a storehouse personnel by a worker to the handing out of the item to the worker) in seconds, saved floor space in meter square and recorded number of health and safety hazards before and after the 5S pilot. The item transactions times were measured for an experienced (>5 years) and inexperienced (<5 years) storehouse personnel to better reflect the reality. The condition of the storehouse before and after the 5S can be seen in Figure 1.

(a) (b)

Figure 1: Storehouse condition before (a) and after (b) the 5S pilot

The recorded benefits of the 5S include some significant improvements in item transaction times, floor space savings and an improved overall health and safety condition of the storehouse. See Table 1 for the benefits of the 5S pilot after the implementation.

Table 1: Recorded benefits of the 5S pilot at Project 1

		Before the 5S		After the 5S		Time savings after the 5S	
	Item	**Inexperienced Pers. (Sec)**	**Experienced Pers. (Sec)**	**Inexperienced Pers. (Sec)**	**Experienced Pers. (Sec)**	**Inexperienced Pers. (Sec)**	**Experienced Pers. (Sec)**
Item Transaction Times	Batteries	67	57	37	29	30	28
	Hammer	48	70	35	27	13	43
	Oil	111	80	40	27	71	53
	Paint brush	87	67	63	26	24	41
	Safety gloves	146	86	63	38	83	48
	Safety googles	75	80	55	38	20	42
	Safety vest	136	60	60	42	76	18
	Safety helmet	203	85	50	40	153	45
		Available Floor Space (m2)		**Available Floor Space (m2)**		**Floor space saving (m2)**	
Space	Floor Space	15		18		3	
		Number of hazards		**Number of hazards**		**Number of cleared hazards**	
Health and Safety	Trip and Fall Hazard	3		0		3	

The pilot 5S project implementation in the storehouse lasted for 3 months between October-December 2015. The warehouse personnel's approach to the implementation process in terms of cooperation and compliance with the requirements from the authors was positive in general. They also stated their content with the improved layout and situation and that they would continue experimenting with the 5S steps at the storehouse during the implementation repeatedly; yet the authors' drive, leadership and impulse had also been constantly necessary during the implementation process. After seeing the benefits, the Project 1 management has been working to sustain and disseminate the 5S to the rest of the project areas.

- **TEAM PERFORMANCE BOARDS**

In Project 1, the management wanted to have an integrated visual system to monitor and coordinate their construction project teams' performance. Also, the management found that the project's meeting routines within their teams were inefficient in identifying and solving problems and needed more focusing. Therefore, an integrated visual performance board and a team meeting system were developed in cooperation with the team members. The management's ultimate aspirations was that the senior management team could walk around the office every day and observe or participate in each and every teams' stand up meetings where they would discuss the days tasks and existing performance. The generic template includes a task promise section (made in public with owner, date and status), the ownership of the task section, the what needs to be done by when section and a team continuous improvement section along with each team's past performance figures (see Figure 2). The teams have their regular daily stand-up meetings around the boards.

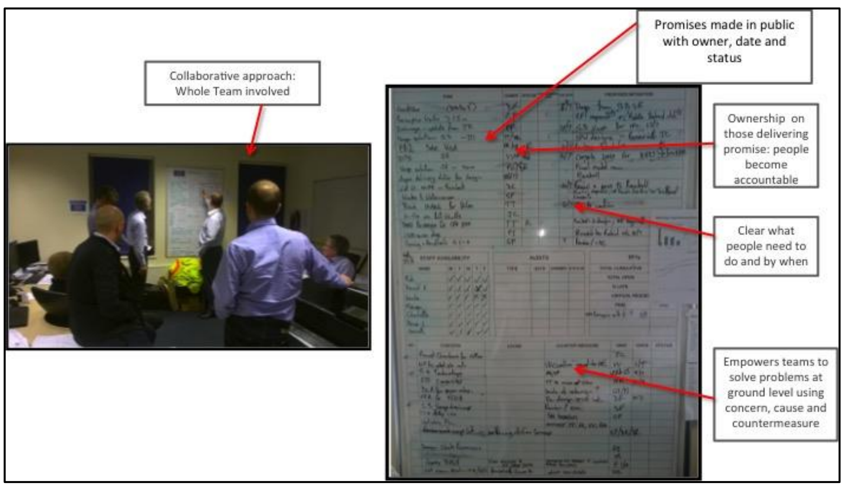


Figure 2: Team performance board

The first benefit recorded after the implementation of the boards is a reduction in the average duration of the team meetings. Previously, the meetings would take around 2 hours (120 minutes) on average per week with some minor deviations for each team. With a more focused and systematic daily meeting approach via the visual boards, the total weekly meeting duration was calculated to take approximately 50 minutes on average for the teams (calculated over a 10 week period after the implementation of the performance boards). After the implementation of the visual boards in June 2015, the overall Plan Percent Complete (PPC) of the teams has shown a general upward trend in time with an average PPC of 76% (see Figure 3). To capture insights from the team members on the boards, an open-ended questionnaire about the visual performance boards was distributed online among the teams for improved anonymity. The collected 10 responses from different team members were mostly positive, giving rich insights: "we have started to take our promises more seriously", "people started to think more carefully before making any promises", "enables meeting focus/structure and makes them more efficient", "they are a great platform for the team to engage in conversation and communicate with each other", "gives awareness of what other members of the team are doing", "they are engaging and give a solid understanding as to where each of our individual team members are up to with tasks", "we can refer to the boards if a team member is not in the office and we need some information", "the boards display dates for upcoming works and act as a simplified schedule", "clear, visual management so everyone can see the actions and discussion points", "we can see what tasks the team members are carrying out, also we can prioritize tasks which involve input from multiple team members", "communication about what is being achieved, identifying what needs to be changed." The team members mainly complained that people could easily get away from the meetings around the board, underlining the importance of monitoring the use of the boards for its sustaining.

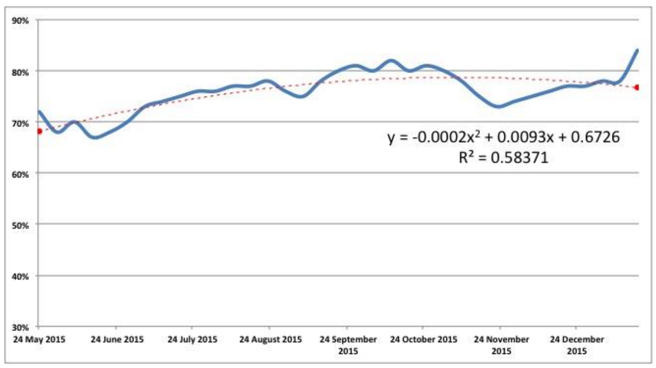


Figure 3: Gradual increase in the teams' overall PPC

- **TRAFFIC MANAGEMENT COORDINATION BOARDS**

While improving a busy highways network in a live traffic situation, permanent and temporary traffic management become highly critical issues. Most of the time, contractors face serious monetary penalties by their contracts for the number of closures they incurred. Therefore, maximizing the utilization of the working window with value adding actives during a closure is of primary importance to contractors.

To improve the coordination and transparency in the utilization of the project's closures, Project 1 management adopted two visual coordination boards. The first board is for the night-time traffic management that was created to allow all construction teams to view 2 week look-ahead traffic management program in order to maximize the use of each closure (see Figure 4a). The second board, which is basically a large project drawing with magnetic traffic management related pins representing different traffic management actions, was put in use for the coordination meetings of the night-time traffic management personnel in the office to record and facilitate their discussions (see Figure 4b).

(a) (b)

Figure 4: 2-week look ahead (a) and magnetic (b) traffic management boards

The first benefit identified from the implementation of the traffic management visual boards is in the downward trend in the percentage of the project's closure working window waste, which corresponds to the total percentage of the work wastes or non-value adding activities during closures in the corresponding month (see Figure 5).

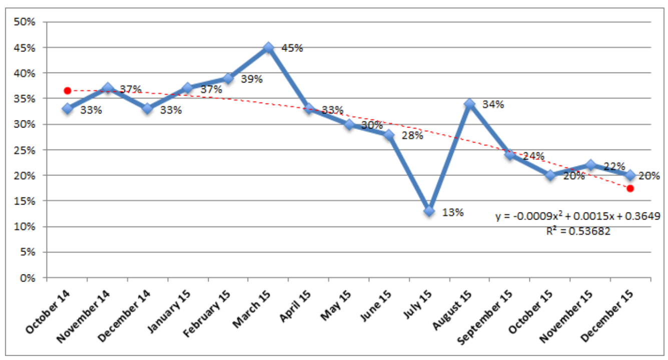


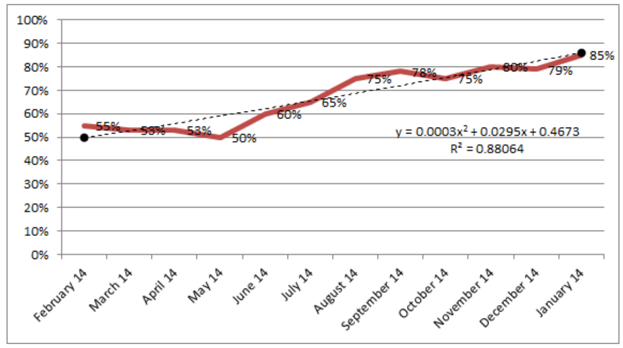
Figure 5: Decreasing percentage of non-value adding activities during the closures

As for the benefits of the boards, the following comments were recorded form 5 members of the traffic management team; "solve problems before they arrive", "visibility for all", "better coordinate and harmonize the teams' works", "it is good for planning the efforts beforehand", "raises awareness of what other traffic management teams do", "the teams can do better forward planning", "helps link the night and day shift teams", "solve problems before they arrive with better coordination", "triggers coordination and discussion", "the night and day shift people can see what is going on any time without asking", "it enables all the foremen and supervisors to avoid clashes, the location of the next nights work and all are aware of he times get of e traffic management and when they can access their work location and when they need to complete works and leave site."

- **PROJECT CONTROL BOARD**

After the start of Project 2, the project management realized that they needed a way to manage and control the site at the activity level as per the Last Planner. Moreover, the PPC figures of the project from the Last Planner were hovering around 55% to 60%, which the project management wanted to increase. To tackle this issue, a 3-week look-ahead visual control board was introduced to the site (see Figure 6a). After the implementation of the board in May 2014, Project 2 management recorded a steady increase in the overall PPC of the project to 85% (see Figure 6b).

(a)



(b)

Figure 6: Project control board (a) and the increase in the project PPC after May 2014 (b)

In figure 6a, the leftmost colour-coded column represents different project site areas (locations). The remaining columns on the board represent days, shifts and weeks (time) for the 3-week period. Bespoke cards were used by each subcontractor to write down and record their activities for a 3-week period on site. Those cards were called subcontractor activity cards and they included information such as the working area, date, activity, manpower and the duration. Each card was colour-coded to match the master schedule (e.g., blue for mechanical works, red for electrical works etc.). The cards then populated the 3-week look ahead boards based on the plans. At the end of every shift, the project's construction manager would review the progress of the shift and confirmed whether or not the activity had been completed. If the activity had been completed, the construction manager 'turned over' that activity card which had the colour green on the back of it. If the activity had not been completed, the activity card stayed as it was. The project team would need to re-plan and develop a follow-up strategy. There were several other cards that site contractors used such as the "ready for inspection" card or the "issue card" to communicate a problem that needed the management's attention.

In a semi-structured interview with two project and one construction manager of the project, the managers strongly agreed that the control board; (i) increased the coordination among different subcontractors, (ii) reduced the work and space clashes among different teams, (iii) helped the managers identify the bottlenecks in advance, (iv) triggered discussions among the work teams and (v) linked the Last Planner with the field personnel. However, the managers stated that the project could not use the board effectively to set the systematic base for the project's continuous improvement efforts.

• DISCUSSION

Particularly with the implementations involving a trend analysis over a period of time (i.e. team performance visual boards, traffic management coordination boards and project control visual board), it is hard to isolate the quantified benefit of a particular visual system to the overall performance from the rest of the other potential contributing factors that might play a role in the performance improvements. The trend analyses show the tendency towards a positive contribution to the overall performance after the implementation of a specific visual system. Therefore, the quantitative findings were supported and elaborated by the in-depth qualitative findings obtained from the people actually involved in the use of those visual systems.

Improved work coordination, triggered project team discussions and better root-cause identification of problems, which translate to an upward trend in PPC figures, decreased waste in limited work-windows or in regular team meetings, come to the fore as the important and common qualitative benefits of some of those systems. The associated benefits of the 5S in item transaction times and floor area savings could be more clearly calculated in that sense. The systems also enable an easier control of the work context at a glance for the management.

It should be noted that all those successful implementations outlined were firmly supported by the senior management of the projects with a lean construction and VM vision. The senior management stated clearly to their teams that they wanted those visual systems to be developed and used in their daily work routines. Even though the personnel were left to decide on and experiment with the implementation phase to a degree, the implementations were essentially top-down, starting with the identification of a need by the management and developing with constant monitoring.

VM offers highly practical solutions to the situations that can be improved through increased transparency. However, the form and content of those visual solutions can change as per specific project conditions, project needs and people involved. Therefore, different visual solutions can be adopted even for the same problem in the transportation construction context in the future.

• CONCLUSIONS

This paper presents the captured benefits of four practical visual systems; visual workplace structuring (the 5S); visual measures (team performance visual boards); visual specifications/indicators (traffic coordination boards) and visual controls (project control visual board) with their implementation characteristics over a two-year period (2014-2015).

The findings confirm the VM benefits identified from the literature (Foromoso et al. 2002; Moser and Dos Santos 2003); (i) increased self-management, (ii) better team coordination, (iii) better promises or an increasing PPC, (iv) easier control for the management, and (v) with the 5S, an improved workplace conditions with decreased item transaction process times, savings in work spaces and a better health and safety condition.

VM in construction, particularly in the transportation sector, generally lacks empirical research. In that sense, future research can present new performance indicators or parameters for the quantitative benefits of VM systems for managers to evaluate their own VM efforts in a more varied way. Also, qualitatively, the perspectives of different organizational roles (i.e. managers, staff, construction workers) on the same visual system can be recorded for richer insights. The 5S can also be implemented in the transportation supply chain on a larger scale to spaces like offices, depots, lay-down areas, construction sites, laboratories, maintenance vans and warehouses. Also, VM benefits can be further investigated for the design and maintenance phase of transportation projects.

The main limitation of the research is the hardship in abstracting a benefit of a specific VM tool from an overall project/team performance. This research effort tried to overcome this issue by collecting both qualitative and quantitative data to support the statements. This limitation can also be partly overcome in future research efforts, when researchers compare projects or teams with and without an analyzed VM tool to better highlight or single-out the tool's benefits.

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. VISUAL MANAGEMENT CONDITION IN HIGHWAYS CONSTRUCTION PROJECTS IN ENGLAND

Algan Tezel[1], Zeeshan Aziz[2], Lauri Koskela[3] and Patricia Tzortzopoulos[4]

• ABSTRACT

Lean construction has recently gained momentum in England's highways construction supply chain. The literature indicates that the current view to Visual Management (VM) within those lean implementations is limited to some VM tools. This paper explores the condition of VM, which is a fundamental sensory information management strategy in the lean production system, in the highways sector in England.

VM in construction is a scarcely researched topic, particularly outside the building construction context. The existing VM research focuses generally on the application of a specific VM tool rather than the VM strategy itself. The paper identifies the current VM condition with its realization means (VM tools), drivers, barriers and future implementation opportunities in England's highways construction supply chain through five case studies and a focus group research effort.

The main findings are; (a) the current implementation of VM, particularly on English highways construction fields, is limited, and (b) along with many drivers and implementation opportunities for VM, (c) there are also some significant barriers before VM. The main limitations of the research are that the paper discusses the issue mainly for the construction phase and limited amount of data were collected from operational site staff.

• KEYWORDS

Visual Management, big room/obeya, lean construction, transportation sector, highways

• INTRODUCTION

Partly due to the concrete lean construction vision from the main public client (Highways England) for significant efficiency gains, lean construction has been increasingly finding a place on the agendas of contractors operating in the highways supply chain in England (Drysdale 2013; Fullalove 2013). One of the fundamental elements of lean construction is

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Visual Management (VM), which is a visual (sensory) information management strategy. There are some specific characteristics of VM (Greif 1991); (a) the information in VM is presented to create information fields, from which people can freely pull information in a self-service fashion, (b) the information need is determined ahead of time to prevent information deficiencies (pre-emptive approach), (c) the information display is integrated into process elements (space, machinery, equipment, components, materials, tools, gadgets etc.) and (d) the communication is simple and relies little or not at all on verbal or textual information.

Galsworth (1997) proposed a general classification of VM tools, i.e.: (a) information giving (e.g. signboards); (b) signalling (e.g. *andon* boards); (c) response limiting /controlling (e.g. *kanban* cards); and (d) response guaranteeing (*poka-yoke* systems) visual tools. In practice, those VM classification types commonly manifest themselves in the forms of some conventional VM tools (Galsworth 1997); the 5S workplace structuring methodology, visual performance boards and *obeya* (big rooms), in which many Key Performance Indicators (KPIs) are located to facilitate meetings and continuous improvement, visual standard operating sheets, the A3 methodology, production, maintenance and safety control cards (*kanbans*), and warning and control type *poka-yokes* for increased operational safety, quality and reduced set-up times.

The literature on VM in construction has been accumulating (Tezel et al. 2015). However, it still mainly revolves around VM's conceptual benefits and the applicability of some conventional and IT based VM tools (i.e. the KanBIM and VisiLean prototypes by Sacks et al. (2013) and Dave (2013) respectively) in construction, particularly in building construction projects. Currently, there is lack of empirical research on VM in the highways context.

Also, without giving in-depth analyses of the realization of the VM strategy itself, the narratives on VM in the highways supply chain in England are limited to the use visual performance boards (Drysdale 2013; Fullalove 2013). This further highlights the current narrow view to the subject. The general condition of the VM strategy in highways construction and maintenance projects is unknown. Therefore, this paper aims at exploring the VM condition in highways construction and maintenance projects in England by (a) identifying its current use, (b) barriers, (c) drivers and (d) future implementation opportunities as the research objectives.

• RESEARCH METHODOLOGY

In order to realize the research objectives, the case study and focus group research methodologies were used. The initial research strategy adopted was of exploratory nature and relied on multiple case studies. Exploratory case studies are suitable when a phenomenon out of the researcher's control is investigated in its real life context (Yin 2003). Five major highway construction sites in England were visited over the course of four months (between April – August, 2015) to collect data. All sites were identified and connected through Highways England. The project sites are known to have some sort of lean awareness and efforts to advance their lean construction practices, which they drive through their process improvement managers. The data collection methods of the case studies include site observations on the field, in the site office and compound, photographic documentation, open-ended, semi-structured interviews with process improvement managers, informal discussions with the construction managers and investigation of the site archives. To triangulate some of the findings from the interviews and field observations, a structured questionnaire was distributed to the site operational staff (i.e. civil engineers, foremen, traffic safety controller, health and safety controller etc.) at Case 2 and Case 3 and 20 responses were collected. See Table 1 for the detailed description of the case sites and corresponding process improvement managers.

Table 1: Description of the Cases

Case No	Number of Visits	Location	Project Cost	Project Scope	Process Improvement Managers
1	1	West Midlands, UK	150 million US$	New motorway construction and upgrade.	Chartered civil engineer (BSc.) with more than 20 years of experience.
2	2	Lancashire, UK	289 million US$	Upgrading the existing motorway.	MSc. in construction management. 5 years of experience in the highways sector
3	2	Cheshire, UK	316 million US$	New motorway construction and upgrade	MSc. in construction management. 3 years of experience in the highways sector
4	2	North Yorkshire, UK	543 million US$	New motorway construction.	MSc. in construction management with more than 10 years of experience in the highways sector
5	1	West Yorkshire, UK	9 million US$	Motorway/ roundabout maintenance and upgrade.	MSc. in production management with more than 8 years of experience in the highways sector

After completing the case studies, a workshop event on VM in highway construction and maintenance projects was organized to set the scene for the focus group research. The event was promoted in the Lean Construction Institute-UK's and Chartered Institute of Building's networks. Focus group research involves systematic discussions with a selected group of individuals to gain information about their views and experiences of a topic (Stewart and Shamdasani 2014). The composition of the focus group participants was as follows; 12 academics/researchers, 6 lean construction consultants working in the highways sector and 22 professionals/practitioners from the highways sector.

• RESEARCH FINDINGS

• CURRENT USE OF VISUAL MANAGEMENT

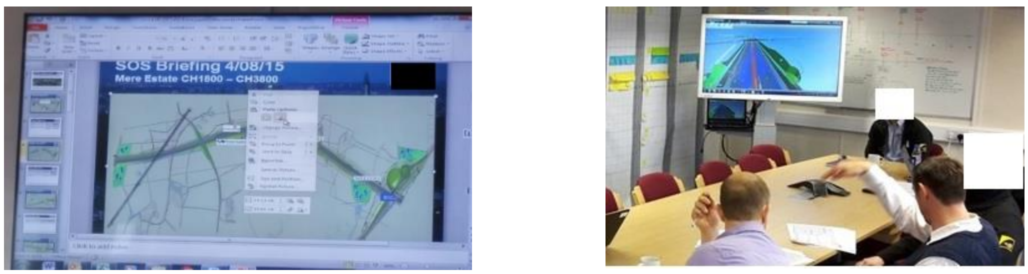
As stated by process improvement managers in Case 1, 2 and 5, the use of VM is limited, particularly in terms of its deployment on the construction areas, outside of the site offices and compounds (see Table 2). Often times, the actual on-site production takes place far from site offices or compound areas in the highways context. Also, it was found that the shared visual information with the site personnel is mostly limited to generic health and safety information on mobile boards/trailers/vans. There are also many similarities among the projects as to the use of VM; the most commonly used VM tools are visual performance boards displaying various project KPIs in the offices/compounds. It should be also noted that some projects had shown efforts to support their VM use with IT systems (BIM and mobile computing). See Figure 1 and Figure 2 for some of the captured VM tools at the case projects.

Table 2: Current VM Use at Case Projects

Case No	VM tools in offices/compounds	VM tools on-sites
1	(a) Visual performance boards, (b) an *obeya* room, (c) static near miss recording/display stations using iPads, (d) decent level of housekeeping but no 5S, (e) heavy plant/equipment tracking boards, (f) color-coded construction site ingress/egress documents, (g) the Last Planner meeting boards	(a) Different housekeeping levels among subcontractors; no 5S, (b) improvisational VM practices by the workforce (i.e. marking underground utilities with colored sticks), (c) generic health and safety information on mobile boards/vans, (d) color-coded tags for equipment safety checks, (e) limited amount of information on the schedule, (e) safety helmets integrated with sensors to warn the workforce of a dangerously close proximity with a heavy plant through vibration (warning *poka-yoke*), (f) goal posts to direct/guide heavy plant, (g) color-coded cones for traffic management
2	(a) Visual performance boards, (b) team meeting/ continuous improvement boards, (c) traffic management 2 week look-ahead board, (d) decent level of housekeeping but no 5S, (e) heavy plant/equipment tracking boards, (f) visual control boards for critical documentation, (g) color-coded construction site ingress/egress visual boards, (h) boards on which people can record their continuous improvement ideas, (i) the Last Planner meeting boards	(a) Different housekeeping levels among subcontractors; no 5S, (b) improvisational VM practices by the workforce, (c) health and safety information on mobile boards/trailers, (d) limited amount of information on the schedule, (e) goal posts to direct/guide heavy plant, (f) 72 iPads distributed to the site personnel to support the flow of information between the site and office, (g) color-coded cones for traffic management
3	(a) Visual performance boards, (b) an *obeya* room, (c) a BIM based work coordination document for the subcontractors (d) decent level of housekeeping but no 5S, (e) heavy plant/equipment tracking boards, (f) color-coded construction site ingress/egress displays, (g) the Last Planner meeting boards	(a) Different housekeeping levels among subcontractors; no 5S, (b) improvisational VM practices by the workforce, (c) health and safety information on mobile boards/trailers, (d) limited amount of information on the schedule, (e) goal posts to direct/guide heavy plant, (f) color-coded cones for traffic management, (g) color-coded tags for equipment safety checks
4	(a) Visual performance boards, (b) an extensive use of BIM in the Last Planner meetings, client engagement, 4D BIM (schedule integrated), design reviews and safety auditing, (c) decent level of housekeeping but no 5S, (d) heavy plant/equipment tracking boards, (e) color-coded construction site ingress/egress displays, (f) the Last Planner meeting boards	(a) Different housekeeping levels among subcontractors; no 5S, (b) improvisational VM practices by the workforce, (c) generic health and safety information on mobile boards/vans, (d) limited amount of information on the schedule, (e) goal posts to direct/guide heavy plant, (f) color-coded tags for equipment safety checks
5	(a) Visual performance boards, (b) decent level of housekeeping but no 5S, (c) heavy plant/equipment tracking boards, (d) color-coded construction site ingress/egress displays, (e) the Last Planner meeting boards	(a) Different housekeeping levels among subcontractors; no 5S, (b) improvisational VM practices by the workforce, (c) generic health and safety information on mobile boards/trailers, (d) limited amount of information on the schedule

(a) (b)

Figure 1: (a) *Obeya* room at Case 1, (b) Traffic management 2-week look ahead board for the coordination of night and day shift traffic management teams at Case 2



(a) (b)

Figure 2: (a) Creating a BIM based visual document to coordinate different work locations of the subcontractors at Case 3, (b) Use of BIM to support the Last Planner meetings at Case 4

To triangulate the initial findings, the researchers distributed a questionnaire to the operational personnel at Case 2 and Case 3 regarding the types of information they want to see more on-site, close to the operational areas. The findings support the comments given by the process improvement managers and the researchers' observations as to the need to share more varied information beyond health and safety with the site personnel. According to the questionnaire, the site personnel want to see more schedule, quality and process related information on-site (Figure 3).

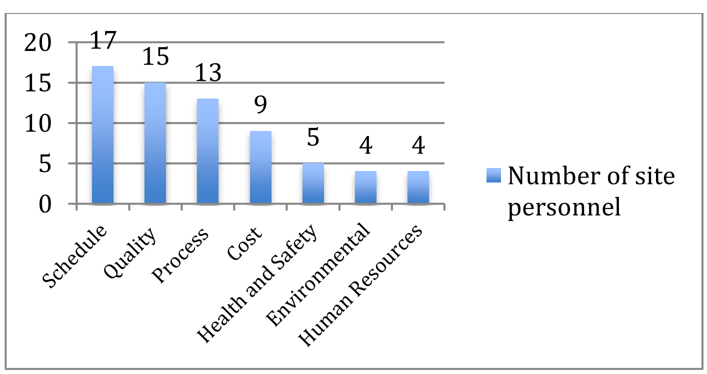


Figure 3: Types of information the site personnel want to see more on-site at Case 2 and Case 3

- **BARRIERS AND DRIVERS FOR VISUAL MANAGEMENT**

There are some barriers that hinder the further dissemination and development of VM and drivers that push the VM strategy in the highways supply chain. The comprehensive data in hand enabled the identification of some of those points for England's highways construction and maintenance context (see Table 3). Some commonalities emerge among many of the identified barriers and drivers from different data sources.

Table 3: Barriers and Drivers for VM

Data Source		Barriers for VM	Drivers for VM
Process improvement managers	Case 1	(a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of the business case for VM (problems in quantifying its benefits for senior management)	(a) Increasing attention given to lean construction and its techniques in the UK, (b) Increasing number of private organizations (consultants) and institutes that are actively working on lean construction (c) Highways England's commitment affect contractors' decisions, (d) cooperation with universities to drive lean construction and VM, (e) VM can help contractors work more efficiently
	Case 2'	(a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of personnel driving VM and lean construction in highway projects, (d) lack of senior management's support and ownership, (e) lack of the business case for VM (problems in quantifying its benefits for senior management), (f) limited communication with operational staff to drive VM further	(a) Increasing attention given to lean construction and its techniques in the UK, (b) Highways England's commitment affect contractors' decisions, (c) VM can help contractors work more efficiently, (d) construction managers can delegate work to their personnel through VM (for increased self management).
	Case 3	a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of personnel driving VM and lean construction in highway projects, (d) lack of senior management's support and ownership, (e) lack of the business case for VM (problems in quantifying its benefits for senior management), (f) limited communication with operational staff to drive VM further	(a) Increasing attention given to lean construction and its techniques in the UK, (b) Highways England's commitment affect contractors' decisions
	Case 4	(a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of the business case for VM (problems in quantifying its benefits for senior management)	(a) Increasing attention given to lean construction and its techniques in the UK, (b) Highways England's commitment affect contractors' decisions, (c) VM can help decrease operational waste and increase work coordination
	Case 5	a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of personnel driving VM and lean construction in highway projects, (d) lack of senior management's support and ownership, (e) lack of the business case for VM (problems in quantifying its benefits for senior management), (f) limited communication with operational staff to drive VM further	(a) VM can contribute to creating more efficient and safer construction environments, (b) Highways England's commitment affect contractors' decisions, (c) cooperation with universities to drive lean construction and VM.

Focus groups	(a) Lack of awareness of VM, (b) limited view to VM (visual performance boards), (c) lack of the business case for VM (problems in quantifying its benefits for senior management), (d) the temporary, project based structure of the industry limits the knowledge transfer for VM among different projects, (e) more pilot implementation projects for VM in the highways sector on more advanced concepts are needed, (f) lack of training documentation, (g) lack of an audit for best practices for VM, (h) limited cooperation/information share among contractors	(a) Obtaining higher lean construction implementation scores from Highways England helps contractors win future contracts; it is an important driver for contractors, (b) pilot VM/ lean construction implementation projects with universities, (c) VM will improve employee morale, work efficiency, collaboration between the main client and supply chain partners and help construction move to the production mind-set.

- **FUTURE IMPLEMENTATION OPPORTUNITIES FOR VISUAL MANAGEMENT**

The captured future implementation opportunities were divided into three main groups; the ideas given by the process improvement managers, opportunities captured from the focus group discussions and observations by the researchers. Whether the proposed VM ideas in this section will yield any benefits in the highways context is yet to be tested in the field, possibly through case study, action and design science research efforts in the future. It will also be useful to collect more data from operational site staff regarding their views on those future VM opportunities. A detailed summary of the captured data on the future implementation opportunities for VM in the highways context can be seen in Table 4. See Figure 4 for an example of the proposed visual control board linking the Last Planner's 3-week look ahead plans with site teams through the use of activity and problem cards.

Table 4: Future VM Implementation Opportunities for Highways Construction

Data Source		Future Implementation Opportunities for VM
Process improvement managers	Case 1	(a) Task-based on-site mobile boards displaying critical quality related steps, best practices and schedule expectations that show where a task is and where it should be according to the construction schedule, (b) communication of the cost of errors/mistakes in a simple manner to the workforce, (c) on-site visual method statements (for safety and quality), (d) on-the-job training documents located on-site, (e) BIM based interactive on-site boards illustrating the KPIs real time.
	Case 2'	(a) Taking daily briefings to the site level by having all the Last Planner and performance boards in the back of a van (mobile), (b) method statements could be visualized, (c) schedule and project cost related information should be taken to the site level, (d) root cause analyses and the continuous improvement process should be visualized both for the office and site staff.
	Case 3	(a) Standardized visual performance boards that can be used in different projects in the future, (b) the continuous improvement process should be visualized, (c) a standard visual control system that binds daily planning (schedule) from the Last Planner efforts with the site staff.
	Case 4	(a) Visual solutions that will demonstrate to the workforce on the site how and what they do on a day to day basis fit into the bigger picture for the project on which they work (i.e. are we ahead of schedule or behind schedule / will the job make a profit? etc.), (b) the formats of the routine reports required by the senior management and client should be simplified and shared with the workforce.
	Case 5	(a) 5S systematic housekeeping implementation to increase the level of on-site visual workplace standardization and order, (b) managers should collect VM ideas more from the on-site personnel.
Focus groups		(a) VM should extend more into actual construction sites in the form of different practices beyond performance boards, such as the 5S, pull production control (i.e. *kanbans*), mistake proofing (*poka-yokes)*, (b) it would be useful to have a visual system on which people can visually record the waste in their work processes (self-auditing), (c) the duplication of data, generated information, produced technical drawings etc. within different stakeholders and between different organizations in the sector is a form of waste; this should be tackled before information visualization, (d) showing the ultimate project

	goals and company vision is important in your VM efforts, (e) it will be also useful to visualize the connections between different work groups and processes, (f) involve the workforce into VM implementations more
Researchers' observations	(a) 5S can be tried in warehouses, material/equipment lay-down areas, offices, depots, construction compounds, material test laboratories, canteens, toilets and changing rooms, on actual construction fields, workshops, traffic control rooms, maintenance and supply vans, wellbeing facilities and material trailers, (b) the A3 methodology can be used to succinctly communicate different processes on-site (i.e. the continuous improvement, concrete or asphalt laying process etc.), (c) visual standard operating sheets on mobile boards or vans, (d) a visual control board linking the Last Planner System with site teams, (e) pull production control (*kanbans*) in materials like prefabricated elements, light poles, cables, aggregates etc. to reduce on-site stocks, (f) *heijunka* leveling for critical plant/heavy equipment (i.e. excavator, roller, asphalter), (g) extended use of cloud BIM (i.e. AutoCAD 360) for better information visualization/ flow among mobile work teams, (h) extended use of BIM based prototypes linking the Last Planner with site personnel (i.e. KanBIM or VisiLean), (i) extended use of systems integrating BIM, Geographic Information Systems (GIS) and mobile computing for advanced visual control of assets/teams on large highway construction sites.

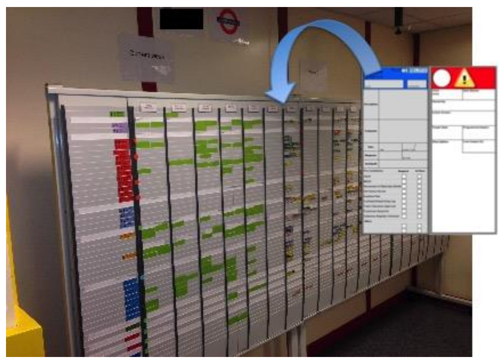


Figure 4: A proposed visual control board example from a metro station upgrade project in London (see Brady (2014) for the details of implementation)

• DISCUSSION

The main finding regarding the current use of VM is that the current VM implementation scope in highway construction and maintenance projects in England could be broadened beyond visual performance boards and extended more into the production area (construction field). Also, as identified from the cases and the questionnaire, along with the existing health and safety information, the content of the shared information on-site should be augmented to cover more schedule/programme related, quality related and process related information.

The most commonly identified points from the case and focus group studies as to the barriers for VM are the lack of awareness of VM, limited view to VM (visual performance boards) and lack of the business case for VM (problems in quantifying its benefits for senior management). For information sharing and benchmarking purposes, a collaboration platform among prominent construction groups in the sector can be formed under the leadership of Highways England. Pilot studies demonstrating the implementation of some more advanced VM concept with their both quantitative (monetary) and qualitative benefits could be conducted. Also, process improvement managers could be trained on some quantification techniques for VM benefits (i.e. statistical analysis, time-motion studies etc.). Auditing the current best-practices and innovative VM solutions in the highways construction sector to establish a VM implementation database may also contribute to the dissemination and standardisation of effective VM practices through the supply chain.

Along with Highways England's lean construction vision as the main client, the increasing general attention given to lean construction in the UK and various practical benefits of VM were cited as the main drivers for the VM strategy. Contractors are closely following Highways England's priorities. Therefore, Highways England's lead and impetus for VM underlining the existence of various VM concepts and opportunities will positively affect the degree of VM deployments in the supply chain.

The identified VM opportunities are worth investigating further and likely to be relevant as they reflect an observed, actual implementation need coming from the sector's professionals and researchers. There are three important points to ponder while implementing the identified opportunities for VM; obtaining the ownership of senior management, the current lack of which was found to be a barrier for VM; clearly illustrating VM's expected benefits or demonstrating the business case (the need for the VM tool/system) and involving workforce in the implementation (i.e. design and use of the VM system) process.

The nature of the current VM practices is mostly office or compound-based, manual and more static, which calls for more actual site-based and dynamic VM tools supported by emerging technologies. The highways context (very large construction areas with many different subcontractors working in different locations) is particularly suitable for those types of dynamic implementations. In connection with BIM, the maturing concepts of the Internet of Things (IoT), advanced photogrammetry, rapid laser scanning (e.g. LiDAR and LADAR), mobile/wearable computing and GIS will find a greater place in lean construction and VM deployments in the highways construction and maintenance sector in the near future.

• CONCLUSIONS

This paper aims at exploring the current condition of VM in highways construction and maintenance projects in England by discussing its current use, main barriers, drivers and future implementation opportunities. Although the current VM implementations are limited in the highways supply chain, the interviewed process improvement managers and participants in the focus group were generally approving the benefits of VM discussed in the literature, which were also found among the main drivers for VM. However, apart from some evidence from Case 2 and Case 3, the general view of both managers and workforce to VM is still unknown and should be investigated in future research efforts.

The significant barriers to VM in the highways supply chain should be carefully addressed to disseminate the VM strategy further. Highways England's lead seems critical at this point. Demonstrating both qualitative and quantitative benefits of different VM tools in practice is essential to create the business case for VM. Also, different indicators for the benefits of VM (i.e. decreasing number of traffic lane closures with better coordination through VM) can be devised. Future research and pilot studies could contribute to this demonstration.

The VM opportunities were proposed for testing in the field as future research and implementation opportunities for VM in the highways context. This is to say the authors do not present the opportunities asserting that they will certainly yield benefits. Whether they will contribute to highways construction and maintenance operations are yet to be seen in future research and implementations.

The main limitations of the research are that the paper discusses the issue mainly in relation to the construction phase from the large contractors' (Tier 1's) perspective and limited amount of data were collected from operational site staff. Conducting similar research efforts for the design and maintenance phase of highway projects presents a future research opportunity for VM in construction. Additionally, the approach of small and medium size organizations (SMEs)- which constitute around 80% of the sector - to VM in the supply chain provides another research opportunity.

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TAKT TIME PLANNING OF INTERIORS ON A PRE-CAST HOSPITAL PROJECT

Adam G. Frandson[1] and Iris D. Tommelein[2]

ABSTRACT

This research presents a case study of Takt time planning developed for interior construction in a healthcare facility in Sacramento, California. This research uses design science to test the method of Takt time planning and answer the research question: how does a team develop a Takt time plan and what challenges exist during plan execution? Data was collected from a project, where one of the researchers worked the entire time during the planning and execution of the work. Evidence for the claims come directly from the scheduling data.

The purpose of this research is to improve upon current practices of planning and project delivery during the interior phase of hospital construction. Findings from the research reveal how the Takt time planning process can help improve construction schedules with (1) smaller batches of work and/or (2) an improved understanding of the work contents. However, executing to a Takt time plan requires rapid feedback and problem solving in order to maintain the plan, depending on the pace of the job. As such, all aspects of the production system need to be aligned in order for a Takt time plan to be executed successfully. A limitation to the research is that it comes from a single case study. The implications from the research are that there may be types of projects or phases of projects where buffering with capacity alone may not make sense during interior construction, and early schedule data collected within the Last Planner system may provide that indication. The research contributes new research questions regarding the relationship between non-field and field production. The research also contributes insight into how to apply Takt time planning on a project.

KEYWORDS

Takt time planning, Production Planning and Control,

INTRODUCTION

This paper presents a case study of Takt time planning developed for interior construction in a healthcare facility in Sacramento, California. The scope of work that was planned to a Takt time began with layout of mechanical/electrical/plumbing (MEP) components on the concrete floor, just after the floors were poured, and ended with hanging of gypsum wall

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board. The project must meet various building codes including California's earthquake design codes and the code requirements from the Office of Statewide Health Planning and Development (OSHPD). The project is a $16,000,000, 2-story, 26-bed, 1,800 m^2 (19,000 ft^2) psychiatric care facility and expands an existing 120-bed hospital. It was delivered with an Integrated Form of Agreement contract.

Development of a Takt time plan for the interior trade activities was selected on this project due to the nature of the work and the speed of the construction schedule. Construction of foundation work began in March 2015 and the entire job was planned to be finished and ready for the owner to move in October 2015. The interior work was released by the pre-cast erection work in two phases (consisting of separate halves of the building). The interior pre-cast walls contained rough installed (known as "rough-in") MEP components, which in theory enables faster inwall rough-in activity durations because installation work is already completed upon pre-cast erection. This paper covers the development and execution of a Takt time plan for the first phase of interior construction.

LITERATURE REVIEW

Takt is German for the word beat. Takt time is "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate" (Frandson et al. 2013). The purpose of Takt time planning is to create flow on a construction site around a beat or multiple beats for different construction phases.

Several case studies have tested methods for Takt time planning on construction projects (Linnik et al. 2013, Frandson et al. 2013, Frandson and Tommelein, 2014). This research also follows previous efforts to pace multiple activities to the same rate in construction (e.g., Willis and Friedman 1998; Horman et al. 2003; Court, 2009, to name a few.).

METHOD

This research uses design science to test Takt time planning. Design science involves four activities: (1) building an artefact (the method of Takt time planning), (2) evaluating an artifact, (3) theorizing why the artifact works or doesn't, and (4) using evidence to draw the conclusion (March and Smith 1995). The goal of the research is to solve a practical problem (in this case the problem of producing flow on site) and to generate new theory.

Design science research is also iterative. This case study iterates on the method of Takt time planning developed during case studies described in Frandson et al. (2013) and Frandson and Tommelein (2014).

Below is an outline of the research steps for this case study.

Review the relevant literature and lessons learned from previous case studies of Takt time planning.

Begin Takt time planning with the project team following the procedure outlined in Frandson et al. (2013).

Detail how the Takt time plan developed.

Evaluate how the project team executed their work according to the Takt time plan.

Rationalize the differences between execution and the plan.

Theorize how the method of Takt time planning (i.e., the artifact) works or can be improved.

DEVELOPMENT OF THE TAKT TIME PLAN

This research, and the related planning work, began in February 2015 and started with identifying Milestones. The team identified Takt time planning as a means to deliver a fast schedule and agreed to go through the Takt time planning process. The team involved in the Takt time planning process was comprised of the foremen for the plumbing, HVAC, and electrical scopes; project managers for plumbing, HVAC, electrical, and drywall scope; the general contractor represented by a superintendent and project manager; the architect, and the structural engineer. The team had experience using the Last Planner system for production control. From here on forward, the term "production team" refers to these foremen, project managers, superintendent, and the researchers. One of the researchers also acted as the scheduler and production engineer on the project.

Figure 31 presents the installation durations provided by the trades in an initial pull planning session held before the research began. The resulting schedule is not shown here, but what is evident from the figure is that these durations would create a schedule significantly longer than the proposed end date if each trade were to have the space to themselves and the work has finish-to-start relationships (or everyone would be working simultaneously and not to the desired sequence). It is unclear to the researchers what effort the project team invested to turn the pull plan into a schedule that met the Milestones before this research started.

Figure 32 shows a colored map of the initial zones (zones A, B, and C on Level 1 and the same on Level 2) created before the start of the research. The stated rationale for initially identifying these three zones was that zone A contained the patient rooms (e.g., similar work), and zones B and C had roughly equivalent work densities (time needed to complete certain amounts of installation work on site) for each MEP trade. Zones B and C contained the spaces necessary for staff and operations (exam, break area, nurse station, storage, etc.). Per the initial pull plan, the activity durations for each individual trade were not balanced through the initial zones.

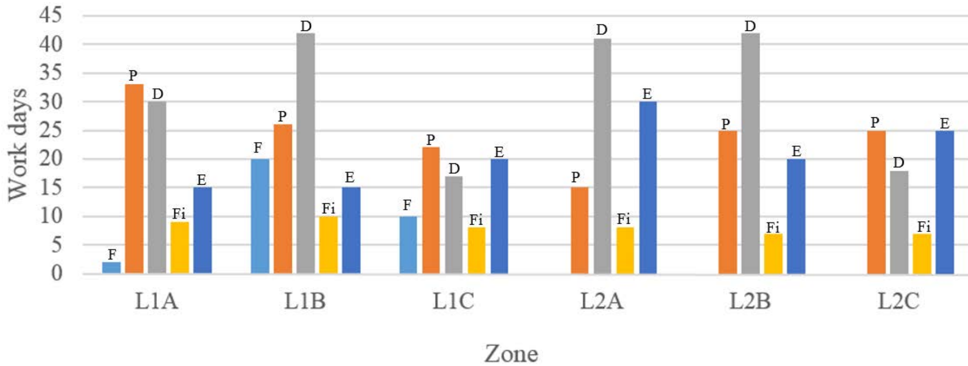

Figure 31: Initial installation durations provided from Pull Plan meeting per zone (L1A = Level 1, Zone A; L2B = Level 2, Zone B, etc.) and per trade (F = framer, P = Plumber, D = Duct, Fi = Fire Sprinkler, E = Electrical)

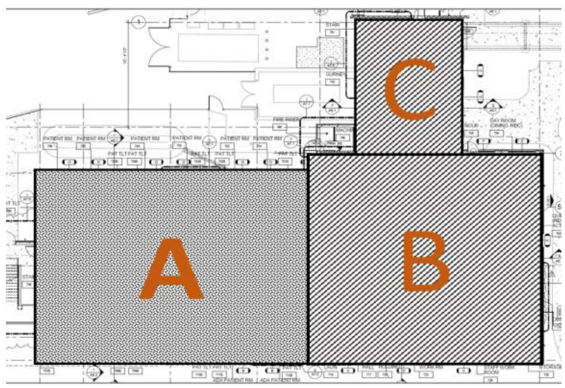

Figure 32: Production areas for MEP installation phase

Based on the Milestones and concrete floors releases to the interior trades, the researcher calculated the required minimum Takt time in order to complete the schedule in the allotted time. The minimum Takt time was calculated by dividing the total number of days for a phase through one zone by the number of activities that needed to move in succession through the zone (e.g., 55 days for a zone with 11 activities results in a 5-day minimum Takt time if all activities move at the same pace). In these early meetings the team agreed to release the pre-cast concrete work in two batches in order to split the project into two phases. These phases would also become the zones the trade activities would work through (e.g., Phase 1 = zones B & C, Phase 2 = zone A). The team then aligned their Takt time plan to four zones: Phase 1 and Phase 2 through levels 1 and 2.

Figure 33 presents the different schedule scenarios on a line of balance diagram, each one represented as a single activity. The time left for the finishes phase of interior construction is delineated by a set of vertical lines. The rationale for the different scenarios was to communicate how much time different Takt times provided for the remainder of the work. The researcher assumed each scenario contained 10 activities (5 passes of MEP overhead, wall framing, and 4 inwall MEP passes) through 2 zones in Phase 1, 11 activities through 2 zones in Phase 2, and a week for layout/fire sprinkler work. The vertical lines each reflect the start date for the finish phase and how much time would remain to complete that scope (which also includes testing and starting up the equipment). With this information, the team decided upon a Takt time, balanced the work, and created a schedule.

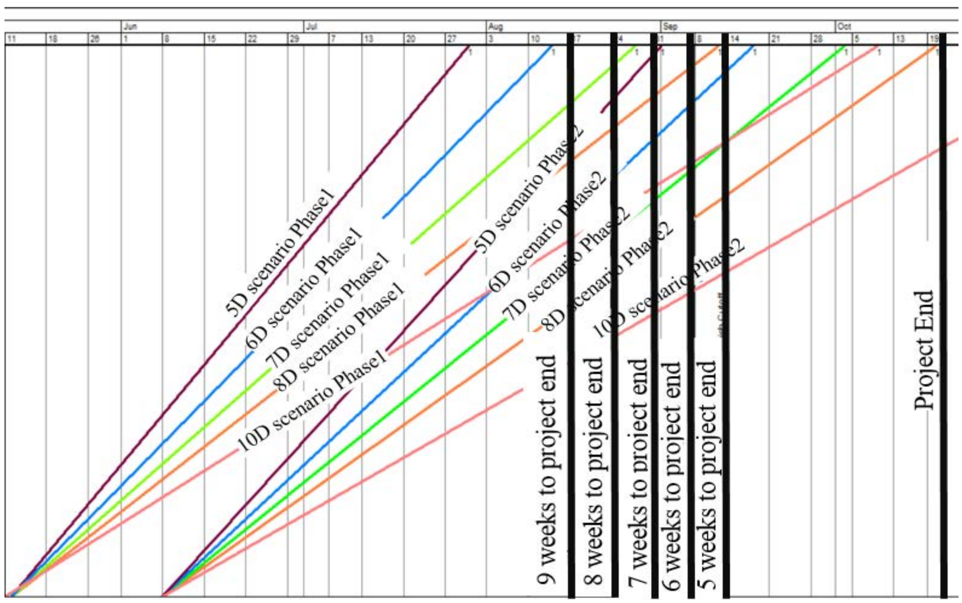

Figure 33: Takt time scenario calculations

Based on the starting production data collected from the initial pull planning session, a 10-day Takt time was the proposed target that the team could meet. However, the researcher's schedule analysis showed that this Takt time would not meet the project requirements (e.g., the demand rate) based on the assumptions of how many passes (i.e., how many times would a trade need to 'pass' through the area and complete all their work for the given phase) would be required through four zones. The option that came closest to meeting the constraint of leaving 8 weeks for the finishes phase was working to a 5-day Takt time, with one crew per trade, through four zones, broken into two phases of work. This was proposed as the design target for the production team to identify how to structure the trade activities so that they would be able to meet this hand off.

After the production team agreed upon the target, the team began to validate the sequence identified in the pull plan and the durations. The durations were validated by marking up the plans for the mechanical piping, duct, and plumbing work. As an example, from this process the duct foreman identified that he had 8 days of duct work per phase per floor. The electrician did not mark up floor plans, but the foreman committed to completing his work in whatever time the other trades were allowed. The electrical foreman was confident his crew could complete the work as fast as the other trades because he had work only in the electrical room, minimal overhead work (just one rack that would take 1 man 3 days to complete), and minimal inwall rough-in because the work was already in the pre-cast walls. Through the course of two meetings, the team committed to a 14 activity sequence at a 5-day Takt time for the overhead and inwall work shown in Figure 34.

PRECAST ERECTION (TAN)	CAST IN PLACE CONCRETE (Light Grey)	DRILL AND LAYOUT ANCHORS, TOPTRACK (Grey)	CAST IRON/ FIRESPRINKLER / VERTICAL SHAFT WORK (Orange)	PRIORITY FRAMING / TOP DOWN (Light Purple)	OH DUCT / PRE RACK PLUMBING (Blue)	OH DUCT / PRE RACK PLUMBING (Blue)
OH PLUMBING / ELECTRICAL HOMERUNS (Green)	TEST AND INSULATE (Yellow)	2ND PASS FRAMING (SOFFITS/WALLS/ HARD LIDS) (Red)	ELECTRICAL INWALL ROUGH and Branch (Lt. Blue)	PULL WIRE / PLUMBING ROUGH IN (Lt. Blue)	HANGING (Lt. Green)	TAPING (Purple)

Figure 34: 14-activity sequence for the interior MEP work (from 1-14)

By working to the production target, the team structured the different activities each trade needed to perform into the 14 activity sequence parade with a 5-day Takt time. Only one of the 14 activities, OH DUCT/PRE RACK PLUMBING, required two 5-day Takt times. The reasons for this were (1) the duct work was dense through zones B&C and could not fit into 5 days and (2) the plumber needed to install some mechanical piping before the duct was installed in some areas in that zone. Furthermore, the amount of work the plumber needed to install before the duct sequence did not require the entire space for a Takt time, so the production team decided to combine the activity with a duct installation sequence. The remaining activities in the sequence were all amenable to a 5-day Takt time. By amenable, we mean that the team was willing to work in the sequence at the Takt time, even if it was not their preferred way, in order for the benefit of the project as a whole. The electrical room work was set as a leave-out area from this Takt time plan. The electricians committed to performing this work around their work in the 14 activity sequence. Each of the 14 activity sequences was formed from a batch of smaller tasks. The 14 activities were also known as “train cars” on site, in order to extend that analogy that everyone needed to move through the space in the same order at the same rate.

Following the agreement on the 14 activity sequence, succeeding production planning meetings aimed to (1) identify the specific hand offs of work for every activity, (2) identify the priority walls (i.e., walls that need to be framed before overhead MEP equipment is installed) and (3) restructure the work as needed to keep a feasible production schedule.

It took one meeting to populate a list of hand offs for all of the activities in this phase. The list was populated by placing one poster size sheet of paper on the wall for every sequence for every week (i.e., “OH DUCT/PRE-RACK PLUMBING had two sheets, one for each week). The trade partners simultaneously filled out the sheets and reviewed the work as a team at the end. The meeting revealed to the researcher how smaller activities could be sequenced within the larger activities and when work really needed to be done. For example, there were multiple alternatives for insulating mechanical piping and duct. The electrical work also had flexibility in when it could be performed, so the decision was to balance the work across the available activity sequences amenable to electrical activities.

RESULTS

The first production activity sequence was vertical work / fire sprinkler rough install. It did not complete as planned because of a pre-cast shaft opening for the vertical duct work. The space was so large that the shaft wall could not be framed, for there was no concrete. Without concrete, there is nothing to attach top and bottom track to. The result was that some specific tasks within the activities could not started as planned and were left out while the remaining activities progressed. A better Lookahead process may have caught the opening conflict with the framing, but the project circumstances resulted in not much time between pre-cast panel erection, pouring the concrete floors, and the start of MEP layout.

The average activity started 3.9 days later than planned, and the standard deviation for the activity starts was 16.2 days. The longest delays came from the work left out due to the shaft challenges. The actual shaft work installation was delayed by 50 days, and the overhead plumbing installed after it was delayed by 28 days. The soffits and ceilings left out due to the shaft was delayed by 28 days as well.

Production tracking for the patient room work was performed weekly. Production tracking is the process of recording the performed work in order to identify what was done, deviations for the plan, and understand causes to plan deviations. The daily production plan, Weekly Work Plan, and colored floor plan were all posted in the field on the first floor (Figure 35). Instead of reviewing production at every daily huddle, the team went straight to identifying problems in the field, where the problems were tracked in an issue log and labelled on a floor plan with stickers.

Figure 35: Field production boards

Figure 36 presents the PPC for the field activities and 'Make Ready' plan for the project. The 'Make Ready' PPC is essentially the PPC for the non-field activities of the project, because the 'Make Ready' plan contained specific activities for the designers, project engineers, owner, and project managers. The activities on the Make Ready plan were generated when people screened construction activities weekly and identified specific activities that needed to be done to make the work ready (e.g., create and send drywall trade the elevation for the west wall of the north stair). The intent of splitting the 'Make Ready' Plan activities from the field was for organizational purposes. This allowed for improved tracking for each plan and did not clutter the field board with non-field related activities. Last, the name 'Make Ready' plan had a PPC metric associated with it, 'Make Ready' PPC, but this should not be confused with the Tasks Made Ready (TMR) metric. TMR measures what percentage of activities in a target week that are included in a later plan for that target week. The 'Make Ready' PPC is a filter of the project's PPC for the non-field activities, and contained activities that were tied to field activities that would be (or soon would be) delayed if the non-field activities were not completed.

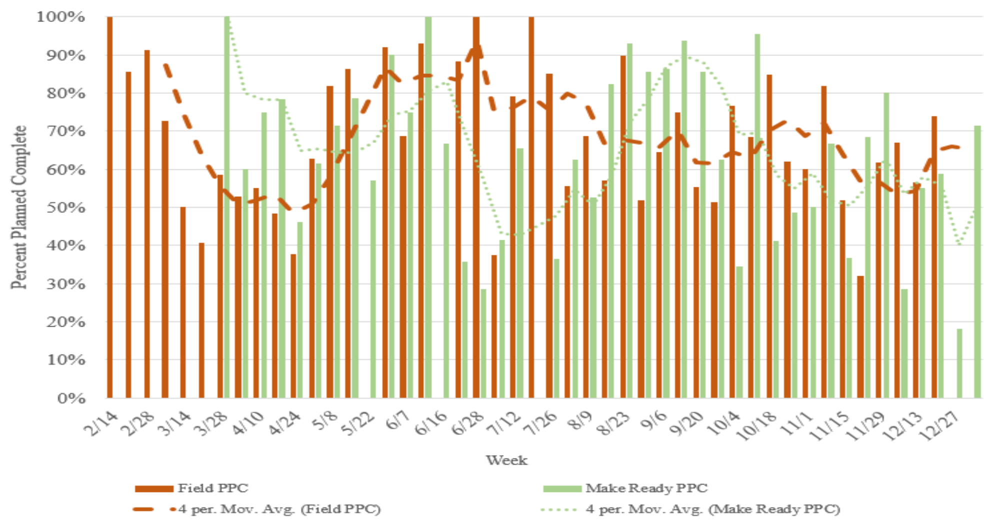

Figure 36: PPC for Field and 'Make Ready' plan over the course of the job

DISCUSSION

The Takt time planning process started with pull plan data that did not result in a feasible schedule. It was not clear to the researchers why the team had iteratively worked on their pull plan to meet the Milestones. The project team did see Takt time planning as a means to produce a schedule that would be feasible however, so it could be that the pull plan was not updated because the Takt time planning process would build off of the data anyway. Indeed, through Takt time planning the team collaboratively found ways to structure work into a 14-activity sequence that adjusted total schedule durations required by each trade (Figure 37). Note that framing did not have any work initially in Level 2 Phase 1, but this changed during the planning process. We rationalize these reductions in activity durations by an improved understanding of the work involved, the work environment, the sequence, and the project requirements. Changes in crew sizes would also affect the data, but the initial schedule data was not resource loaded so performing this analysis is impossible.

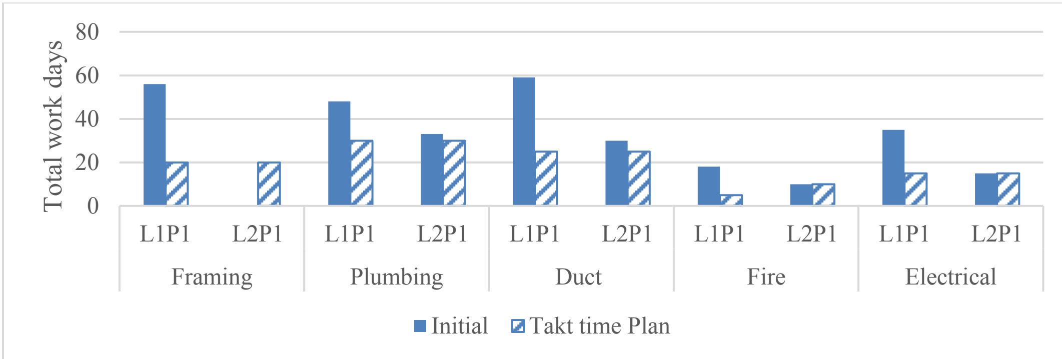

Figure 37: Changes in durations from initial to Takt time plan (L1P1 = Level 1 Phase 1)

While the Takt time planning process resulted in a feasible schedule with seemingly improved durations, the plan could not be followed perfectly. One cause for this was a misalignment between the rate at which the field could complete work and the rate at which the work could be made ready by the non-field personnel. As such, using a capacity buffer (e.g., Frandson et al. 2015) to maintain fast, reliable flow is not effective in these circumstances when the bottleneck is not production related. There may also be potential opportunities on a project during execution to strategically use a time buffer to allow for the non-field related work to catch up. An example time buffer may be added between the layout of walls and MEP work, and the start of the first sequence of actual installation. Overall, the lesson learned is that in order for a Takt time plan to execute accurately, all aspects of the production system need to be aligned.

The relationship between the field and the Make Ready work was a surprise. It seems intuitive that if field work is not being made ready (i.e., there is a low Make Ready PPC), then the field PPC would decrease because the Make Ready work contained activities that needed to be completed that week or else field activities would be delayed (or soon would be). However, the researchers found no correlation between the two values, nor a correlation between the PPC of Make Ready plan and the following weeks' PPCs in the field.

One explanation for why there is no correlation is that people simply do not plan to do work that they know is not ready that given week, instead they "make do" and work on something else that is captured in the commitment meeting. As such, there may not be a correlation between the PPCs values for the Field and Make Ready plan. This sort of "make do" behaviour may be caught if Tasks Anticipated (TA) were tracked, for the committed work would differ from the previous week's plan one week out. These are new questions for future research. Would the TA metric realize this behaviour? Should there be a correlation between PPC's if the field and non-field activities are tracked separately? How would a Task Made Ready (TMR) metric capture these effects? A production relationship certainly exists between the Make Ready work and the field, for the field activities will not complete if the work isn't being made ready. As such, the actual schedule figures reflect that relationship, where some activities started much later than planned.

CONCLUSION

This paper described and evaluated the use of Takt time planning on a construction project. Through collaboration, a project team used Takt time planning to take an infeasible construction schedule and develop a schedule that would fit the project requirements.

The project was not able to perfectly follow the Takt time plan. The second activity in the 14-activity sequence could not be completed as planned, which resulted in some work being left out and completed later. Nevertheless, balancing the work to a 5-day Takt time provided new insights into the production system and provide contributions to knowledge. First, a balanced production system in the field requires that the entire system, including the capability of the project team to make work ready, must be balanced as well. Second, during execution, there are likely strategic moments on projects to place time buffers that allow project teams to resolve problems before field activities are impacted, so it would be good to identify and use these opportunities in order to improve project performance. Third, if work is not ready, PPC data for the field and non-field may not correlate, but more data from multiple projects is required to improve understanding of this relationship as well as understand how the TA and TMR metrics relate or identify the problem.

ACKNOWLEDGMENTS

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LAST PLANNER SYSTEM: IMPLEMENTATION, EVALUATION AND COMPARISON OF RESULTS IN THE CONSTRUCTION OF A SOCIAL HOUSING PROJECT IN CHILE

Arroyo, Paz[1] and Valladares, Oscar[2]

ABSTRACT

This paper shows a detail implementation and lessons learned from the Last Planner System (LPS) in the context of a social housing program of the government of Chile. Specifically the "Condominio Juanita Aguirre" (CJA) project in the commune of Conchali in Santiago, Chile, which includes the construction of 80 apartments of 56 m², in buildings of 4 stories high on a contractual period of one year. We followed the trajectory from the general contractor perspective, Oval Company, which has extensive experience in the construction of social housing. This company has obtained highly variable projects results in the past, and thus the company decided to implement the Last Planner System (LPS) in the CJA project**.** This research measures the results of the implementation throughout the construction process. Additionally, we make a comparison against previous projects of similar characteristics built by the same company with traditional management systems. Finally, the research shows that CJA project achieved significant improvements compared to previous projects, in the areas of: construction schedule, construction costs, safety, and final quality of housing.

• KEYWORDS

Last Planner System, Planning.

• INTRODUCTION

This paper shows a detail implementation and lessons learned from the Last Planner System (LPS) in the context of a social housing program of the government of Chile. We followed the trajectory from the general contractor perspective, Oval Company, which has

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extensive experience in the construction of social housing. This company has obtained highly variable projects' results in the past in terms of duration and profits, for this reason the company decided to use the CJA project for the implementation the Last Planner System (LPS).

Previous studies have measured the benefits of LPS in many countries and project types (AlSehaimi, Tzortzopoulos, and Koskela 2009, Leal and Alarcón 2010, and Kim and Jang, 2005). This paper differs from other documented applications of LPS in that it has the complete history of the project; the researcher was able to measure the customer satisfaction a month after occupation started, as well as other measurements on cost, and schedule reductions. In addition, this paper shows results on safety measurements. In summary, this paper research focuses in measuring direct and non-direct benefits of implementing LPS. This implementation also explains the role of different last planners including the role of non-traditional planners such as the Safety Specialist.

RESEARCH QUESTIONS AND METHOD

The present study aims to evaluate the results of the implementation of the LPS in the performance of a social housing construction project in Chile. The implementation context is given by a social housing project. Specifically the "Condominio Juanita Aguirre" (CJA) project in the commune of Conchali in Santiago, Chile. It includes the construction of 80 apartments of 56 m², developed in buildings of 4 stories high on a contractual period of one year. However, the company has a 10-moth target for completion, from March to December 2014. This research follows the guidelines of Ballard (2000), Alarcon (2008), and Sabbatino (2011) for the implementation of the LPS.

The research questions in this paper are:

- What are the benefits of applying LPS in this context?
- How do the results of this LPS implementation compares with similar projects?

This research is based on a case study methodology. Following Guidelines from Yin (2013). This research measures the results of the implementation throughout the construction process measuring quantitative and qualitative results (schedule, cost, safety, and customer satisfaction). The second author of this paper, who also is the CEO of the company, facilitated the LPS implementation. Additionally, the authors compare CJA project outcomes to similar projects previously built by the same company using traditional management systems.

APPLAYING THE LPS IN CJA

Next sections describe the implementation of the LPS according to Ballard (2010).

LAST PLANNER MEETINGS

The core of LPS is in the planning meeting (Ballard 1999 and 2010, Ballard and Howell 2003), where the detailed analysis of different activities planned is performed, possible constraints are identified, those responsible for the different tasks are appointed, the Reasons of Non-completion (RoN) are analysed, and the new weekly commitments of all participants in their various specialties are created, all for the purpose of complying with the proposed goals. The duration of the meetings was around 2 hours and even more at the beginning of the project. However, duration was reduced over time up to 45 minutes due to better preparation of participants.

Participants of the LPS meeting are professionals (e.g., scheduler engineer, safety specialist) and site supervisors, as well as administrative personnel (e.g., logistics chief), who have extensive experience in developing projects with similar characteristics and seniority in the company. In addition, they have been trained in LPS by an organization belonging to a recognized university in Chile. Thus, it can be established that the personnel carrying out the construction and implementation of LPS in the CJA construction work is suitable. This was the first time in the company that all last planners had finished their LPS training before the start of the project.

The meetings were held continuously throughout the construction process, the team measured main LPS indicators, such as the Plan Percent Complete (PPC) results, RoN percentages.

LOOK AHEAD

The analysis and identification of constraints, the commitment to release them, including the responsible and delivery terms are carried out at this stage during the weekly meeting. It is understood that constraints are all those elements or conditions affecting the fluidity of an activity. These constraints are identified according to a 4-week program delivered to each supervisor

The constraints analysis process is performed prior, during and after the coordination meeting (Alarcón 2008). Due to the fact that it is a sequence belonging to a production line, the task to be developed, the person in charge, date or term to run the task and the prerequisites to execute this task must be determined. The state defines whether the task is free from "ok" constraints, or under a release process of "Pending" constraints. This allows assigning defined commitments, responsibilities and impediments that could restrict the job execution.

MEASURING PPC AND RON

The team shows PPC of committed tasks and performance of each site manager graphically, and also reports RoN of tasks not performed. This information is very important in the meeting, as it allows visualizing and analysing indicators of productivity in an extensive and specific way for each supervisor in charge of a job execution.

Due to the characteristics of the project that involve a tight contractual term, high expectations from the Government and future owners and, not ease and tight construction budget to face imponderables, the management of the company has established the need to require a weekly PPC that at least reaches 85% in monthly average, considering that by obtaining this percentage of compliance, the contractual schedule will also be fulfilled.

Researchers note that showing results graphically causes an immediate positive impact on all participants, and it helped the meeting facilitator to motivate attendees.

RESULTS OF THE LPS IN CJA

During the first 10 weeks, the results obtained in the field after the LPS implementation show that there is a variability in the compliance with commitments and 85% PPC is not achieved until 6th week (Figure 1). This was because practitioners did not have a practical knowledge of the LPS methodology at this stage despite the previous training. An effective Look Ahead was not being performed and constraints were not well identified, and also personnel still had some mistrust and rejection towards the system, which is a situation that leads to uncertainty and noncompliance.

After week 10 the PPC improved, coincident with the strongest stage of the structural work (Figure 1). The tendency of incremental improvement in PPC agrees with most of the prior studies (Ballard, 2000; Fiallo and Revelo, 2002, Junior et al, 1998; Kim and Jang, 2005; AlSehaimi, Tzortzopoulos, and Koskela 2009; Leal and Alarcon 2010). This is mainly due to the fact that after the LPS implementation in the project, all participants have a greater understanding of the methodology. Participants stared identifying constraints for activities that will be perform within 4 weeks regarding safety training, scaffolding installation, materials, and equipment among others. The Look Ahead allowed for better visualization of the constraints and the supervision began to understand that constraints must be monitored in order to release them and improve productivity.

After nearly five months of the LPS implementation, the uncertainty significantly decreased, therefore less variability and better results of the PPC could be observed. This is due to at this stage of the construction work the vast majority of design constraints have already been removed. Moreover, most critical tasks have been performed by company personnel and not by subcontracts, allowing for better control of the construction work progress. In addition, a more mature process is observed of the LPS implementation in the site, as commitments are more reliable and it was possible to perform daily monitoring of constraints for their release.

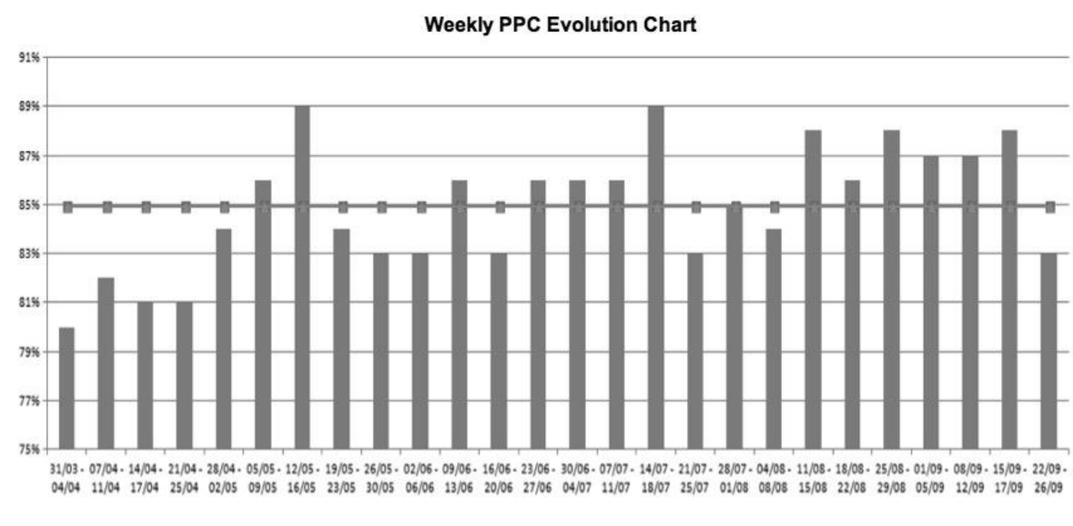

Figure 1: PPC results by week.

Clearly identifying and keeping records of RoN in the LPS implementation allowed for making decisions at the right time. Therefore, mistakes can be corrected protecting the schedule. The RoN helped in defining strategies to address contingencies at the building site, identifying those responsible and ultimately improving construction processes. The practitioners could identify problems with pre-requisites not done, subcontractors, and labor. These 3 RoN were mainly related with lack of labor, due to the market conditions in Chile construction labor was missing, people did not stayed at the work and left without notice. In addition, other improvements were done in material procurement procedures, sales schedules, and treatment of subcontracts.

Figure 2 shows RoN in CJA project. It can be seen that there are several variables that affect the effectiveness of planning, some with more impact than others on the schedule.

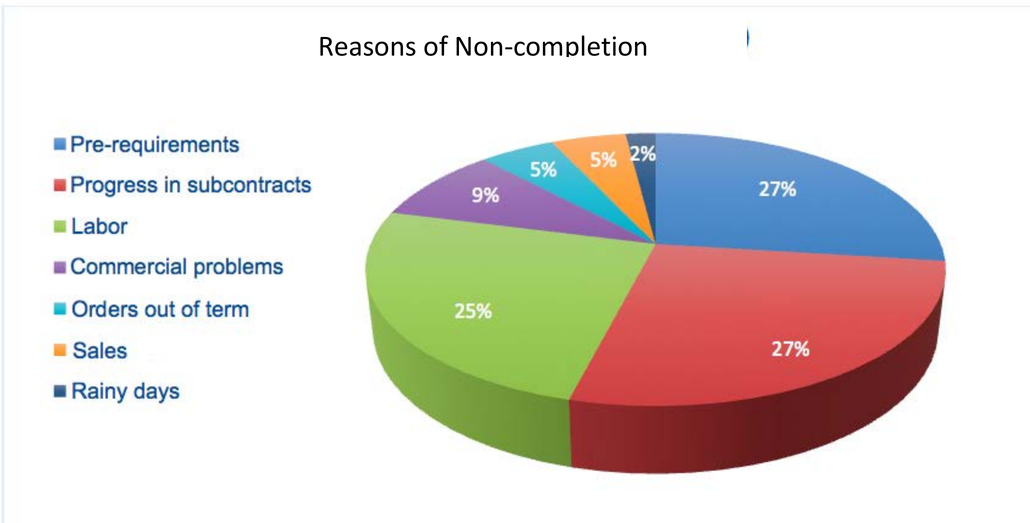

Figure 2: RoN acumulated.

• PROJECT´S PERFORMANCE

Table 1 summarises the results of CJA and previous projects of similar characteristics done previously by Oval Construction Company arranged by year of construction. Early projects did not have implementation of LPS.

Table 1: Projects performance by year of construction.

Work	Year	Amount of apartments	Duration	Profit	Safety	Quality
Portal del Bosque	2010/2011	80	12 months, 25% delay	5%	36 accidents	217 after-sales complaints
Aires del Sur	2011/2013	150	18 months, 50% delay	-2%	47 accidents	285 after-sales complaints

Nuevo Imperio	2011/2013	150	18 months, 50% delay	-3,5%	56 accidents	237 after-sales complaints
Los Almendrales	2012/2013	150	18 months, without delay	12%	14 accidents	47 after-sales complaints
Los Mañíos	2012/2014	184	20 months, 23% in advance	18%	9 accidents	119 after-sales complaints
Bicentenario del Bosque	2013/2014	136	12 months, 20% in advance	17,5%	12 accidents	94 after-sales complaints
Condominio Juanita Aguirre	2014	80	10 months, 17% in advance	18%	0 accidents	25 after-sales complaints

The following sections present the detail results in the CJA project after the implementation of the LPS.

- **SCHEDULE**

Regarding the project construction duration, housing construction works ended within 10 months, which means a 17% early of the contractual period of 12 months. This was due to a well elaborated planning process that focused on meeting goals was in place. The implementation of LPS passed on the Lean philosophy to all employees. Practitioners were actively committing, everyone was involved in the planning of the production system. They understood the importance of agreements reached at the planning meeting, and that everyone is responsible for identifying and releasing constraints in order to improve production.

- **COSTS**

Throughout the construction process, cost was monitored using a monthly Cost Control Box. This project achieved a profit of 18%, which equates to an 80% increase on profit compare to the profit considered on the sales budget. This result is only comparable to the best project undertaken by the company.

- **SAFETY**

The LPS implementation allowed to substantially improve historical safety rates, which translates into a work development without accidents and lost days a very positive scenario for the company confirming that productivity can be achieved with the safety needed to protect the integrity of all construction workers. The accident rate was zero. There were no accidents with lost time. This is an excellent result considering that on this type of projects, there are several activities considered to be critical.

This change can be explain by a paradigm shift by safety specialist and supervisors, before this implementation safety and production where not considered the same, and safety specialist was acting as a consultant outside of the production system, not involved in the planning, nor identifying constraints. After the implementation of LPS, practitioners included safety constraints in planning every activity.

OWNER SATISFACTION

To collect feedback on the performance and results of the CJA construction work, a survey was conducted to the construction work technical inspection and the customer (Department of Housing and Urban Development). The survey was focused on knowing the opinion of the technical inspection and customer regarding the management made by the OVAL Construction Company on issues related to the compliance with terms, construction quality, quality of the technical project team and job safety at construction sites.

The result shows that there is a the technical inspection and the Department of Housing and Urban Development were very satisfied regarding the management done by OVAL Construction Company in the CJA project. Both inspections agree on qualifying the results obtained as very good (the maximum scale in the survey used) during project construction and consider that the planning was fulfilled. And gave a very good qualification with regards to construction quality, materials used, expertise and response capacity of the professional team during construction, safety management, and relationships with future homeowners.

END USER SATISFACTION

Finally, an opinion poll was conducted to future owners of the CJA, which was of great importance since they represent end customers.

The results show great satisfaction of owners regarding issues such as compliance with scheduled terms, and construction quality.

In addition, after the families moved in they were allowed and encouraged to make after-sales complaints to OVAL Construction Company during the first month, this metric was also historically collected in previous projects. The CJA project had a significant decrease in the number of complaints received. Of course, the size of the project could also have an impact on the result. However, medium and small projects can also have deficient performance.

DISCUSION

The team experienced several barriers to implement the LPS on site. At first, the researcher observed field personnel reluctance when being on a meeting for a long time, as well as unpunctuality and poor preparation for the meeting. Another barrier was that participants in the meeting did not understand why they were assessed weekly. The management had to show to that measuring performance of each participant was essential to measure PPC. Once workers understand the purpose of the measurement, an atmosphere of healthy competition and collaboration is created, because they understand that LPS requires teamwork, and that in order to comply with commitments, they depend on other areas.

The researchers believe that it is essential to train all personnel involved in the planning meeting in order to establish a common language and to introduce the concepts of Lean Construction, besides daily reinforcing the main concepts of LPS. Each of the participants is important in order to achieve a successful planning and to comply with the schedule. The work team must be essentially composed of skilled personnel with expertise and knowledge according to the tasks to be performed.

A fundamental difference between planning with LPS and the traditional system are the commitments. The personnel of the construction work must understand that the commitment undertaken should be as reliable as possible and planning should be focused on what can be done, taking into account that planned activities are based on the compliance with the schedule.

Another important point is that commitments should be taken as a “mission” and not as a task. The difference is that when planning tasks, the person in charge will worry on fulfilling them at the moment the "ground" or prerequisites are available and only then the resources will be provided to do it. However, when taking it as a “mission”, the person in charge should worry on identifying constraints and conduct a monitoring in order to release them. This creates a greater involvement for the personnel and integration of the different areas of construction in order to achieve commitments. Therefore, being pro-active is required when implementing LPS.

In the particular case of the JCA project, a high variability was obtained during the first three months of execution of the project. However, this was diminished as months passed, mainly because planning was improved and commitments acquired were fulfilled. During the following months, variability was stabilized and average PPC over 83% were obtained. These results had a positive impact on the overall progress of the construction work, achieving the programmed timing curve and meeting terms.

JCA construction work began without LPS during the first two months, then the methodology was implemented and once the team work started to learn more and adopt the system, the results were better, managing to finish the structural work on time, which were only a week late. At the finishing stage, LPS allowed to improve the quality of constraints analysis and generating more reliable commitments, which enabled to complete the work within 10 months.

Another important point is the end customer satisfaction including families that inhabit the apartments, who expressed their agreement with the execution. The low number of after-sales complaints received in the project provides evidence of the end-user satisfaction.

The LPS implementation improved results regarding construction quality. This is because when planning in detail, it is possible to observe all elements necessary to do the job right at the first time and decreasing technical inspections rejections and rework.

The LPS implementation improved results in accident rates. This was because when integrating the Health and Safety Specialist of the construction work to the planning meeting, allowed the person to have full knowledge of the tasks to be executed, and also advise the teamwork on the conditions and unsafe acts that may occur during an activity. After implementing LPS, safety is seen as everyone's responsibility. Planning contributed to anticipate possible conditions that could cause an accident, having better control of the task to be executed, and finally identifying all elements of personal protection to be used and properly guiding employees on their use.

It was also very important that the safety specialist adopted commitments during the planning meeting. This greatly improves the relationship with field personnel, who not only sees this professional as a safety inspector, but as a participant generating optimal conditions for developing field works, safely complying with productivity for workers.

Regarding construction costs, a monthly monitoring was conducted on cost control, which is summarized in a 18% profit, considering that the profit projected for this work was 10%, the profit had an 80% increase. This result is equivalent to one of the best results in the company and invites to move forward in the line of investing on this system in other construction works of the company.

The LPS implementation improved productivity, especially due to when performing the Look-ahead the team was able to better identify constraints and taking the necessary commitments to release them, so the construction can be performed continuosly avoiding obstacles.

CONCLUSIONS

The implementation of LPS in CJA shows multiple benefits, such as reduction of construction time, increase profits, improve safety, and increase quality of the project. In comparison the CJA project is considerably better than previous projects of similar characteristics. The most impressive result is that CJA had 0 accidents compared to 56 accidents on Nuevo Imperio project in 2012. This may be explained by a constant and permanent monitoring of working conditions in LPS meetings, since safety has been considered as a weekly topic, incorporating and delivering responsibilities to the safety specialist, and last planners in all planning meetings.

The implementation of LPS had to overcome several batrriers. Therefore the support of the company's management was crucial for the success of the LPS, due to the need to allocate time and resources to change the traditional way of performing the work on site. The figure of "facilitator" of the system is an essential piece for a successful implementation, as he provides technical support and also led the group, guiding meetings and permanently motivating the team.

The analysis and monitoring of constraints was not only performed during the meetings, but also as a daily task of each of the team members and especially the leader, who should be permanently identifying ad managing constraints.

After a successful LPS implementation, it was possible to obtain better results in the various areas studied. As a result of a more reliable planning, continuous works are obtained, reducing downtimes, timeouts, reworks, rejections by the technical inspection, days lost due to accidents, avoid fines for noncompliance with terms or quality, etc. That is why this system does not only improves planning, but also align the goals of the project with those of the team and company, obtaining better results on different areas.

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A PROPOSED LEAN PROJECT DELIVERY PROCESS FOR PRESERVATION PROJECTS IN JEDDAH CITY, SAUDI ARABIA

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ABSTRACT

Preserving sites with historical significance, especially those with international recognition, helps protect the world's heritage. The historic centre of Jeddah City in Saudi Arabia encompasses a United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage site that contains about 400 historic buildings, many of which are in poor condition. Since the UNESCO recognition, attention towards the area increased significantly. Owners of historic properties in the World Heritage site area have shown interest in preservation, though the local market struggles to deliver preservation projects.

This paper presents a proposed lean project delivery process for maintaining and preserving historic buildings in Jeddah City, Saudi Arabia. This process allows the local market to deliver value to the owner and permitting agency, as it makes their expectations explicit. The paper presents a process map illustrating the proposed lean process for preserving historical buildings in Jeddah City. It leverages planning tools and the local legislature's statutes and standards. This paper presents an implementation of the statues to help move the market toward routine implementation of the Supreme Commission for Tourism and Antiquities (SCTA) standards. Finally, the paper discusses challenges associated with implementing this process in Jeddah City.

KEYWORDS

Process mapping, historic preservation, Lean project delivery process

INTRODUCTION

Jeddah city is located on the west coast of Saudi Arabia and is considered the main gate for Muslims on pilgrimage to perform their rituals at the holy city of Makkah. The historic part of Jeddah, "Albalad," comprises the old centre of the city (Baker 2007). In 2014, a portion of historic Jeddah was nominated by UNESCO as one of the world heritage sites (World Heritage List 2013(. The nominated area includes buildings built more than 350

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years ago; these older buildings incorporate inherited characteristics from the era when they were built (Baik, Yaagoubi, and Boehm 2015).

Since the nomination, government officials, property owners, and other stakeholders have focused more of their attention toward revitalizing historic Jeddah. The SCTA and the Historic Jeddah municipality prepared many administrative guidelines and technical standards for stakeholders seeking to begin a preservation project in historic Jeddah. The Historic Jeddah municipality classified properties located in the historic area into three categories based on their cultural significance and structural condition. Specifically, a building can be classified as: first class, meaning it requires restoration and rehabilitation; second class, or requiring rehabilitation; or third class, requiring reconstruction. In addition, the number of periodic social events, which attract a lot of visitors to the area, increased since the UNESCO nomination. Finally, the government honoured and supported the owners of the 400 buildings located in the nominated area that took the initiative to improve or work on their properties, whether at the owner's expense or using government funds (Saudi Press Agency 2014). This increased attention to the area, as well as the potential for government recognition, creates a welcoming environment for performing preservation projects in Historic Jeddah.

For many years, building owners and operators in Historic Jeddah did not perform repairs and maintenance, leading to poor conditions in many of these buildings (Nomination Document for the Inspection on the World Heritage List 2013). Given the general lack of maintenance of buildings in Historic Jeddah, the authors hypothesize that the local construction market in Jeddah is inexperienced with building restoration and rehabilitation projects in historic buildings. This inexperience extends to design services as well. In fact, some building owners have complained that they find the cost of preservation more expensive than new construction, which seems counterintuitive (Reuters 2013). For instance, the Ministry of Islamic affairs recently refused to pay for the restoration of Alshafey Mosque, a building they own, because they discovered the contractor did not follow the exact specifications for restoring the property (Almadina, 2015). Similarly, one of the authors worked for a firm hired to perform consulting services for a rehabilitation project in Historic Jeddah. The firm did not have experience with this type of project, so they struggled to prepare a proposal for such a project, and they lacked the human resources required to complete it successfully. For instance, the firm could not find a local historian to assist in the restoration process. Therefore, the firm hired a foreign historian who was knowledgeable about the building type, but was not familiar with local issues. In turn, the client rejected the proposal when he saw the costs required for personnel with the requisite skills and experience to successfully complete the rehabilitation. These general and local challenges can increase the chances of negatively impacting the performance of these potential projects. On the one hand, the new regulations represent a difficult new undertaking for the local market. On the other hand, owners do not understand the skills and services required to successfully deliver a preservation project. The process proposed herein aims to make values of each transparent, through value stream mapping, allowing local building professionals to understand and meet the expectations of building owners, while also illuminating for owners why it can be challenging to meet these new standards.

To assist owners and professionals in their delivery of preservation projects in Historic Jeddah within the required standards, the authors propose a new project delivery process, documented in this paper. This process focuses on making value transparent for all parties, ultimately allowing the local market to deliver value to owners. In turn, this will support efficient performance of preservation activities in Jeddah City. The process map presented herein adapts best practices from other historical preservation literature and aligns those practices with the municipal regulations in Jeddah City, thereby creating an environment for successful preservation project delivery in Jeddah.

METHODOLOGY

The authors first conducted a literature review to identify best practices for preservation projects. Based on this review, the authors developed a process map (e.g., Damelio 1996) that illustrates the general guidelines for maintaining the integrity of the historic properties located in Historic Jeddah (Figure 1). The authors developed this process leveraging lean values –they recognized that a failure in the current system is that the local contractors do not understand what constitutes value for their customers, in this case the building owners and permitting agencies. This map documents a process that provides value to the permitting agencies, and in turn, building owners. In making the process transparent and explicit in the map, the authors support achieving the lean ideal, giving your customer exactly what they want, exactly when they want it, with nothing in store. In particular, this map illustrates a process to give the customers what they want when they want it.

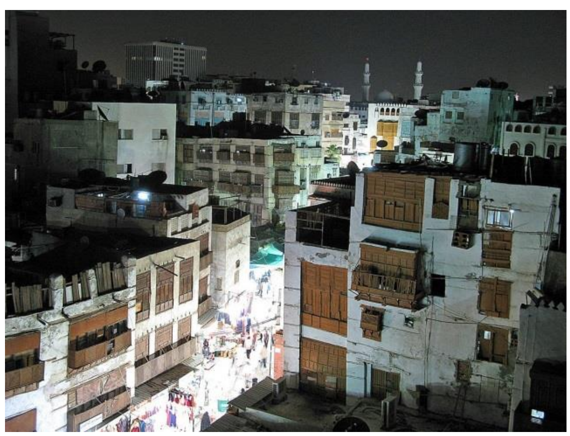

Figure 1: Historic Jeddah (from http://ai.stanford.edu/~latombe/mountain/photo/ksa-08/ksa-08.htm, visited 1 April 2016)

To mitigate the risks to building owners and other stakeholders, the authors propose a new process for preservation projects that adapts best practices from existing literature on historic preservation. For instance, the Whole Design Building Guide provides detailed descriptions of the objectives of each project phase for a preservation project (WBDG Historic Preservation Subcommittee 2015). This guide and others (e.g., AIA 2001) generally describe the same process for successful historic preservation projects; they support the notion that planning is critical to gain the best results when working with historical buildings, due to the special characteristics associated with these projects.

According to the Department of the Interior restoration model, “successful restoration implementation demands a high level of advance scheduling and foresight that constitutes planning by any measure” (US Department of The Interior 2011). Developing a project management plan (PMP) is essential to help control projects’ activities and achieve the expected results (Patrick 2010).

PROPOSED LEAN PRESERVATION PROJECT DELIVERY PROCESS

Figure 2 presents a map of the proposed preservation project delivery process, described in the balance of this section.

FINANCIAL PLANNING [PROCESS]

After the owner initiates the project, the owner and his/her consultants identify the expected needs and resources to complete the project (“Financial Analysis” sub-process) and determine how it will be funded (“Funding Allocation” sub-process); they document this in a financial plan. As part of the Funding Allocation sub-process, the owner’s team should identify SCTA incentives that the project qualifies for, e.g., financial or easement incentives. This process also involves determining a contingency to cover unforeseen issues that may impact the project.

INITIAL PLANNING

The initial planning process aims to ensure the owner is prepared, financially and technically, to move forward with the project. It comprises four sub-processes.

Conduct Preliminary Survey [Sub-process]

Historical properties tend to have unforeseen site conditions that might be hard to identify in the planning stage. Nonetheless, the project’s consultants evaluate the building’s structural integrity as well as the physical site conditions for this preliminary survey. The Construction Industry Institute recommends leveraging advanced technology like laser scanning for this process (CII FEP Research Team 2009). Moreover, this process involves developing a preservation work plan, including a discussion of professional services that will be needed, and preliminary cost estimates (AIA 2001). Project teams may also want to develop a mitigation plan during this process to minimize the impact of any unidentified site or structural issues, e.g., determine a lean buffer in the schedule, include contingency in the cost estimate.

Review building documents [Sub-process]

One of the main issues with historic properties is the lack of documentation. Any photographs, drawings, or other documents that depict the original status of the property supports effective initial planning and restoration efforts if required.

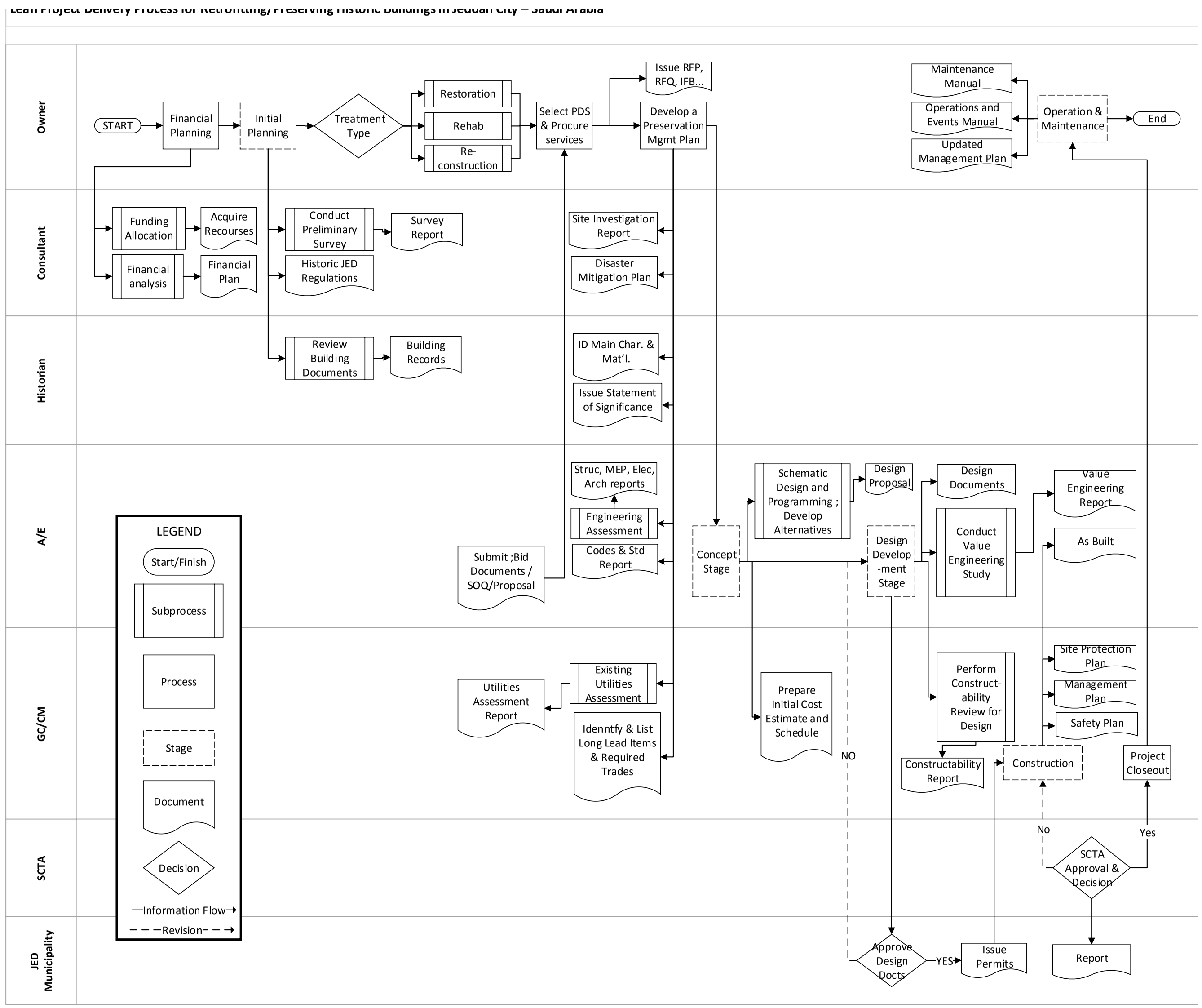

Figure 2: Proposed Lean Process Map for Historic Preservation Projects at Jeddah City

Review Historic JED Regulations [Sub-process]

The regulations and guidelines provided by the municipality and SCTA guide owners and professionals who engage in performing preservation projects in Historic Jeddah. The regulations address matters related to urban and architectural work. Additionally, these regulations and guidelines guarantee compliance with UNESCO standards and help the owner and consultants determine the type of treatment required for the property (Nominated Property Document 2013).

TREATMENT TYPE [DECISION]

At this stage, the owners or their representatives review the municipality regulations to determine the property's classification status that in turn determines the type of treatment required for the property. The municipality classified historic properties into three categories based on their historical importance and their conditions as previously described (World Heritage List 2013(.

SELECT PROJECT DELIVERY SYSTEM (PDS) & PROCURE SERVICES [PROCESS]

The owner must select the best contracting strategy for the preservation project. The type of coordination, leadership, and ownership requirements affects this selection. For instance, the municipality requires design-bid-build for public projects, so if the preservation project is publically owned, and then the PDS selection process is straightforward. The process leader – be it an architect, a contractor or specialty consultants – also affects the PDS decision, as different PDSs support different levels of involvement for each party.

The owner must also procure a project team, comprised of individuals or organizations with the appropriate qualifications and experience to successfully complete the project. Professional services may be critical on preservation projects due to their public sensitivity and relative complexity (compared to a new construction project). Owners may opt to hire design and contractor teams with experience in preservation, which may rule out many organizations in the local construction market. The municipal guidelines suggest required qualifications for professional services on preservation projects in Historic Jeddah. If experienced professionals are not available, the owner may set requirements for training prior to hiring.

DEVELOP A PRESERVATION MANAGEMENT PLAN [PROCESS]

This process involves reviewing multiple documents to develop a comprehensive plan for the project. The authors describe documents reviewed in this development effort below.

Site investigation and survey report [Document]

The project team conducts a detailed site investigation, including geotechnical studies, environmental assessment, and other studies; they document their findings in this report.

Disaster mitigation plan [Document]

Severe floods in Historic Jeddah deteriorated the condition of many historic properties in the area. To protect these properties from future damage, the teams develop and document a disaster mitigation plan to reduce the probability of damaged resulting from any unexpected natural or non-natural event. This disaster management plan is akin to the risk management and mitigation plan discussed in the WBDG (WBDG Secure/Safe Committee 2015).

Identification of main character and material [Document]

The historian and the design team can coordinate at this stage to list the materials and structural elements that frame the project, as well as the material and structural needs to return the property to its original status. When dealing with historic buildings, less is more, so every effort should be taken to use existing materials when it is safe to do so.

Engineering assessment of existing conditions [Sub-process]

The SCTA reports that many properties in Historic Jeddah were not well maintained, so many are now in poor structural and architectural condition (SCTA 2013). Figure 2 illustrates this disrepair. Therefore, project engineers must assess the existing engineering systems, including the structural, mechanical, and electrical systems and determine if the systems should be repaired or replaced. The engineers prepare reports with their findings ("Struct., MEP, electrical reports" in Figure 2).

Figure 3: Existing Conditions of some properties at Historic Jeddah (left: from from http://ai.stanford.edu/~latombe/mountain/photo/ksa-08/ksa-08.htm, right: from http://gvshp.org/blog/2014/12/26/historic-preservation-in-context; both visited 1 April 2016)

Existing utilities assessment [Sub-process]

The engineers must assess the availability and condition of the site utilities. Many of the historic properties in Jeddah have long been vacant; thus, most buildings either do not connect to utilities or the connections have issues.

Codes and standards review [Sub-process]

The design team reviews the codes and standards that apply to their preservation project. Coordinating with the municipality and SCTA offices can help the team comply with the new guidelines and requirements, reducing the risk of delays and rework that would result from not meeting the required standards.

Identify long lead items and required specialty trades [Sub-process]

In most preservation projects, minimal disruption to the existing building is preferred (WBDG Historic Preservation Subcommittee 2015). However, at the need of repairs, finding the original materials may be difficult; they may not be available in the local market. Therefore, identifying required materials, especially with long lead time, is a critical issue for successful project planning. Procurement may not be the only issue with uncommon materials: it may also be difficult to find workers familiar with these unique elements. Identifying and procuring required materials, equipment and labour early on in the project help ensure efficient project delivery.

Issue the statement of significance [Document]

The historian or an archaeological consultant should issue a statement that describes the property's importance and defines its essential integrity (AIA 2001).

CONCEPT STAGE

Following the development of the preservation management plan, the project is generally turned over to the design and construction teams, who design and build the project.

Schematic design & programming; Developing alternatives [Sub-processes]

The design team must develop spatial programs that match the needs of the building services as well as its potential users. Following space programming, the design team may develop initial design proposals or propose alternative conceptual designs appropriate for the treatment type.

Prepare initial cost estimates and schedule [Sub-process]

The design and construction team (i.e., GC/CM and A/E) should collaborate to develop preliminary project cost estimates and a schedule so these initial items will reflect both the design and construction realities of the project.

DESIGN DEVELOPMENT

Conduct value engineering study [Sub-process]

This process, led by the architect or engineer (A/E), supports review of design options to identify design options that offer similar functionality for less cost.

Perform constructability review for design [Sub-process]

The GC/CM (General Contractor/Construction Manager) assesses the A/E's designs to determine the feasibility and cost of building the design. This process often reduces the construction schedule, as the GC/CM can begin to plan their work activities. Moreover, in identifying issues early on, the GC/CM and A/E can develop buildable design options, reducing the need for change orders and rework during construction.

Prepare design documents and municipality review [Sub-process]

The A/E prepares final design documents and submits them to the municipality to request project permits and approval to proceed with construction. The municipality reviews these documents to ensure the design complies with their standards.

CONSTRUCTION

Site protection plan [Sub-process]

The GC/CM prepares this plan to ensure the building and site's structural integrity during construction and operations. Given the dense nature of buildings in Jeddah, this plan also documents construction practices that reduce the risk of damage to neighbouring sites.

Safety plan [Sub-process]

The safety plan documents the plan for informing construction workers and the public about ongoing construction activities and how to complete them without injury. The safety plan includes discussion of additional precautions necessary given the unknowns of historic sites (e.g., wearing masks during demolition in case mold is discovered).

SCTA supervision and approval [Decision]

The Jeddah municipality and SCTA review and monitor design documents and construction activities to ensure following the guidelines, in turn ensuring the property will qualify for UNESCO recognition. SCTA supervise on site activities and review final reports and documentation to issue permits as required. Early coordination from the design and construction team with SCTA the SCTA can result into non-compliance issues before construction and consequently smooth the process.

As built drawings [Document]

The design team prepares drawings that reflect the final design, specifications, and construction details of the building after construction ends.

OPERATION AND MAINTENANCE

Prepare maintenance, operations and events manual [Sub-process]

Many of these properties will be used for public and special events. During these events, there is an increased probability of damage to the building. Therefore, in addition to typical operating manuals, the building owner may also want to issue a manual that describes actions necessary for protecting the property during special events.

Update preservation management plan [Sub-process]

The owner should update the preservation management plan and building documents periodically to reflect the conditions of the property, particularly when changes occur.

DISCUSSION

The suggested process provides a guide that owners, designers, and builders can follow when working on preservation projects in Historic Jeddah. Additionally, following this suggested process facilitates preservation projects that comply with UNESCO management plans and standards. The suggested process requires collaboration and commitment from project stakeholders to achieve quality results and reduce the impact of, or altogether eliminate, the challenges associated with preservation projects. Consequently, this reduces projects' failures and wastes, furthering supporting a lean process that the authors sought to deliver in making transparent the roles, responsibilities, and expectations of the various stakeholders involved in preservation projects.

CONCLUSION

Treating and preserving historical projects share some similarities with new construction projects. Yet, preservation projects tend to be more complex due to, e.g., unforeseen conditions, material availability and disrepair. All these factors require project planning strategies to mitigate risks and successfully deliver preservation projects. Following a defined process, particularly one rooted in best practices for preservation, supports successful project delivery. This paper presented such a process, and in making this process transparent, the authors hope to undertake more preservation projects while recognizing the complexities involved in such projects. Ultimately, undertaking preservation projects will help revive and protect the heritage of Historic Jeddah.

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PRACTICAL BENEFITS OF USING TAKT TIME PLANNING: A CASE STUDY

Mats Erik Vatne[1] and Frode Drevland[2]

ABSTRACT

Takt time planning (TTP) aims to increase productivity by reducing waste. This is achieved by optimizing work packages and team sizes to fit the desired rate of production. Takt time planning has shown to reduce non-value adding time spent by work crews. This reduction makes workers produce more in less time, thus reducing the costs of construction. However, when performing TTP in practice, extensive plans have to be made in collaboration with subcontractors to make the process as smooth as possible. This, in combination with the time used to follow-up on the plans during the construction phase, takes time to perform and can be costly.

Little documentation exists on the benefits of using TTP and exactly what kinds of efforts are worthwhile. The purpose of this research is to examine a practical application of TTP and evaluate the usefulness of the efforts made in the planning process. By doing this one can prioritize where to spend extra time or resources to optimize projects.

This paper is a case study of a project from a major Norwegian contractor where TTP is being used. Methods used and experiences gained are compared to tried and tested methods to evaluate how TTP has affected the case project. The paper concludes that TTP has been beneficial to the case project in terms of completion time and worker comfort, but also identifies some obstacles that needs to be overcome before the true value of their method of TTP can be identified.

KEYWORDS

Takt time planning, production planning, case study

INTRODUCTION

Takt Time Planning (TTP) is a method of production planning with a focus on creating continuous flow of production at a steady rate (Frandson et al. 2013). This is achieved by managing the parade of trades to keep up with the desired takt time (Tommelein et al. 1999). TTP has been proposed as a step in the right direction to improve upon project-based production systems by maximizing the utilization of available resources (Frandson et al. 2014). Although there exists theory on how TTP should be done and its possible effects on

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a project, limited documentation on practical application of TTP exists. Previous research into applications of takt has posed questions for further research on TTP (Frandson and Tommelein 2014) and indicate a lack of empirical data to analyze and evaluate, as concluded by Frandson et al. (2015). They recommend examining projects where it has been used as to provide useful data and experiences.

One of Norway's largest construction companies has adapted several Lean Construction principles, including TTP. Up until now they have completed two projects using it. Project 1; a wing of a modern university hospital, and Project 2; a housing project consisting of several row houses. Both projects and their way of applying TTP has been studied, with a goal of understanding better how it affected them.

While examining Project 1, Smiseth (2013) found that only 32% of the scheduled work packages started when they were supposed to. This was related to the fact that just 35% of the same work packages were completed on time. The reason for this was a lack of variability control. The project was a limited success takt-wise, and the research concluded that, among other factors, efforts to reduce and control variability will be necessary to improve results.

Mordal (2014) found that in Project 2 there was a measureable reduction in construction time and costs. By comparing construction time of two identical part of the projects, one with TTP and one without, it was shown that there was a significant reduction in both time spent by the carpenters and start-to-finish time. Still, there are indications that TTP does not combine properly with Norwegian construction culture and tradition.

are improvements to be made, and while providing valuable information about TTP and the projects it was applied on, they both conclude that there is still need for more research. By examining an ongoing project and its takt plan, this paper aims to look at:

- How the takt plan was generated
- If and how it affected the project in terms of completion time and cost
- If and why the craftsmen and project administration preferred the takt plan

The analysis compares the case project to established theory and comments on any similarities or deviations. This will aid future applications of TTP in making good decisions and identify potential obstacles that needs to be overcome for future analyses and improvements.

THEORETICAL FRAMEWORK

Frandson et al. (2013) identified a process for generating a takt plan which consisted of the following six phases; (1) gather information, (2) define areas of work, (3) understand trade sequence, (4) understand individual trade durations, (5) balance the workflow and (6) establish the production plan. Through collaboration with the production team these six phases are iterated until a takt plan emerges. This production plan consists of work packages that can be completed within one takt time, and also gives the order of which they must be completed. This helps insure that only work packages that *can* and *should* be done *will* be done, which is also an important part of The Last Planner-system (Ballard 2000).

Bølviken et al. (2015) proposes a set of criteria a project can fulfil that makes different planning concepts work well with the specific project. They are divided into four categories;

the tasks, the use of time, the use of space and fit for purpose. The following are proposed as indicators that takt planning would work well.

- **The tasks:** Should be as independent as possible, and all preconditions for the tasks to become sound are identified.
- **The use of time:** The right sequence and logic should be identified, and the duration should be in compliance with the framework conditions.
- **The use of space:** The project should be able to have a good division in zones, with a suitable direction of construction where only one trade works in each zone at any given time.

Although Bølviken et al. (2015) points out that TTP works well when the project can be divided into clear zones with repetitive work it is not a requirement for takt to work; it has been used by Linnik et al. (2013) on an experiment with a non-repetitive project. One of the benefit of having repeating zones is shown by Kenley and Seppänen (2009), it gives the possibility to plan work for one zone and copy the plan to every other zone.

METHOD

The data was collected by conducting eight face-to-face semi-structured interviews. Key personnel where chosen from both the main contractor and subs, with a mixture of persons from both the project administration and craftsmen. The site manager from the main contractor was in charge of both making the takt plan and following it up. Therefore, much of the information gathered about making the takt plan is based on his experiences. Others were interviewed with a focus on uncovering how it had been to work with it, and if they had any thoughts about pros and cons compared to past experiences.

The interviews consisted of two parts. The first part established background information about the interviewees, projects they had worked on earlier and if anyone of them had experience with TTP from before. During the second part of the interviews the current takt plan was reviewed together with the interviewees. They were asked to talk about their participation in generating the plan and how it later on was to work with. This included how comfortable the project was to work in, especially regarding the predictability of their work day considering the repetition of tasks. To conclude, the last topic asked if they would be positive to using TTP in future projects.

FINDINGS

The case project, Project 3, is the contractors latest attempt at TTP. Being the largest massive wood project in Europe (Egge and Nilsen 2016), the project consists of five high rises and a kindergarten, all made of cross-laminated timber elements. The high rises each have nine floors, where all but the ground floor are student dormitories with a total of 632 dorms. These floors are more or less identical while the ground floor houses different types of public facilities in each high rise. This makes for a project with a high grade of repetitive work packages, which is ideal for TTP.

The project is being built for a student welfare organization in Norway, with a goal of completing the first three high rises and the kindergarten before school starts in august 2016. TTP was considered necessary in order to reach the deadline and has been used on the interior of the high rises. Combined with the rapid rate of construction using massive wood elements and prefabricated bathrooms the project has progressed quickly. By studying the inception and progression of the projects takt plan and comparing it with other experiences using TTP there are some similarities and differences.

THE TAKT PLAN AND ITS DEVELOPMENT

e process of generating the takt plan started early, with the site manager leading the way. He has been trained in Porsche Takt, but with his own adaptations based on previous experiences from the two aforementioned projects. He was by far the most experienced person with TTP within the company, and had spent much time evaluating the previous projects and their takt plan. He pointed out that his method focuses on identifying trade order while minimizing the number of times each trade enters the same zone as to reduce time wasted on non-productive work. Also, it emphasizes on collaboration during the planning process. The following is a summary of what was done.

Initial plan and deadlines: According to the site manager, the main limitation for the takt plan was completing the project in time for the deadline. Initially the project had a traditional production plan, but it was discovered early on that it would not be possible to complete it on time using it. The site manager made a rough takt plan to illustrate how it could be done using TTP. This was sent over to the project owner which agreed that it was necessary to do things differently. The original plan was scrapped and work begun on a takt plan for the high rise interior based on the deadlines identified earlier.

Since the takt plan only encompassed the interior work of the high rises the original plan helped identify some deadliness the takt plan had to confine to. For instance, sealed building had to be achieved in order to start a takt planned work package involving gypsum boards. Since exterior cladding and roofing was not a part of the takt plan it was important to identify when this precondition was met.

Takt plan meetings: When the timeframe for the takt plan was set it was time to identify work packages and their sequence of completion. This was done through arranging “takt meetings”. A total of three takt meetings were arranged, and in these meetings the site manager invited foremen and project managers from the different trades. The goal of these meetings were among other to identify:

- Each trades required work
- Order of work packages
- Zone size and buffer
- Takt time

During the meeting the participants divided into group consisting of representatives from each trade. While studying a floor plan they talked about what each trade had to do, and how it affected others. For instance, if the HVAC company could finish more work if the electrician had already completed certain parts of his job.

Considering the layout of the high rises, the zones were set to one floor and takt time set to one week. Initially a two day takt time was considered, which was rejected due to areas being to constricted. There was also discussion about having two week takt because one subcontractor found it better for them. This would have made it necessary with two-floor zones, which would have been impractical. Since the work crews could end up being as small as two persons there would be too much back and forth between the floors. This meant time would be wasted doing non-productive work, which is the takt plans goal to reduce. The idea was abandoned and they got on board with the one floor/one-week plan.

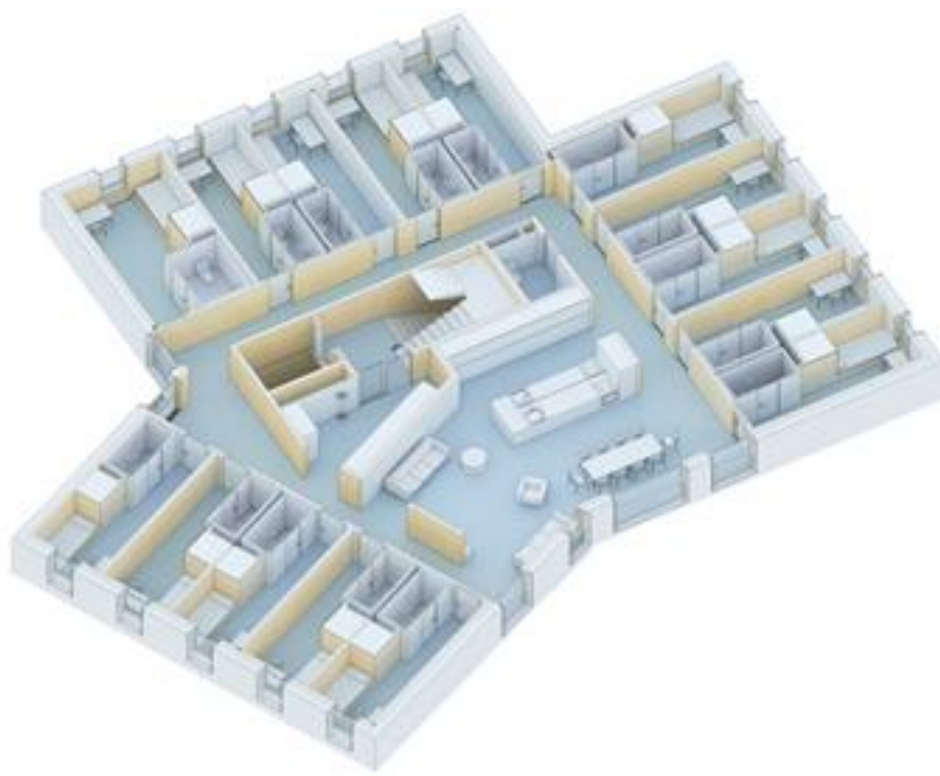

Figure 1: 3D model of one floor – the takt zone

With the previous decisions and discussions in mind, the time came for arranging the order of trades and work packages. The method used was collaboration on a post-it wall calendar. Each trade got their own color post-it-pad and wrote down the different work tasks. This was then arranged on the calendar while commenting were other trades put their notes. This method gave the trades the possibility of understanding each other's work. It also helped highlight alternatives or potential problems before locking down the takt plan. Using Porsche Takt terminology, each post-it represented one "wagon" in the takt train that moves through the zones, and by combining as many similarly colored notes into the same wagon there was less need for each trade to visit the zone many times. For labor intensive wagons it was possible to compensate by increasing its staffing.

The takt plan: After completing the three takt meetings the foundation for the takt plan was laid. The preferred trade order, takt time and zones were all discussed. The idea behind the takt plan was to progress as smooth as possible during the main parts of the production, and then including a smaller completion phase at the end. This left some room to correct errors while not hampering subcontractors that did not need to be a part of the completion team.

Figure 2 shows a cut-out of the complete takt plan, with floors on the y-axis and weeks/takt periods on the x-axis. It includes the entire progression of high rise A and most of B and C, with a total of 26 individual wagons per high rise.

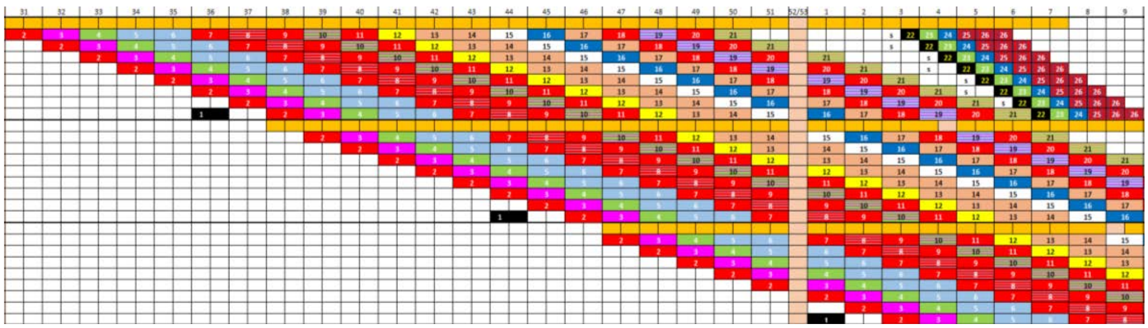

Figure 2: Takt plan of Project 3

Each wagon got an associated color which indicates what trade has work to do. For instance, red is carpenter, pink is plumber, green is HVAC and blue is electrician. Some wagons required two trades to cooperate, and these are marked with a combination of the trades colors. This made the takt plan easy to understand. The orange floor is the ground floor and due to being unique and non-repetitive it was set as a task buffer and is not included in the takt plan in other way.

THE TAKT PLAN IN USE

At the time of writing this paper the takt plan has been executed on the first high rise and well into the second. Interviewing those involved in the production shed some light into how the takt plan had been performing so far. Both employees of the main contractor and subs were interviewed, from craftsmen to administrators, and careers spanning from 10 to 30+ years. Since TTP is not that common, at least in Norway, the focus of the interviews was to compare how this project had compared to their past experiences. Some of them had never worked with a takt plan before, while others had worked on Project 1 or Project 2.

Past experiences:

Those that worked on Project 1 all agreed that, due to the complexity of the project, it was a difficult project for their first attempt at TTP. This project had little repetition and, due to being a hospital, demanded a lot from the technical utilities and the subcontractors installing them. This made it difficult to proceed with a single parade of trades, and it was often necessary to move back and forth between zones. The lack of repetition as found in Project 3 required tighter control of variability through a more flexible work force and more follow-up. Considering the low percentage of work packages completed on time, this was said to be one of the reasons. Most agreed that it would have been easier now that they have more experience. One positive outcome was that when something went wrong, the takt plan made it easy to spot. Due to the nature of a takt plan, when one work package fails to complete on time it indicates that something is not working and measures can be taken at once. Using a more traditional approach, there might not be an indication until it is too late.

On Project 2 the takt plan worked much better. As indicated by Mordal (2014) there was a clear increase in productivity, which reduced both total time of the project and costs. This was in compliance with the interviews, where it was pointed out that Project 2 was a much simpler project with a much higher grade of repetitive work. The project consisted of several two story row houses where all but the last row was built without using TTP. By logging hours spent during construction and the increase in productivity from house to house, it was quite clear that TTP affected productivity positively, both in terms of construction time and costs. The site manager had used much of his spare time to evaluate the experiences gained from Project 1 and applied his findings to Project 2. This was of great use, and even though the project did not go without any hiccups, the takt plan was robust enough to cope with it.

Working with TTP on Project 3:

When asked about how the takt plan had worked on their current project the answers were unanimously positive. Logistics were pointed out as a key aspect for the takt plan to succeed, and so far it had worked well with just minor complications. Considering the small amount of on-site storage in this project, more problems could have been expected. With a large amount of repetitive work, many of the crews had experience an increase in productivity. Some work packages that started out with as much as five craftsmen were reduced to as little as two before completing the first high rise. This was somewhat expected, and past experience told the site manager to ask for larger crews to begin with so they could be reduced over time.

There were some that pointed out that there had been some problems with work packages not completing on time. This lead to delays as the next trade had to wait. The reason for this was explained as a problem with delivery of doors from the manufacturer. The solution here was to install temporary doors and having the manufacturer install the correct doors later. Otherwise the work packages were completed on time, and the site manager pointed out that there had been a significant reduction in wasted time due to waiting. This resulted in more time doing productive work, and due to the piece pay system it made for good salaries for the craftsmen. The system works by giving each element of the building (meters of wall, square feet of floor or roof, etc.) a price from the work that goes into them, and then calculating hourly rates out of what has actually been produced. When converted to hourly rates they reached as high as 325 NOK/hour. Other projects without TTP is usually expected to be in the area of 270-280 NOK/hour, giving Project 3 an ~18% increase. The result being that using a takt plan did not reduce the projects costs that much in terms of the production unit. The site manager pointed out that he would recommended paying by the hour, and that a revision of the salary system is in order to get the most out of TTP. In terms of costs due to the on-site project administration, there was a possibility of a cost reduction since they had a fixed salary. This was something they did not experience, since this project demanded a larger project administration compared to other projects they had experienced.

When asked about buffers one common answer was that it did not work correctly. The site manager planned to use the ground floors as off-takt buffers, which to begin with did not get much support from the rest. Since the ground floors required trades to complete their work in a specific order just as much as the rest there were some problems regarding available work. When one trade had extra craftsmen they wanted send to the buffers there might not be anything for them to do yet. It was suggested to include the ground floors in the takt plan, but due to their lack of similarity from the remainder of the floors it would require significant changes to the entire takt plan. The site manager said that if this was going to work they might have had to go for 2-days takt instead of one week.

Future use of TTP:

Most of the interviewees had little to no experience with takt planning from before. When asked about being interested in using it in the future they were unanimously positive, and wanted to contribute to making it work better. They realized that in order for TTP to work it is essential that everyone got on board with it, even though there were some that always blamed failures on others.

Some of the things pointed out as possible improvements on future projects was to start the planning process earlier, at least involving the craftsmen earlier. This was in order to get better feedback on the order of work packages, and also identifying everything that need to be done. If something is missed and has to be included into the takt plan there might not be enough time to complete it, since the plan is already optimized to a high degree. Still, when everything went according to the plan it was a comfortable way of working, especially when they got into the groove. Since the work was defined in such a detailed way they always knew what todays work was going to be, and there was little hesitation about what to do next.

There was some skepticism about other projects lacking the degree of repetition found in Project 3. Though TTP is not depending on repetitive work it makes it much easier. They pointed out that this was the reason Project 1 did not work as intended, but that because of the experience they now had gained it would have done better if they were to do that project again.

DISCUSSION

The method used for creating the takt plan has clear resemblances to the six phase process identified by Frandson et al. (2013). While not following the process step by step, the iterative takt meetings seems to be quite efficient in establishing the foundation of the takt plan. By using the post-it calendar like a reverse phase schedule, a lot of work was done in a short time. Still, generating the actual takt plan involved a lot of manual labor. One example is the use of Microsoft Excel as the tool for visualizing the takt plan as a line-of-balance view. This could be done more efficiently in software like Vico Control as a flow line view.

From the interviews conducted there is an indication that the takt plan worked much better in the case project than previous attempts, but there are still improvements to be made. At Project 1 they experienced problems with controlling variability. This was not a problem in Project 3, though much of this can be attributed to the lower complexity in the project. In Project 2 they managed to reduce both total completion time and costs, but the success was limited by the effect experienced when combining TTP and piece pay. This effect was also seen at Project 3.

By design, the project has properties that meets many of the proposed criteria for takt-suitability. Additionally, the process by which the site manager chose to generate the takt plan helped enforce these properties.

The tasks: Due to low complexity of the building there were few tasks that required trades to cooperate directly. This was highlighted by the site manager as he wanted each trade to perform as much as possible before having to move on. Even though a task buffer was not one of the criteria for takt it has still been put to good use here.

The use of time: Much of the work performed could not be completed without the previous trade finishing their work. Therefore, the right trade sequence and correct logic was easily identified and resulted in very little setbacks.

The use of space: The project was very well suited for dividing into zones, and while some trades had to be in some zones simultaneously they rarely had to work on top of each other.

There are clear benefits from using TTP. Regarding completion time this proved essential for this project to even be able to finish on time. Having a shorter start-to-finish time can potentially reduce project costs by reducing overhead costs, but more research on this has to be conducted in order to identify how it can be utilized. A potential reduction in direct costs can be expected by switching from piece pay to hourly rates. This is may be the most attractive benefit from using TTP, and a recommendation would be to attempt at using TTP with hourly rates in parallel with piece pay so that they might be compared directly. Hopefully this might not impact worker comfort as their rates will return to the previously expected level. Even so, the other benefits to worker comfort gained by using TTP would be a welcome addition in any project since most were happy having a predictable work day.

CONCLUSION

The takt time planning method in Project 3 has been reviewed and compared to previous projects and experiences. Even though there has been a positive development during the three projects completed by the contractor there are still improvements to be made, especially when considering the benefits. There are incentives to use TTP regarding construction time, costs and worker comfort, but due to the piece pay salary system there is little change in costs. It would be interesting to do trails runs with TTP and other salary systems, for instance hourly rates.

Future research should focus on identifying indicators that could be used to replace piece pay with hourly rates without hampering the positive effects TTP contributes. To identify the true cost of performing TTP it would be necessary to gather data on overhead costs attributed to it and ways to reduce it. This can then be balanced out with the gains.

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APPLICATION OF LEAN PRINCIPLES TO MANAGING CONSTRUCTION OF AN IT COMMERCIAL FACILITY – AN INDIAN EXPERIENCE

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ABSTRACT

Application of lean strategies in the Indian projects is in its infancy. Initial experience has been around application of the last planner system and value stream mapping. The authors have tried to implement that and other techniques including usage of BIM drawings and LBMS to improve project execution of a 200,000 sqm commercial facility to be delivered in 24 months.

Using case study and implementation report research, the authors present their experience applying various lean process in this project. Specifically, the impact of the Last Planner System™ (LPS) in the civil phase of the project helped reduce the cycle time and eliminate delays. For the MEP phase, LPS combined with location based management system was used to effectively coordinate workfront across the subcontractors. A big room was created to share information and collaborate between owner, PMC, general contractor and fifteen subcontractors. The big room helped with improving coordination, reducing communication latency, and streamlining communication among the various agencies. The experience shows that while it took a couple of months to convince all to participate in the process, they all saw value once the new methodology was adopted. The paper concludes by discussing what limits successful adoption of lean techniques like these in the Indian context and potential ways of overcoming them.

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KEYWORDS

Last Planner System, BIM, Location Based Management System, India, Commercial Real Estate.

INTRODUCTION

Lean construction practices have been coming of age in India for the past few years. Although there are sporadic instances of it being practiced pre-2009, the Institute of Lean Construction Excellence (ILCE) that came into existence in 2009 has been instrumental in making lean construction a common word in the industry today. It has been creating awareness and propagating lean practices across owners and contractors pan India actively since 2009. But the body of knowledge, and the level of awareness is still in its infancy. Similarly the exploration of the various tools and techniques are also in the exploratory stage. The authors have independent experience in the application of various tools like the Last Planner System™ (Howell 1999, Ballard 2000), Value Stream Mapping, Work Sampling etc. at the current project being discussed here and in previous projects (Udhayakumar and Jaisankar 2015, Vaidyanathan et al. 2015).

The initial application of these tools have been done based on the learnings and experience from the available literature from around the world. But as the authors gain local experience, the tools are getting adapted to the Indian construction environment. As an example, typically good for construction (GFC) drawings are not available at the beginning of the project. The drawings come in tandem to execution. So, this is a key constraint in the lookahead planning that demands a lot of attention. But the general realization is that the learnings have matured to a point wherein, if applied diligently, we are able to get predictable results and measurable improvement in the civil works stage for residential and commercial buildings.

But the complexity of coordinating finishing was more complex because of the larger set of stakeholders involved. This and the onsite labor productivity challenges meant that a successful application of LPS alone was inadequate for the improving the reliability of delivering the finishing activities. Literature survey by the authors revealed that location based management system (LBMS) along with LPS came up as a viable alternative to try (Kenley and Seppänen, 2010, Sepanen et al 2010). This paper chronicles the authors experience of applying the lean techniques in a commercial real estate facility.

PROJECT DESCRIPTION

The project is a 200,000 sqm IT commercial facility, to be owned and operated by Tata Realty and Infrastructure Ltd., (TRIL). The project – Ramanujan IT City – is being developed in three phases and the project being discussed here is phase 2 of the project. The project is on a site spread over 25 acres (about 100,000 sqm) in the city of Chennai, India. Phase 1, consisting of four towers A, B, C, and D is a 500,000 sqm commercial office space was completed and delivered in 2013. The first phase of the project used Alliance based contract and was a successful application of that. Although TRIL was inclined to continuing the Alliance concept for Phase 2, there were not too many contractors willing to work in that model. So, for phase II, TRIL went in for a conventional contracting approach, but insisted on the application of lean principles to have better project control as well as better relationship between owner and contractor.

The Phase 2 consists of two towers E and F. Each tower is a total of 18 floors including 3 basements. The structure is a conventional frame structure with post tensioned flat slabs. Finishing consists of façade, elevators, and common area amenities including electrical, fire-fighting, HVAC, and toilets. The project duration for construction was contracted out to be 24 months between April 2014 and March 2016. The key stakeholders involved in the project are as follows. The project owner is Tata Realty and Infrastructure Ltd. (TRIL) (http://www.tril.co.in). The general contractor at risk and the civil contractor is URC Constructions Pvt. Ltd., (URC) (http://www.urcindia.com). The project management consultant is CBRE (http://www.cbre.co.in), and the principal architect is Edifice Consultants Pvt. Ltd., (http://www.edifice.co.in). Nadhi Information Technologies (http://www.nadhi.in) was the lean coach creating and inculcating lean practices among the site team members. Their technology nPulse™ was also used to manage all project information and monitor the project progress. Apart from these principal stakeholders, there were ten to fifteen engineering consultants and about 20 trade subcontractors responsible for supply and erection of the finishing activities.

LPS FOR CIVIL WORKS

The civil works was to be completed in about 18 months. The contractually agreed upon intermediate milestones were the following: the basements and the podium level had to be completed by December 31, 2014, the fifth floor had to be completed by March 31, 2015 and the roof flab had to be completed by August 15, 2015. To achieve these goals, the schedule indicated an average cycle time of about 25 days per slab. Each slab was broken into eleven pours below the podium level and six pours at the typical floor superstructure levels above the podium. Nadhi was brought on as the lean coach around August 2014 to bring lean practices. At that time the site was running around 45 to 60 days behind schedule. The LPS program was kicked off by holding a day long workshop with all the URC planning engineers, execution supervisors, project controllers, CBRE, and TRIL. Discussions with the onsite team revealed that the team could practically, under the site conditions achieve around 30 days at best. Weekly planning was done every Saturday that helped the execution team arrive at a weekly work plan and discuss, identify, and eliminate constraints for the six week lookahead plan. The lookahead plan served the purpose to identify procurement needs, drawings coordination and other issue management and also plan for labor and material coordination.

Although there was some initial scepticism, the team was very cooperative and supportive in adopting the new processes. In fact, one of the site supervisors remarked, almost six months after LPS had run on the site, “it is now I understand what you were trying to tell us in the workshop on the first day. Now I know the value of the LPS system”. When LPS was first started, the team was achieving about 40 days per slab. Through diligent application of the LPS system, some iterative learning and targeted interventions, the average pour cycle was reduced to about 20 days in the superstructure level (Figure 1).

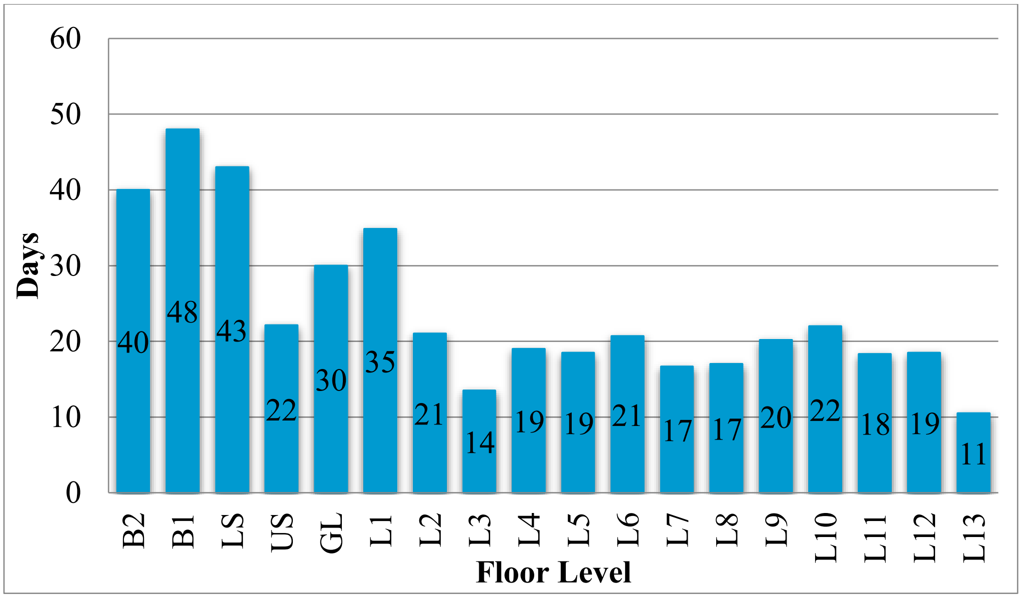

Figure 1: Average slab cycle time

The following are the various interventions that were done as a result of the PPC measurements and root cause analysis over the duration of the civil works stage:

- The first learning was that although at a high level sixty column sets of formwork was adequate to achieve the desired pour cycle, at a working level, this was inadequate. This is mainly due to the differences in the various column sizes. So, one of the first things that URC had to do was to procure additional formwork material.
- A value stream mapping analysis on starter columns revealed that by moving from wooden starter columns to steel starter columns, the pour cycle time could be reduced by upto 2 days. In addition, carpenter labor productivity could be increased by about 33%.
- The slab formwork was re-designed to be a table form system from a cuplock system. This again improved formwork productivity by 300% and reduced the pour cycle time by about four to five days.
- Another learning from labor work sampling was that, there was ad-hoc movement of labor gangs that happened during the day for a variety of reasons. The impact of the labor movement was slower productivity and rework. A strict process of dis-allowing labor movement was put in place significantly improving productivity, and practically eliminating rework.
- The weekly work plan helped set measurable targets for the formwork carpenters, and the bar-bending steel riggers. Focus was made on ensuring that workfront was available to them in a timely manner. This significantly improved the confidence of the executing team in the LPS mechanism and further served to reinforce the adoption.

- Visual signages were put up on the site indicating target dates and progress to be visible to all the laborers onsite. While this had no direct impact on the pour cycle time, it did create a sense of ownership and transparency across the entire hierarchy of staff and laborers onsite.

In addition to all of these there were several material wastage reduction measures that were done that helped reduce reinforcing steel waste, concrete waste, and other consummables waste.

MEP WORKS – BIG ROOM WORKSHOP

Inspired by the success in the civil works, the team wanted to adopt the same techniques for the finishing works. But from past experience, the team knew that drawing coordination would be the biggest challenge in coordinating the finishing activities. Getting coordinated drawings in a timely manner would be a big reason for the inability to generate adequate work backlog. So, the first attempt at bringing reliability to execution in the finishing works was to create a “big room” (Khanzode and Senescu 2015). But unlike the big room being at the design development phase, this was attempted at the execution phase. The goal was to produce a coordinated GFC drawing for finishing activities in the lookahead period – one month prior to execution. With that objective, a workshop was conducted.

In April 2015, a two day workshop was organized by Nadhi. The participants included TRIL, URC, CBRE, the architect, structural consultants, and the mechanical, electrical, plumbing (MEP) consultants. The goal of the workshop was to create a coordinated BIM model based on the GFC drawings.

The workshop was done with only the consultants and there were a few learnings that came out of the workshop. The first was that, the consultants could not all agree on version numbers of drawings that were the latest. That was resolved by putting a better document control procedure through a collaborative technology solution (Vaidyanathan and Mundoli 2015). The second was that the engineering consultant relied on the trade subcontractor to produce shop drawings with drops (from the roof), offsets to walls, size of pipes etc. Hence, these details were not typically available in the design stage and only available at the shop drawings stage during execution. This means meaningful design coordination, clash detection etc. could not be done in BIM. The root cause of this could be addressed by putting better design requirements with the consultants to ensure adequate information was available for creating a BIM drawing. This also meant that timely procurement (of services) was linked to the ability to do clash detection and design coordination. And in this case since some of the contracts for the trades had not all been issued, the trade subcontractor was not onboard (yet); implying that clash detection will happen only on the field and cannot happen earlier unless procurement is done earlier. The third was that the root cause of any potential rework in the finishing activities was this inter-dependency between the design consultants and the trade subcontractors in creating details for the drawings.

Suffice to say, the first attempt at creating a coordinating “big room” was not so successful. Although the team was able to resolve clashes at the basement levels, the exercise had to be abandoned. The big learning was the value of design coordination and the need to better define design deliverables from the design consultants, and also timely procurement of trade subcontractors. And surprisingly none of this was specific to this project or these set of stakeholders, it seemed like this was the typical Indian scenario.

LPS WITH LBMS AT MEP WORKS

The team decided to try a different approach to better coordinate the works in the finishing activities. The team knew that setting up the LPS process for finishing was more complicated than that for civil works because of the number of agencies involved.

Hence, LPS had to be implemented with a simplified process and in a way that would appeal to the subcontractors. To achieve this, a coordination wall was created. Each trade subcontractor gave six weeks of lookahead. To keep the process simple, each vendor had to do two things in the weekly meeting:

- Put a yellow post-it against a commitment that they can make over the next six weeks. These are *commitments* that they felt confident to make
- Put a red post-it for any constraint that they expect in the next six weeks. A *constraint* is a coordination touchpoint between the site execution team and some other stakeholder. The touchpoint could be with another subcontractor who has to release workfront, an internal stakeholder who has to procure materials or mobilize labor, an engineering consultant who has to release drawings, or some other stakeholder (owner, or PMC) who has to make other decisions or commitments.
- This lookahead wall was used to shape the commitments and from this a weekly work plan (WWP) was evolved that gave the executable schedule for the week.
- Daily monitoring was done on the WWP and PPC measured.

The process worked well. The simple fact that the subcontractors could “air” their real issues and that TRIL, URC, and CBRE would respond to them was a welcome change. Also, the fact that the team was willing to work together to “solve” problems rather than blame each other meant that the subcontractors were willing to expose their inner constraints early. In fact, on more than one occasion, TRIL was willing to go beyond the contract terms and release payments in advance when vendors had working capital issues. This ensured that material procurement and labor mobilization was not impacted for the project due to financial constraints of the subcontractor. Within a few weeks, the coordination challenges reduced significantly and progress was starting to become more streamlined.

Soon it became clear that coordination challenges were the maximum in the toilet areas which was also the critical deliverable in making progress on a floor. The subcontractors were shifting crews from one toilet to another within or across floors to maximize the utilization of their labor crews while meeting commitments. The productivity of each vendor was measured in different units making labor crew movement, a technical challenge. So, while the process of handing over workfront from one trade to another based on the LPS worked, managing the challenge of the scheduling the labor crews was becoming a challenge. So, after some deliberation and research, the team decided to try the LBMS technique to managing the toilet area completions on top of the LPS.

A planning meeting of all the agencies that had to work on the toilet was called. A plan to complete a toilet was created. The initial assessment was that it would take about 60 days to complete a full toilet (post civil works) with durations, quantities, and sequence (see Table 1 below). All of this was done based on the experience of the subcontractor foremen (without a formal productivity basis). With this the team tried to monitor the progress. The team realized that there was more data gathering and structuring that was needed to setup a full scale LBMS. So, a detailed LBMS implementation was deferred. It was decided instead that the team will carefully monitor the movement of labor (aka trades) within a toilet and movement of labor (of a single trade) across toilets and create a sense of flow. The primary focus was to avoid ad-hoc movement of labor and planned generation of workfronts for all trades.

Table 1: LBMS at MEP Works

TRIL - LBMS Toilet work labour productivity									
			Planned			Actual			
Activity	Category	UOM	QTY	Duration	Productivity /labor	QTY	Duration	Productivity /labor	Reason for deviation in duration
Wall Chasing, Pipe laying	Plumber	RM	30	6	2.50	35	4	4.38	2 days duration reduced, Manpower ratio also changed
Cistern fixing	Plumber Helper	Nos	8		0.22	8		0.40	
Electrical Conduit		RM							
Water proofing	Water proofing Labour	SQM	90	7	4.29	90	6	5.00	1 day duration has reduced
Screed	Masons	SQM	50	3	8.33	50	2	25.00	1 day duration has reduced, Mason 1 nos is sufficient
	Helpers				4.17			5.00	
Soil Line- 110 mm	Plumber	RM	13	4	1.63	16	3	2.67	1 day duration reduced
Soil Line-75 mm	Plumber Helper	RM	25		1.56	22		1.83	1 day duration reduced
Brick bats	Masons	SQM	50	3	8.33	50	5	5.00	helper - 7 nos reduced , material has stored near by working place well in advance
	Helpers				0.98			1.00	
Duct Erection	Duct man/fitter	SQM	25	2	2.08	27	2	2.25	
Wall tile	Masons	SQM	110	7	3.93	125	6	3.47	
	Helpers				3.93			6.94	
False Ceiling- Channel	False Ceiling labours	SQM	50	3	2.08	50	2	6.25	Manpower planned wrongly
Counter Angle	Carpenter	Set	2	5	0.10	2	2	0.50	Standard size counter, so the productivity has increased
Counter Granite	Mason	Nos	2		0.10	2		0.75	
Floor tile	Masons	SQM	44	4	11.00	50	3	8.33	
	Helpers				11.00			16.67	
False Ceiling- Board	False Ceiling labours	SQM	50	2	3.13	50	2	8.33	
Cubicles	Fitters	Nos	7	4	0.44	7	2	0.40	
Final fix for NC	Electrician, fitters			2	0.00		2	0.00	
Painting	Painters	SQM	50	2	8.33	50	3	5.56	
Water Closet	Plumber	Nos	8	3	0.27	8	1	1.60	
Urinals	Plumber helper	Nos	3		0.10	3		1.00	
Painting	Painters	SQM	50	3	5.56	50	2	8.33	
	Cycle time			60			47		

Labour Productivity improv	27%
Planned cycle days reduced	13

Table 2 shows a partial plan for the toilets and actuals against the various activities for a few toilets. After a few iterations, the team was able to get some reliability into movement of labor across various workfronts. Each day, the various trade foremen came together at around lunch time, spent a few minutes reviewing the progress from the previous day and coordination issues for the day in a standing only meeting. And once the process was setup, the reliability of generating workfront meant that the subcontractors stopped ad-hoc movement aka deviating from the committed plan.

After running these meetings for a couple of months, the following was observed on the cycle time for toilet completion (Figure 1). Upto Level 4, the average actual dates for completion of toilets was around 95 days, then the middle floors upto Level 8, the average duration was about 75 days and finally the upper floors, the actual duration was about 50 days. The cycle time of toilet completion reduced by about 50% (50 days vs 95 days) in the upper floors from that of the lower floors or in the upper floors, the cycle time reduced by about 15% (50 days vs 60 days) compared to the plan. Concurrently, the productivity of the labor increased by about 27% from the original assumptions (see table 1). As of this writing the project progress is delayed due to payment issues (see Discussion below). The team is using this experience to do a more detailed LBMS and LPS implementation in the next phase of the project that is upcoming in the following year.

Table 2: Plan vs Actual for Toilets

E Block			Block work / plastering	Cistern Packing & Pressure testing	Water proofing Protection on Screed	Laying of Drainage Pipes &	Final fix for NCs	Painting	Fixing of CP & Sanitary Fittings	Final painting / Cleaning / Handing over	Plan vs Actual Duration
Duration			0	8	10	4	2	1	2	1	
Cum Duration			0	8	18	22	56	57	59	60	
L9	E1	PLAN	27-Dec-15	4-Jan-16	14-Jan-16	18-Jan-16	21-Feb-16	22-Feb-16	24-Feb-16	25-Feb-16	60
		ACTUAL	17-Jan-16	25-Jan-16	30-Jan-16	5-Feb-16	11-Mar-16	15-Mar-16	19-Mar-16	20-Mar-16	63
	E2	PLAN	29-Dec-15	6-Jan-16	16-Jan-16	20-Jan-16	23-Feb-16	24-Feb-16	26-Feb-16	27-Feb-16	60
		ACTUAL	20-Jan-16	27-Jan-16	8-Feb-16	11-Feb-16	22-Feb-16	26-Feb-16	1-Mar-16	2-Mar-16	42
L10	E1	PLAN	31-Dec-15	8-Jan-16	18-Jan-16	22-Jan-16	25-Feb-16	26-Feb-16	28-Feb-16	29-Feb-16	60
		ACTUAL	22-Jan-16	28-Jan-16	2-Feb-16	8-Feb-16	20-Mar-16	24-Mar-16	28-Mar-16	29-Mar-16	67
	E2	PLAN	2-Jan-16	10-Jan-16	20-Jan-16	24-Jan-16	27-Feb-16	28-Feb-16	1-Mar-16	2-Mar-16	60
		ACTUAL	25-Jan-16	30-Jan-16	11-Feb-16	14-Feb-16	27-Feb-16	2-Mar-16	6-Mar-16	7-Mar-16	42
L11	E1	PLAN	4-Jan-16	12-Jan-16	22-Jan-16	26-Jan-16	29-Feb-16	1-Mar-16	3-Mar-16	4-Mar-16	60
		ACTUAL	23-Jan-16	28-Jan-16	9-Feb-16	15-Feb-16	17-Mar-16	21-Mar-16	25-Mar-16	26-Mar-16	63
	E2	PLAN	6-Jan-16	14-Jan-16	24-Jan-16	28-Jan-16	2-Mar-16	3-Mar-16	5-Mar-16	6-Mar-16	60
		ACTUAL	27-Jan-16	31-Jan-16	5-Feb-16	8-Feb-16	28-Feb-16	3-Mar-16	7-Mar-16	8-Mar-16	41
L12	E1	PLAN	8-Jan-16	16-Jan-16	26-Jan-16	30-Jan-16	4-Mar-16	5-Mar-16	7-Mar-16	8-Mar-16	60
		ACTUAL	28-Jan-16	1-Feb-16	6-Feb-16	9-Feb-16	29-Feb-16	4-Mar-16	8-Mar-16	9-Mar-16	41
	E2	PLAN	10-Jan-16	18-Jan-16	28-Jan-16	1-Feb-16	6-Mar-16	7-Mar-16	9-Mar-16	10-Mar-16	60
		ACTUAL	29-Jan-16	5-Feb-16	14-Feb-16	19-Feb-16	25-Feb-16	29-Feb-16	4-Mar-16	5-Mar-16	36

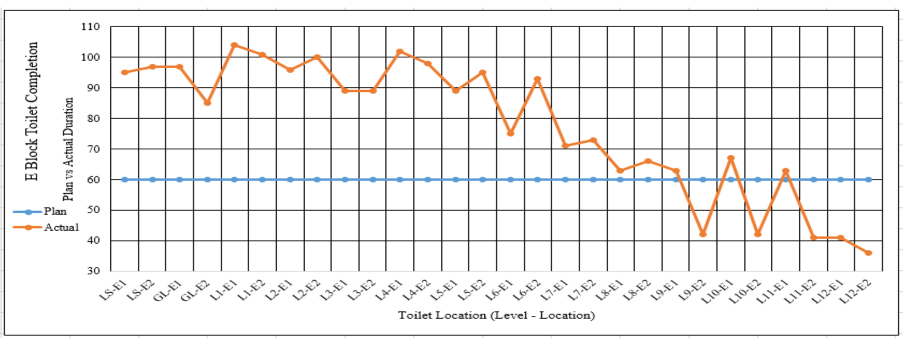

Figure 1: Plan vs Actual Duration of Toilet Completion of E-Block

DISCUSSION

The project discussed here is a reasonably sized, complex commercial real estate facility with multiple stakeholders. The project setup in terms of stakeholders, contractual structure, and processes is reasonably representative of a typical scenario of Indian construction environment. In this environment, the authors find that LPS is useful to managing civil works progress. The simple act of disciplined planning, the social aspect of collaboration between the various stakeholders, and the transparency achieved by discussing and displaying the schedule with all helped with improving the reliability of the planning process. There were targeted interventions done, but they were done on the platform of the reliable planning done using LPS. The direct impact of the LPS process in the civil works in this project is to reduce the average slab cycle time by about 50%.

In the MEP stage, the team attempted creating a coordinated BIM in a *big room* workshop. The learning from the workshop is that design coordination process should be improved and a stronger push is required from the Owner to get GFC drawings prior to starting projects. Also, the expectations from finishing design consultants to provide adequate details for coordination should be set. Unless these happen, doing clash detection using BIM cannot be effectively achieved. As an additional process modification, procurement of the services of subcontractors by the Owner has to be done earlier and not in advance of the progress of the project (for example, say 90 days prior to beginning of the trade). With this, in addition to the above, the authors feel that the project can gain additional value of using BIM processes since constructability inputs from the subcontractors can also be incorporated. Both of this will eliminate significant rework that happens onsite. Still, while this probably reduces the efficacy of LPS, it does not eliminate the value of it.

LPS in the MEP areas helped identify bottleneck areas. In this case, the toilet areas was a bottleneck area. Coordinating labor movement and calculating labor requirements for balancing the flow of activities across the toilet activities was attempted using the LBMS technique. This being the first attempt by the authors, there was a learning experience which limited exploiting the full potential of the LPS LBMS combination, but within the limits of what was practiced, the team got moderate results. There was a reduction in the cycle time to deliver toilets and an improvement in the productivity of labor.

Every contractor and subcontractor has cash flow problems. Unless they receive their monthly payments in a timely manner, all attempts at creating reliability in the planning process project progress fails. It should be noted in the context that all the contractors work on multiple projects and there is a multi-project impact on cash flows. In other words, the site team raises invoices and get paid (timely or not), but procurement of materials and labor is done centrally by the HO of each subcontractor. In the project being discussed here, the owner, TRIL, paid bills on time. In some cases, they even paid in advance to help with the cash flows of the subcontractors. But the portfolio level cash flow problems of the subcontractors meant that even though this project was financially paid on time, the onsite team could not get the required materials and labor to be procured and mobilized in this project per the project's requirements. This also limited the ability to implement lean techniques effectively.

To address this, the authors propose a project level escrow account. The goal will be for the owner to create an escrow account that will hold all the payments made to the subcontractors. The subcontractors can use the money from the escrow account to spend for material and labor procurement for the project only. This insulates the project from the portfolio level payment impact. The authors acknowledge that this will complicate the accounting that medium and large contractors need to do to manage a portfolio of projects, but we feel that this might be required in the interest of the project progress.

CONCLUSION

The paper attempts to discuss the authors experience in implementing lean construction processes in an IT commercial facility. LPS as a social, collaboration process to improve the efficiency of delivering civil works worked. The team was able to increase the reliability of completing pour cycles, eliminate delays, and reduce the cycle time. LPS combined with LBMS was attempted in the MEP stage. While early results have been achieved, this being the first experience of the authors on LBMS, there is significant room for improvement. It is the authors' view that without some fundamental process changes in design and finance management, attempts to bring lean construction processes to the Indian industry has a risk of failure of adoption. It is also the authors' view that a more refined application of the lean techniques with the aforesaid process changes will be more beneficial to all stakeholders.

ACKNOWLEDGMENTS

The authors wish to thank the respective organizations that they each work for granting permission to present the information about this experience. The discussions and conclusions noted here are personal opinions of the authors' and not of their organizations.

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LAST PLANNER® SYSTEM: IMPLEMENTATION IN A MOROCCAN CONSTRUCTION PROJECT

Habchi Hicham[1], Cherradi Taoufiq[2], and Soulhi Aziz[3]

"The Last Planner production control system is a philosophy, rules and procedures, and a set of tools that facilitate the implementation of those procedures. Regarding the procedures, the system has two components: production unit control and work flow"

(Ballard & Howell, 2003)

ABSTRACT

As Morocco is a North African country witnessing constant initiation of major development projects, this paper attempts to integrate the Last Planner System® (LPS), for the first time, in a Moroccan construction project. Our case study tackles the structural work of a 21 building-residential project consisting of 396 housing units with four floors each. Works were launched in the site in June 2015. This paper aims to describe the implementation steps of LPS into a Moroccan site, and to analyze the latter's evolution. Given that this system is still considered as unfamiliar in Morocco, we will try to answer the following questions while trying to apply LPS procedures on the Moroccan platform:
What are Moroccan specificities that can contribute to smooth integration of LPS?
What limitations may hurdle implementing LPS in Morocco?
Are there any recommendations that shall help to adapt and improve incorporation of LPS within the Moroccan construction atmosphere?
As far as data collection is concerned, we organized weekly site meetings with all the involved stakeholders of the project. During these meetings, activities of the following weeks were planned, and PPC of the previous one was calculated. Meanwhile, the root causes of variance were analyzed. As for the work flow, we drew a future six-week plan to check the probability of any potential constraints, in order to deal with them proactively. This work will considerably contribute to developing LPS implementation data base. It is indeed an unprecedented trial of its kind as this paper is about describing its first implementation in Morocco, a French-speaking country.

KEYWORDS

Last Planner System, Production Unit Control, Transformation Management, Workflow Management.

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INTRODUCTION

The construction sector in Morocco has become a strategic field of economic development. It currently involves more than 53.000 production units, nearly 1,500 structured companies, 10.000 units already located, and 40.000 units unallocated, which are independently working on construction sites. The total turnover of all of these companies exceeded an annual amount of 30 billion Dirhams, with an average turnover of 15.9 Million Dirhams (Zarouali, 2014).

The sector has achieved influencing numbers in 2012. Khalfaoui & Zenasni (2014) maintain that it has contributed to GDP with up to 6.5%, boosted the workforce with a share of 11.3%, and represented 50.1% of Gross Fixed Capital Formation (GFCF).

Unfortunately, this field is currently experiencing some sort of breakdown, and that is due to some obstacles that have directly affected the pace of its dynamism. These barriers fall into two main factors, external and internal:

- **External factors**: given that this sector has been influenced by international competition, agreements between Morocco and Europe to set up a free trade zone have had a negative impact on the area. "Foreign firms slash prices, destabilizing the Moroccan construction market" ((Benhamida, 15 janvier 2008.)
- **Internal Factors:** (these are company-specific factors) Moroccan companies acting in such economical activities run into several challenges, namely:

Unsatisfactory competitiveness atmosphere: informal firms and SMEs, which alone shape 95% of the business, promote for either unfair or limited competition climate.

Less activity, sticky prices, weak liquid assets, foreign supply, higher expenses, debt recovery, and local procurement. according to business surveys conducted by HCP (Haut Commissariat au Plan, 2013)

Being the case, Moroccan companies constantly need to optimize their activities in order to make more possible profits in light of the critical situation highlighted above.

In such a tight economical context, the new production control system LPS, the Last Planner System created by G. Ballard, has been applied on management of a Moroccan construction site. This system is supposed to optimize execution of the ongoing activities, along with preventing the maximum number of constraints. That has absolutely ensures smooth workflow.

LPS® - THE LAST PLANNER SYSTEM

In Morocco, project management is directly related to transformation management. The master schedule is frequently confronted with the progress of work, and, in case of deviation from the deadlines, a catch up plan is often suggested.

As mentioned in the CCAG-T (Cahier des Clauses Administratives Générales applicables aux marchés de Travaux executés pour le compte de l'état), after the company carries out its respective estimation procedures, the contractor is expected to provide the project ownership with an execution master plan in addition to the general measures needed for this end (CCAGT Article 37). The case where the general schedule conflicts with the actual progress amounts to an instance of delay. Be it retards involving the entire project, or just a part of it, daily penalty is imposed on the contractor for execution deadlines (or target dates) are not successfully met, according to Article 60 **(CCAG-T)**.

This perspective of transformation management was criticized by Koskela and Huovila (1997), and (Koskela L. , 2000). According to them, the production process can be conceived in three different ways:

1) As a transformation process,
2) As flow of materials and information through time and space,
3) Or as a process of value generation for the end customer.

To integrate the flow within the production process, Ballard has developed LPS (The Last Planer System). This system takes into consideration the flow in a participative approach of project planning. Ballard (2000) asserts that "the Last Planner production control system is a philosophy, rules and procedures, and a set of tools that facilitate the implementation of those procedures. Regarding the procedures, the system has two components: production unit control and work flow".

- The production unit control

At the production unit, the key dimension of a planning system's performance is its output quality, namely the quality of the produced plans by the last planner.

Performance of the planning system is easily measured through schedule execution results. This is achieved by measuring PPC (Percent Plan Complete), which stands for the ratio of the executed activities to the total activities as were planned earlier.

This indicator serves to highlight the realization percentage of the fore planned activities. That is, a high PPC means that the contractor has executed more workload with the given resources, notably increasing work progress and productivity.

The second benefit of calculating PPC is that constraint analysis involves the planned tasks, which are not completed yet. By analyzing and eliminating any root causes that may lead to non-accomplishment of the planned works, work performance is significantly improved accordingly.

- Project Flow Control

While production unit control coordinates the implementation of work in the production units (site-based teams for instance), project flow control coordinates the flow of design, supply and installation through the production units.

An anticipatory planning (look-ahead plan) is established to highlight what needs to be done on the short term level.

PROJECT DESCRIPTION

Located in the North of Morocco, the project is a real estate program composed of 4 blocs covering a surface of nearly 10.600 m^2. The program consists of 396 housing units in the form of 21 4-story buildings. Works of this program started in June 2015. The main stakeholders in this project are: the project ownership, the architect, the design firm, the coordination office, the technical laboratory, the surveyor, and the main contractor. Representatives of the project owner were responsible for implementation of LPS.

What made this project present with some challenging specificity (compared to any other ordinary building project) is the fact that works were due to take place on a sloping platform, given the mountainous nature of the site.

RESEARCH METHODOLOGY

At the time of project launch, we held meetings with teams that used to manage transformation. By means of training, we tried to gradually introduce concepts of flow management and production control that is based on the spirit of Lean Construction, which aims to bringing about a step by step change in the team's habits.

To enable stakeholders from having a clear perspective on the contractor's productivity, we proceeded first by explaining the need of introducing weekly reports as an essential part of site management. We also calculated PPC starting from the very first week. During site meetings, we analyzed the constraints that led the non-accomplishment of the planned tasks. We realized that we succeeded at changing some site-based teams' habits (as the case of foreman -the last planer- who also started attending in-site meetings), and at identifying, in coordination with the contractor's project manager, the tasks to be executed along the weeks to follow. During the first weeks, we focused only on production unit control.

Secondly, we noticed that non-accomplishment of the planned tasks throughout the week was linked to constraints that were absolutely external to the project. These constraints needed to be identified in order to maintain a tied workflow. As a result, we explained that it was necessary to introduce the six-week look-ahead schedule in order to properly determine such constraints. Indeed, training on the subject matter was also conducted in the benefit of all the stakeholders. Figure 1 represents a timeline showing the evolution of implementation of the LPS.

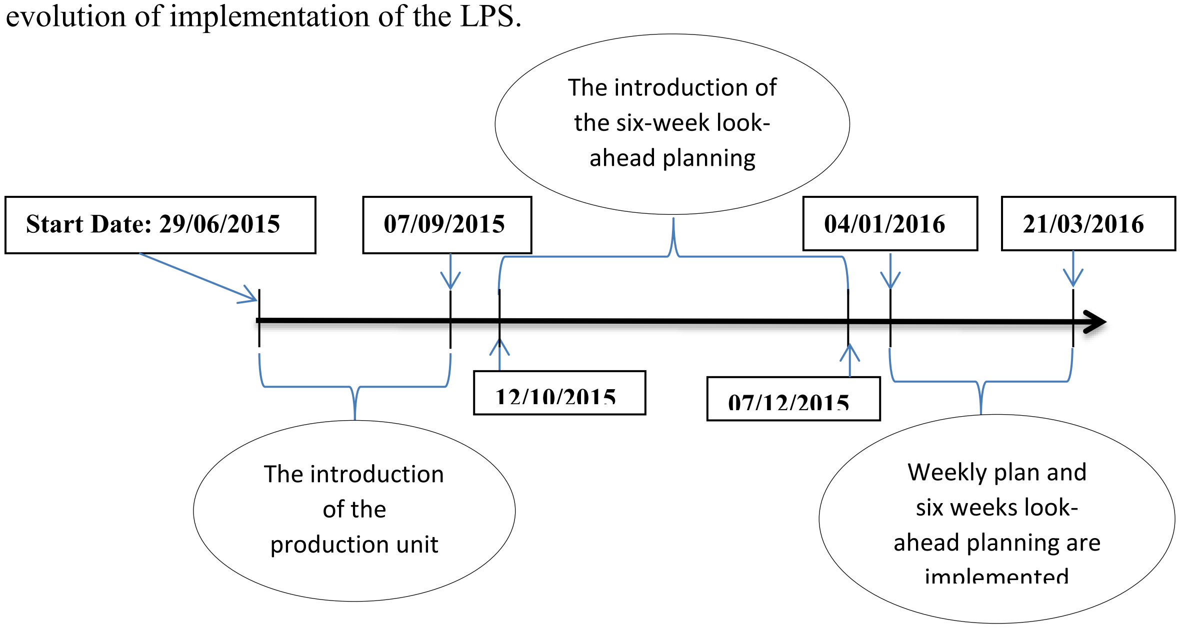


Figure1: A timeline of key events showing the steps of implementation of the LPS.

With regards to collecting information, we held weekly site meetings with all stakeholders. During these gatherings, we began by contrasting the project's progress against the predetermined schedule (transformation management). Subsequently, we tackled the contractor's productivity through both calculating the previous week's PPC and analyzing constraints that had caused non-accomplishment of some other tasks. Later, pursuing a participatory approach, we attempted to draw the following week's tasks. Finally, we developed the six-week look-ahead plan, and predicted all possible limitations that may emerge during that period. For that, we tended to attribute every possible constraint to one of the stakeholders who was appointed as responsible for its treatment.

CASE STUDY

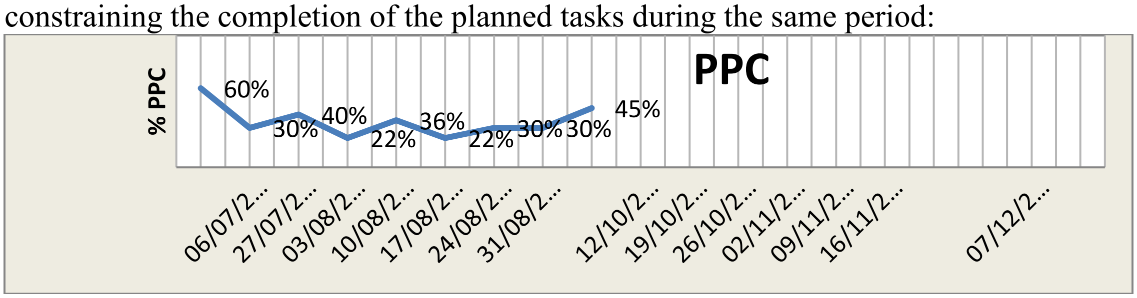
1st PHASE OF THE PROJECT (Between 29/06/2015 and 07/09/2015: before site off for holidays)

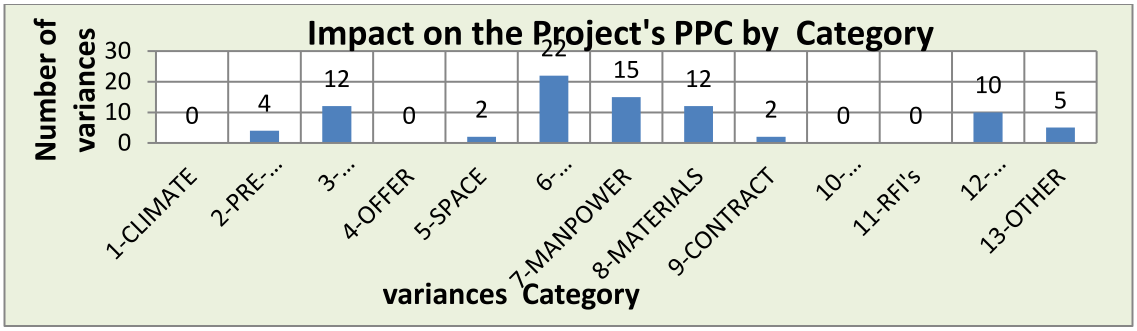
Phase Features:

- Works on the platform were initiated and the site was installed.
- The company encountered a problem due to the sloping nature of the site floor. The design firm requested to perform earthworks so to level all the footings of the building (which, unfortunately, was not mentioned during the geotechnical study of the project). This lack of coordination between the geotechnical laboratory and the design firm resulted in unforeseen earthworks of up to 7 m deep bellow natural grounds (instead of the 1.2 m that was predicted earlier).
- This was the first project undertaken by the company in this city, bearing in mind how far the site is from Rabat the capital.
- During this phase, the company had to stop the works due to religious holidays along the period between 13.07.2015 and 27.07.2015.
- This phase marked the introduction of the production unit control. We held training for all stakeholders on the elaboration of the weekly report, calculated PPC, and analyzed the presented constraints.

Findings of the 1st phase:

The diagrams below show the evolution of the PPC during this period, and the factors constraining the completion of the planned tasks during the same period:





Results analysis

- Note that PPC was unstable during this period; this connotes that most of the scheduled tasks are not executed. To explain this PPC's instability, we had to analyze the type of constraints encountered.

Regarding constraints, we note that we faced almost all types of them.

It is clearly observed that the predominant constraint was equipment. During the excavation phase, the company outsourced this task to a subcontractor with whom it had no previous experience. This subcontractor confronted failures owing to the low quality of the excavation machines.

By the end of the 1st phase, launching concrete work (form and reinforcement works) marked accentuation of manpower-related problems. Furthermore, we encountered structural drawing problems. Drawings had to be redesigned to taking into account the nature of the field after excavation works.

2nd PHASE OF THE PROJECT (between 12/10/2015 and 07/12/2015)

Phase features

Earthworks were almost complete.

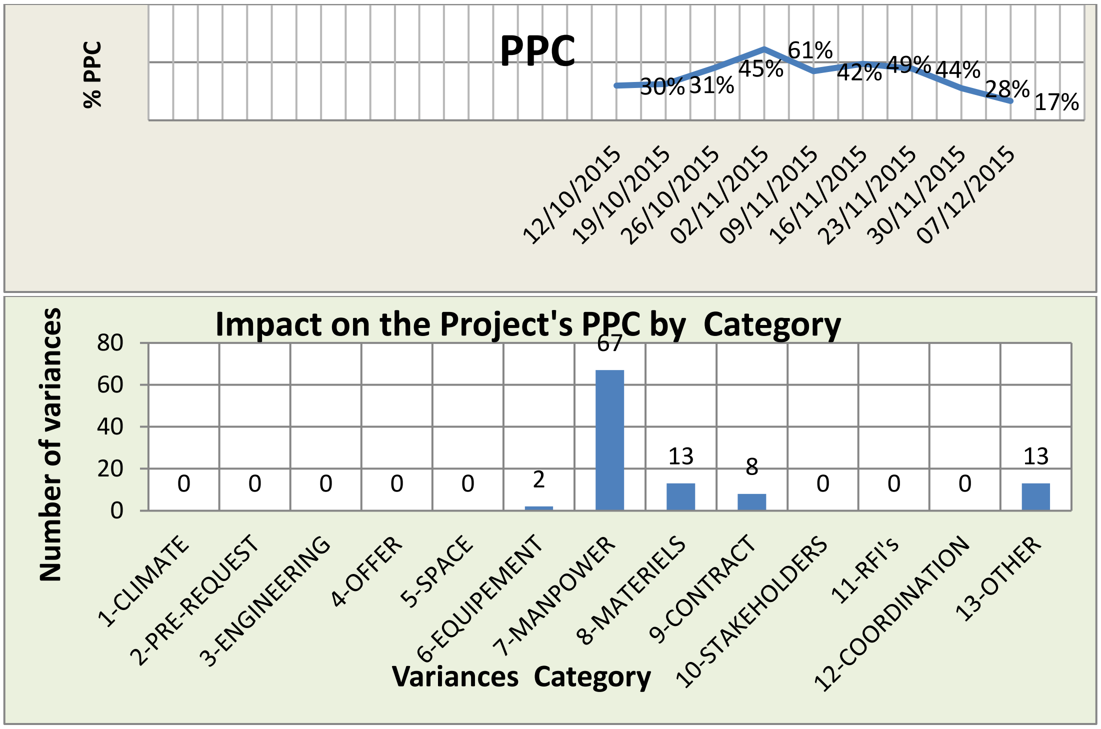
Foundation works were on-going, much of these works were accomplished by the end of this phase.

All problems linked to structural drawings have been resolved.

We deduced that the factors constraining good performance of the planned tasks are not always related to the production unit, given that stakeholders became familiar with elaboration of weekly reports, calculation of PPC and examination of the constraints. In this phase, we decided to introduce the six-week look-ahead planning and the constraints analysis linked to the overall flow of the project.

Findings of the 2nd phase

The diagrams below show the evolution of PPC during this period, and the factors constraining completion of the planned tasks during the same period:



Results analysis

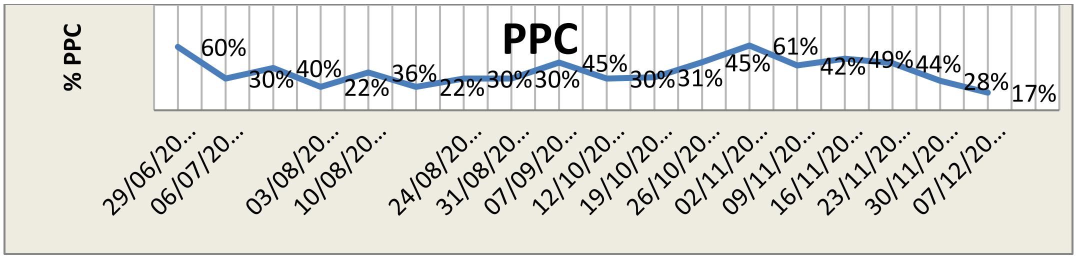
- Note that between restarting construction works and the week of 02.11.2015, the company's productivity was increasing while the evolution of PPC thereafter decreased.
- By analyzing the constraints that affected PPC, it is clearly noted that performance was hurdled by crucial lack in manpower, especially with progress of concrete pouring works.

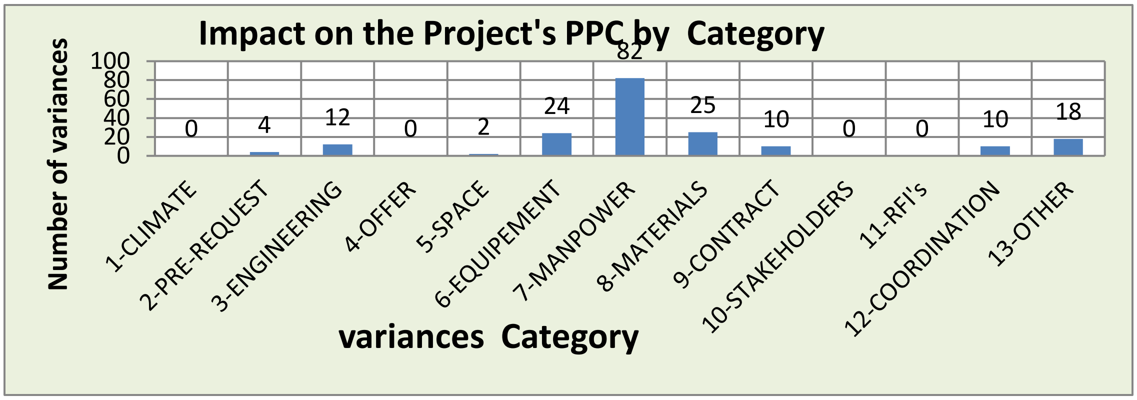
The contractor could not satisfy this need. That is because of scarcity of labor in the project area, as well as some of the company's internal financial problems. As a result, even if LPS weekly reports and the six-week look-ahead planning enabled us from identifying the constraints related to the production units and the project flow respectively, the contractor could not overcome these challenges.

PROJECT RESULTS FOR 2015

- In the second semester of 2015, the project PPC was far from being stabilized. That is owing to the large number of unexpected challenges the contractor faced (sloping grounds, inadequate drawings, etc.).
- The main constraint that hindered positive evolution of productivity is lack of manpower.
- To maximize the benefits of the LPS system, the company had to react regarding this constraint. The contractor found it difficult to successfully manage his internal financial constraints.

The diagrams below show the evolution of PPC during the second semester of 2015, and the factors constraining the completion of the planned tasks during the same period:





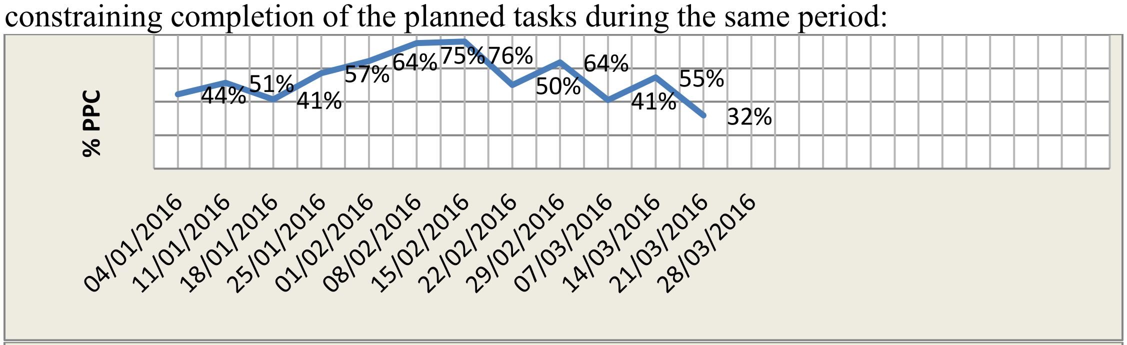
3rd PHASE OF THE PROJECT (between 04/01/2016 and 21/03/2016)

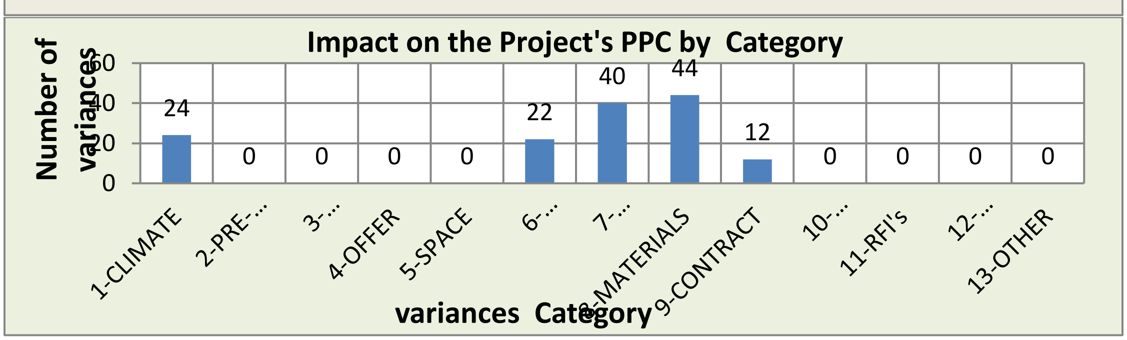
Phase Features

- Basement works were completed.
- Superstructure works were ongoing.
- During this stage, weekly reports and the six-week look-ahead plan were established. They are the key elements in the project's management.

Findings of this phase

The diagrams below show evolution of PPC during this period, and the factors constraining completion of the planned tasks during the same period:





Results analysis

- Note that the PPC curve has evolved in the period between 18.01.2016 and 15.02.2016.
- During this period, tasks were scheduled with more precision since we maintained a good mastery of the pace of the superstructure works (columns-slabs).
- After this period, as manifested above in the lack of manpower and materials, the contractor's productivity has dropped drastically; that was essentially a direct outcome of contractor's internal financial problems.

BENEFITS AND LIMITATIONS OF LPS IMPLEMENTATION

Benefits of implementing LPS

- Traceability is among the main advantages of implementing LPS. The project's history is easily retrieved since all weekly planned activities, the number of non-completed ones, and causes of their non-achievement were all kept track of.
- Applying LPS provided stakeholders with constant data regarding the contractor's productivity. As a result, decision-making proceeded with more fluency. For instance, based on the PPC value (17%) of the week of 07/12/2015, the project owner was obliged to warn the contractor, calling him on to review the overall schedule as well as the main project's milestones.
- LPS implementation ensured realistic weekly schedules, notably while involving the foreman (the last planner) in planning activities.
- The six-week look-ahead implementation enabled all stakeholders from discussing future constraints, which promoted team spirit and information sharing among all stakeholders.

Limitations of implementing LPS

- Training on elaborating weekly reports and planning the six-week look-ahead was sometimes effort and time-consuming. Such training needed to be taken by all the involved participants (representative of each stakeholder). So when a certain representative resigns during the on-going of the works, the same training had to be ensured for the newly recruited that is substituting for the one who had resigned.
- Implementation of LPS is successful at identifying the weekly and the six-week constraints only when all stakeholders are cooperative. As a case in point, we could have reached better results if the contractor had proved signs of better interactivity. Once the company had financial problems related to other projects, it was no longer positively responsive. Such lack in cooperation does not contribute to ensuring better anticipatory elimination of the various pre-identified constraints.
- Applying LPS provided us with a precise follow-up of the contractor's productivity, but not of his production (transformation management). During every weekly site meeting, we needed to contrast the phase planning to the current progress.
- After final accomplishment of the project, transfer of the knowledge acquired upon implementation of LPS as a first experience in Morocco is not likely to be ensured elsewhere.

CONCLUSION

After both describing the implementation steps of LPS in a Moroccan construction site and identifying the strengths and weaknesses of this implementation, it sounds of notable significance to develop a model that contrasts examination of the general schedule against the actual progress. Such a chart will help in making proper decisions regarding strategic milestones while including personnel from the project's hierarchy; that is, the foreman and his team to plan weekly tasks, and the project manager to control the project's milestones and make optimal decisions.

Therefore, it will be interesting to include LPS® production control system in the company's internal procedures. In our case, the project owner is currently establishing one within his own firm's internal procedures.

Finally, as was noted above, the success of LPS® implementation is closely linked to the positive involvement of the construction company through its commitment to resolving the constraints identified during the weekly and six-week look-ahead plan.

This is not obvious if the company undergoes financial problems in other projects. For this reason, it shall be of more satisfaction to link LPS® to the multi-project management in the construction field.

It is noteworthy to say that we are still intending to implement LPS in future sections of the same program with the same contractor, so as to evaluate to which extent this company will develop mainly in terms of adopting this system.

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OVERCOMING "BUT WE'RE DIFFERENT": AN IPD IMPLEMENTATION IN THE MIDDLE EAST

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ABSTRACT

What are the key success factors and barriers that can be expected when implementing Integrated Project Delivery (IPD) for the first time in a traditional construction culture? We present an in-depth case study of the "Saxum" project under construction in Abu Ghosh, Israel, the first implementation of IPD in this traditional construction culture. The goal is to glean insight into the dynamics that support and/or subvert the required paradigm shift. The researchers interviewed the key participants, visited the site and reviewed source material from this and other IPD projects.

Despite cultural and historical factors that were expected to prevent or weaken implementation of a collaborative approach like IPD, the key participants built the project according to the IPD framework. The insistence of the overseas project owner's representative that IPD be employed, coupled with the openness of the local partners to work differently, were found to be critical success factors. The participants' mindset and their behavior changed fundamentally with respect to their traditional roles, as did the character of the project (which was measured on a multi-factor sliding scale from "traditional" to "pure IPD").

Prior to this successful implementation, the opinion of local practitioners on IPD could be summed up as: "Nice in theory, but not applicable in our adversarial construction business culture." Yet this project has shown that given the right combination of agents, it is not only feasible but also rewarding to adopt.

While there are multiple accounts of IPD implementations, we focus here on viewing the case study through the lens of change management with an analysis of the local cultural barriers that were overcome.

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INTRODUCTION

> "This was a difficult project, and without the collaborative approach, I have no doubt that we would have ended up in court over some of the problems that came up. But because we had the IPD framework, we managed to work things out internally, since everyone was committed to finishing the project, not just to their own personal financial interests." - *Project Manager, Saxum Center*

In 1994, a worldwide Christian institution decided to realize the vision of its founder and build a center in Israel (Saxum Foundation 2014). After years of searching, in 2007 a 15,000 m^2 plot was acquired in Abu Ghosh, a town not far from Jerusalem, and the development of the initial design was begun.

A European engineer with years of experience in the construction industry was hired as the Owner's Representative (OR) for the project in 2010. The complex will consist of 7,700 m^2, distributed in three main zones: a Conference Center, for spiritual retreats, workshops and conferences, with 50 guest rooms, two chapels, and common areas, dining room and classrooms; a Hospitality Center for training in professional hostelry skills; and a Multimedia Resource Center, where pilgrims will have access to information for their sojourn in the Holy Land, offering also training courses for tour guides and travel operators (Saxum Foundation 2014). The contract budget for the construction of the building was US$17 million (without landscaping, design costs, taxes or equipment).

The OR had previous good experiences using transparent agreements, although none as collaborative as IPD. From these experiences, he realized that collaborative approaches were essential in creating win-win relationships between owners and contractors, as opposed to the traditional situation in which the two parties are contractually opposed from day one. Thus the OR decided that he would introduce Integrated Project Delivery (IPD) (AIA 2012) into the project.

There was only one problem: no one in the country had ever implemented IPD in a construction project before. Although the approach is taught in construction management courses at the Technion and had been presented at an industry conference in 2010, no building had ever been built in Israel using a collaborative contract such as partnering, alliancing or IPD. Yet ultimately the OR prevailed. The project was successfully delivered, while using IPD principles. Since this was the first IPD implementation in a country, we seek to explain the dynamics at work so that future IPD practitioners who wish to break into new markets can learn from the experiences (both positive and negative) of Saxum.

MANAGING CHANGE

Though IPD is technically a method of contractual agreements among the parties in a construction project, at root, it seeks to drive new ways of working for the professionals involved in the project. Thus the process of implementing IPD can draw on knowledge about the field of Organization Behavior, specifically the domain of Change Management.

Change Management researchers seek to understand the mechanisms and phenomena at work when an organization and the individuals within it undergo a shift in their work processes and mindsets. One of the pioneers in the field was Lewin (1952), who proposed the "Unfreeze, Change, Refreeze" model of change. Kotter (1996) built upon this, outlining eight stages that organizations go through when undergoing change: establishing a sense of urgency, creating the guiding coalition, developing a vision and strategy, communicating the change vision, empowering broad-based action, generating short-term wins, consolidating gains and producing more change, and anchoring new approaches in the culture.

An underlying assumption of "Organizational Change Management" approaches (Todnem By 2005) is that there is an existing organization with prevailing "ways things are done around here" that is changed. Yet in construction, each project is an ad-hoc collection of companies joined together for the extent of the particular project. Thus a better-suited model may be the ADKAR model (Hiatt 2006), which focuses on the level of the individual. Which phases does each person go through as they experience change?

Awareness – an initial understanding that the change is on the horizon

Desire – identifying "what's in it for me" and becomes a change supporter

Knowledge – "how" to make the change, typically through formal learning

Ability – the ability to work in the new way, typically gained through hands-on experience with the new methods

Reinforcement – the new patterns of behavior are reinforced by the new work environment

Like many deeper changes, the transition to IPD entails not just changing behavior but changing the more deeply-held beliefs they have about their behavior and the organization: their paradigms (Barker 1993). AEC professionals implementing IPD must learn to see other project participants not as opponents to be overcome – an example of a zero-sum approach (Emiliani 2008) – but rather as colleagues to cooperate with in order to attain mutual success for the project and each of the participants. This is "non-zero-sum" thinking: for each party to succeed, it need not be at the expense of another.

EXPECTED DIFFICULTIES

When the OR approached the Israeli construction market with his desire to use IPD, he was met with skepticism about the applicability of the approach to the local culture and construction sub-culture, since the mainstay of Israeli construction remains the traditional Design-Bid-Build method. According to the Hofstede's Cultural Dimensions Theory (2001), Israeli culture is marked by very low power distance and high uncertainty avoidance. Israel's history as a melting pot of immigrants has left its legacy in the low-context nature of the culture. These elements help to explain the fricative nature of Israeli discourse. Short tempers and shorter fuses are not considered amenable to the collaborative approach that IPD requires. Israeli construction companies are staffed by people who come from various ethnic backgrounds, in which smaller companies (subcontractors) are typically homogenous in their ethnic makeup (Priven and Sacks 2015). Given the complex political history of the country, this means there is even more of a tendency to keep inter-company relations at arm's (and contract's) length. Rached et al. (2014) explored the openness of construction professionals in the region to IPD, and found that many of those surveyed indicated that IPD would likely conflict with the local construction culture.

Another difficulty is that which confronts any implementation of IPD regardless of underlying regional cultures: the natural tendency to slide back into well-known behaviors. Though collaboration has the potential to reward all participating parties, as game theory explains, individual actors may be tempted to “defect” and attempt to exploit the collaboration in pursuit of their own particular agendas. As the success of the “tit for tat” strategy has shown (Axelrod and Hamilton 1981), this is a fool’s errand, but for people and organizations used to maximizing their own short-term payoff, it will no-doubt beckon. Each member of the collaboration has to navigate a network of different considerations and competing priorities: their interests as a member of the project (and commitments to that project, to which they have committed their reputation and good name), their own personal interests regardless of the project, their prior interactions and relationships with the other parties, as well as their expectations of future relationships and contracts with the other parties.

THE TEAM AND THE CONDITIONS

In that context, the OR set about assembling the team that would bring Saxum and IPD to life in Israel. The first partner to come on board was the Architect. Though initially skeptical about IPD, the OR’s drive and commitment to the method brought him around. The OR also brought in a local professional construction Project Manager (PM) after numerous interviews and much additional explanation of the IPD approach. The OR, the Architect, and the PM then sought the right contractor. Though they met with some major contractors, the response was lukewarm. Ultimately they found a General Contractor (GC) who agreed to work under the conditions IPD requires: transparency, target cost, share bonus and penalties, preconstruction services, fixed fee, etc.

Before signing the contract, it was necessary to explain IPD to the lawyers of each partner. A baseline document helped; ConsensusDOCS 300 was selected and adapted to suit the Israeli legal system. Finally, an ‘IPD-like’ agreement was signed with the following stipulations: the direct costs “as built” of the project would be paid back-to-back to invoices and team salaries throughout the construction phase; at project completion, the total Real Cost (RC) of the budget would be measured up against the Target Cost (TC). If RC > TC, then there is “Pain Sharing”: the owner and GC cover the additional expenses in an 80-20 ratio, with the GC’s contribution capped at one third of his fee.

In the opposite scenario where RC < TC, there is “Gain Sharing”. The savings below the TC are distributed as follows:

20% to the GC

10% to the Architect

10% to the PM

60% to the owner

The Target Cost was developed by the OR in collaboration with the owner and other construction professionals and colleagues. The proposed construction budget was created during the pre-construction design phase. The design team created a construction budget to determine if it could be brought within the TC. Through successive iterations of design and cost estimation refinement informed by the GC’s input as to constructability and preferred construction methods, the construction budget achieved the desired level. Once that happened, construction began immediately with the existing team without the need to go through a bidding process.

The project was overseen by the "Collaborative Project Delivery" (CPD) team, composed of the OR, the PM, the Architect, and the GC. The CPD was responsible for all of the major decisions about the project; in the case that the CPD was not in consensus about a particular issue, it was put to a vote. The Architect and GC each had one vote while the OR and PM shared a vote. At the same time, the OR retained a veto over decisions that were deemed unacceptable. The day-to-day management of the project was in the hands of the Project Execution Team (PET), composed of the site engineer (representative of the GC), site inspector (representative of the PM), an architect from the studio of the Project Architect, and the OR.

SELECTED PROJECT EXPERIENCES

While the project was eventually considered a success, along the way there were inevitable ups and downs. This section describes three vignettes that illustrate such situations.

THE AIR CONDITIONING SYSTEM

The project was initially designed with a radiant heating and cooling system based on a proprietary technology to be supplied from abroad. However, the supplier went bankrupt, which meant the system would not be delivered to the project. The team scrambled, eventually deciding on a conventional ducted HVAC system. However, since construction had already begun, all the new ducts had to be routed around existing systems, and openings had to be created in existing poured concrete walls and precast hollow-core flooring planks (including the engineering complications the latter entails).

Had the project been conventionally structured, a change of this magnitude so late in the process could have led to infighting and recriminations. But instead of going head-to-head, the team members worked shoulder-to-shoulder in order to persevere. The members of the CPD accepted responsibility for jointly managing the process, and the influence that comes with it. But with that responsibility came their participation in the risks of the project, like the bankruptcy of a key supplier. This incident was a test of the strength of the commitment of the parties to the project and to the collaborative approach, and they passed with flying colors. Their response to the unexpected development was focused on solving the problem at hand for the project, and not exploiting the mishap as an opportunity to redress grievances with other parties to the agreement.

THE BIM MODEL

The OR proposed that the project be designed using Building Information Modeling (BIM). However, the designers were used to designing in 2D, and it was decided that instead of designing in BIM, an external company would be hired to take the output of the designers (2D engineering drawings) and convert them into the 3D model in BIM, where clash detection could be performed, with the clashes reported back to the designers. However, this added an additional layer of complexity to the management of the design process, with the outcome being that the process was much less efficient than it could have been.

A second BIM model was developed internally by the site engineer to support production organization. This was useful, but stopped when the person left the project. The use of BIM is highly recommended for IPD projects (Sacks et al. 2010), and the inefficiencies encountered in Saxum are testament to the opportunities that were missed.

USE OF PROJECT MANAGER HUMAN RESOURCES BY THE CONTRACTOR

Once construction began, the CPD realized that additional resources needed to be devoted to the management of this phase. Rather than bring in new people, two members of the PM's team, the site inspector and design coordinator, would take on additional roles as the site engineer and production assistant, respectively. They remained employees of the PM, but were paid an additional amount from the construction budget, taking instructions from the GC. "In a regular project, having people from the PM team work for the GC would be an unheard of conflict of interest, but thanks to the collaborative effort, we made it work," commented the PM. The shared commitment to complete the project on time and within the target cost (coupled with the financial transparency) allowed the team to consider a unorthodox solution. In order to resolve the inspector's potential conflict of interest, an outside quality assurance firm was hired.

RESULTS OF THE PROJECT

As of this writing, the project is still a few months away from completion, but the end is within sight and the OR is very satisfied. The quality of the product is very high, which is one of the most important aspects for the customer, and is the major factor driving their satisfaction. As for cost, even with the setbacks, changes in personnel, and unexpected developments, the project will come in at or slightly below the target cost. While this means that there may be little or no "gain sharing," this also means the owner will be paying more or less the price they were expecting. In terms of schedule, the project is about four months behind the initial predictions. Despite the delay, the owner is satisfied, since their priority was to achieve a high level of quality at a reasonable cost.

The owner's lawyer reports that, unlike typical projects in which participants are in frequent contact throughout to clarify the requirements of the contract, in the Saxum project he hasn't really heard from the partners since the contract was signed. There have been no legal claims among the parties despite the many unexpected problems.

The Saxum project did not exploit all of the commonly recognized opportunities of IPD and apparently the project could have been delivered for less money, yet it did manage to maintain the core principles of IPD and achieve a successful outcome. Table 1 portrays the authors' assessment of the project's position within the range from "traditional" to "full IPD" for a number of different factors, based on the factors described by the AIA (2012).

DISCUSSION

What lessons can be abstracted from Saxum that are relevant to other IPD pioneers in new countries or regions? Specifically, what are the important points which lead to the success of the project, and what were the difficulties that were encountered along the way?

Table 1: Saxum on the scale from "Traditional" to "IPD": tabular explanation

Subject	1: Traditional	Saxum	5: IPD Vision
Contract	2-sided, costs and work content	3: Used ConsensDOCS, but Architect has separate contract	Multi-party, relational contract
Design Process	By Architect, prior to bidding	4: GC involved, but no Big Room	Collaborative, with GC integrally involved. Use of "Big Room"
Pain/Gain Sharing	Set prices for set work content	3: GC, Architect, Proj Manager share gain. GC shares pain	After agreeing on TC, all parties share gain and pain
BIM	Used primarily for design	2: Only partially used for construction	Used as tool for collaboration, during design and construction
Cooperation	Sporadic, and only as it befits local optimization	4: CPD cooperates fully. Subcontractors less so.	Ongoing, to jointly pursue project-level optimization
Decision Making	Divided, each party decides in area of speciality	5: CPD responsible for major decisions	Core team jointly decides, together with owner
Subcontractor Selection	By GC, mostly by lowest cost	5: Chose subcontractors based on prior experience, by CPD	By CPD, by reliability and quality of subcontractor
GC Selection	DBB: Lowest-cost GC bid, after design complete	4: Chosen ahead of time based on quality	First choose team members (including GC), then design together

Interviews with the key site personnel showed the relevance of the ADKAR model of change discussed above. The IPD contract provided the basis for gaining the Awareness and Knowledge, and the Gain/Pain Sharing mechanisms helped align their interests and contribute to their Desire to work collaboratively. Each occasion in which the team cooperatively resolved an issue that would under other contractual terms lead to confrontation, such as the need to replace the HVAC system, provided positive reinforcement.

KEY SUCCESS FACTORS OF THE IPD IMPLEMENTATION

The **personalities of the individuals** involved in the project has been identified as the key success factor, both by project participants and in the analysis of the authors. Each participant had to have enough openness to be willing to try working in a new way, one that differed from their years of experience. They are what Rogers called "early adopters" (Rogers 2003).

Each of the individuals on the CPD had key personality traits that enabled success. The OR was the driving factor who brought IPD to a new country. Interestingly, and perhaps crucially, despite his commitment to IPD, he had no prior experience in the local construction industry. It may be that as a foreigner and cultural "outsider" he was granted more leniency to stray from cultural and business norms, at least enough to make his case. Despite being told that local conditions were different from those he was familiar with, he decided that they were not different enough such that IPD would be unviable. And of course, as the representative of the owner (who is paying for the project), he retained the privilege to place demands on the suppliers, including the use of IPD. By submitting himself to the collaborative approach, the OR released some of his control over the project; decisions about the project would be made jointly by the CPD. Though he retained a veto over the CPD's decisions, but he was disinclined to use it so as not to negatively impact the collaborative spirit. In practice, the veto was never used, even though there were some decisions in which he was in the minority.

Owner of overseas projects tend to be risk-averse, preferring a "fixed price" contract arrangement. Here the opposite was true: the pain/gain sharing mechanisms meant that the owner had no idea ahead of time what the final price would be; there was no "guaranteed maximum". This may actually be a more realistic worldview on the OR's part. The "security" and "control" supposedly offered by fixed-price traditional contracting models are to a large extent self-delusion; the owner will ultimately bear the brunt of inefficiencies and cost overruns. In IPD there are incentives for the bad news to come out much earlier, even during the design phase, rather than having problems simmering "behind the scenes" until they become too big to hide (more typical of an environment in which information hoarding is incentivized; fixed price contracts are a prime example). One underlying assumption for owners adopting IPD is an understanding that the bid price of a traditional contract is not really going to be the actual price.

The personalities of the other team members were also crucial to the outcome of the project. The PM was hand-picked by an authority familiar with both IPD and the players in the domestic market as someone with an academic background who was open to new methods. Rather than being a turn-off, the OR's description of IPD was one of the main reasons the PM joined; this was an opportunity to gain experience with an innovative method. The Architect demonstrated enough openness to go forward with IPD (even though he was not contractually bound to do so, since his engagement to work on the project had begun even before the OR arrived). The GC was willing (unlike most of the contractors that were approached) to use IPD, including all the changes it would entail in the way he was used to working: transparent accounting, shared decision-making responsibility with the other members of the CPD, and participation in the pain sharing mechanism.

Another key success factor was the **pre-existing relationships** among some of the parties prior to beginning work on the IPD project. The Architect had previously worked with both the GC and the owner. The GC requested (and was granted) permission to employ subcontractors he had worked with in the past, rather than going with the lowest bid for each trade, in order to reduce the number of "surprises". When participants have worked together in the past (and had positive experiences doing so), they will be more willing to commit to a collaborative venture. This is due to the **trust** they have for one another, which is the underlying element of this success factor. Without trust, even the most detailed IPD contract in the world cannot force the team members to cooperate and work as partners. Personal acquaintance and "good chemistry" between the stakeholders are a must.

BARRIERS TO IPD IMPLEMENTATION

Despite the eventual success of the project, there were items that could have been improved upon along the way. In Lean terms, by engaging in *hansei* (reflection) upon the negative aspects of the implementation, it is possible to improve upon them in future journeys down this path.

It is interesting to refer back to the "barriers" that the OR was told to expect when he decided to bring IPD to Israel. Ultimately the culture proved to be a non-issue; the lively and brash style that marks Israeli interpersonal communication may actually be a boon to a collaborative approach, since it is through discussion that a team can create the best solutions to the problems they face. The team members were able to adapt to new collaborative modes of working. For example, the site inspector related how, despite his initial gut reaction was to default to a confrontational, offensive position, in time he learned to consider the site engineer a partner.

At the same time, the temptation to slip back into established patterns of behavior was ever-present, and there were examples of "local optimization" at the expense of the project. One case in which this happened was early in the project during the earthworks to prepare the site. The subcontractor who excavated the foundations of the building submitted an invoice that didn't align with the expectations of the team. The GC wanted to pay the bill as written, whereas the PM (who releases the money) objected. This almost led to a conflict that could have threatened the continuation of the IPD. Luckily the sides calmed down enough to work together to address the situation as partners (they disputed the invoice). Even though an IPD agreement has been signed, constant effort must be made in continually developing relationships and learning new ways of working.

The project struggled with the best way to involve subcontractors in the collaborative efforts, like many other implementations of IPD. Despite the OR, Architect, GC, and PM participating in the CPD and a collaborative approach, from the point of view of the subcontractors (who actually performed the vast majority of the work in constructing the building), there was no major difference in Saxum; their contracts and compensation were not far from the norms they were used to. Had there been a more effective way to get them on board as part of the collaborative effort (or some critical subset of the prime trades), the project outcome could have been even more successful.

CONCLUSION

A Jewish architect and GC, a Christian OR, a Muslim site engineer and a mixed Jewish-Muslim workforce met in an Israeli-Arab town in the Jerusalem foothills to build a project using a new method of contractual relationships – though this sounds like the beginning of a bad joke, the Saxum project moves closer to successful (quality, schedule, budget) completion with each passing day, and with it, the first building to have been built using IPD in the country (and perhaps the region). If IPD can work here, as the project has proven, then it can likely work anywhere (to a greater or lesser degree). This includes other projects domestically, other projects in the region, and even other parts of the world where the culture is thought to be less than conducive to collaborative approaches. Yes, the project owner was a non-profit organization whose primary interest in the project was not making money. But like any owner, they still had the same project goals of cost, quality, and reasonable lead time. The IPD approach is not based on expectation of ethical behavior arising from altruistic motivation, but on the right alignment of the common interest of all of the stakeholders to get the right money for their work.

The main challenges for a would-be IPD pioneer are thus:

Finding the right principal people for the project, i.e. professional and open-minded;

Inculcating the values of IPD;

Educating a team to exploit the opportunity provided by the collaboration to remove waste and gain values, primarily through the use of Lean Construction and BIM.

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INTRODUCING LEAN CONSTRUCTION PHILOSOPHY IN E-P-C PHASES OF A LARGE INDUSTRIAL PROJECT

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ABSTRACT

A manufacturing organisation in India contemplated augmenting their capacity and took up a green-field expansion project in a new location. The internal construction division of the organisation decided to introduce Lean construction philosophy. A study was taken up to understand the impact of Lean on the engineering, procurement and construction phases where multiple stakeholders who are entrenched in traditional approaches are involved.

A detailed case study and action- based approach was adopted. The data included both primary observation data collected by the researchers present in meetings and other data from various reports. . There were some interesting insights into the dynamics involved when groups with diverse approaches are brought together on a Lean construction journey. There was also a challenge of implementing Lean with multiple project teams all working in the same organisation and therefore with little or tacit contracts involved in the project. The initial attitudes of the people which ranged from enthusiasm to outright scepticism and engagement with reservations evolved progressively over time to embracing Lean in varying degrees and formats.

The complexities present in the organisational structure contributed to the formation of institutional voids which were leveraged by the Lean group to promote Lean practices.

KEYWORDS

Big Room, Transformation, Change Management, Culture, Institutional voids

INTRODUCTION

Lean Construction management has become popular in countries around the world. In India, though the concepts of Lean are practised widely in the manufacturing sector, the philosophy is only gradually gaining popularity in the construction sector. Several initiatives, including seminars by international faculty, under the auspices of Institute for Lean Construction Excellence (ILCE) have generated interest among the construction agencies to adopt and practice Lean (Ballard 2015; Raghavan 2015; Raghavan et al. 2014).

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Having experienced some of the benefits of Lean in an earlier Lean construction training-cum-implementation programme, the top management of the construction division of a reputed manufacturing organisation desired to implement Lean in all their sites progressively.

The present project is a Greenfield industrial expansion project of this organisation which presented an excellent opportunity to introduce Lean from the beginning. Though some members of the construction team of the Group had some exposure to Lean, the other teams had no Lean background. The various team members had come from different backgrounds, were staunch practitioners of traditional project management paradigms and had considerable reservations against Lean practices. The time-honoured organisational structures and practices of the parent organisation and the complex web of independent roles and aspirations of the various divisions of the parent organisation involved, created dual reporting structures and autonomous pockets, posing problems for integrated working. However, the pressure from the top as well as certain developing group dynamics induced them to adopt the Lean way over time. This paper presents a case study approach on how people who are well entrenched in conventional project management learn to open out into an inclusive Lean culture and provides interesting insights into the Lean cultural transformation and the group dynamics involved.

Another interesting aspect of this study is that the complexities present in the organisational structure contributed to the formation of institutional voids which were leveraged by the Lean group to promote Lean practices.

OBJECTIVES OF THE STUDY

The Study aims to explore the evolving group dynamics between the various teams as they progressively migrate from a conventional project management paradigm into a Lean management paradigm. In the particular project under study the various circumstances are rather unique and present a good opportunity for exploring the possibility of leveraging any institutional voids to promote the implementation of Lean concepts.

THEORETICAL LENS

Implementing Lean Construction practices is essentially an exercise in organisational and cultural change where established practices of planning and monitoring are replaced by newer practices that emphasize minimisation of waste. Institutional theory offers a theoretical lens through which these dynamics may be used.

Simply put, institutions are the ‘Rules of the Game’ (North 1991) that define the interaction between players. Scott (2008) unpacks these ‘rules’ and suggests that they consist of three varieties – regulative institutions enforced by legal rules, normative institutions enforced by social pressures and cognitive institutions that are deep seated guidelines enforced often on a personal basis. While early institutionalists considered institutions to be somewhat immutable, scholars have subsequently drawn upon theoretical formulations such as Structuration that describe the interplay and consequent change between structure and practice to show that institutional change is indeed possible (Giddens 1979).

Subsequent literature addresses responses to institutional conflicts (Oliver 1991) and pathways to institutional change. Attempts have been made to integrate social movements perspectives into mainstream institutional theory to describe the dynamics of how new institutional forms take root by overpowering the old (McAdam and Scott 2005). More recently, institutional change has been formulated as a process by which institutional entrepreneurs work institutional voids to achieve change (Mair et al. 2012). Institutional entrepreneurs are skilled actors who can leverage resources to transform exiting institutions to suit certain objectives. Institutional voids arise when existing institutional arrangements are in flux due to endogenous or exogenous change forces. These voids represent the inability of the present institutional arrangements to deal with particular new and unique situations. Such voids afford opportunities for institutional entrepreneurs with skills to create new ‘rules’ that can be followed. We argue that in the case that we are about to describe, a series of top-level announcements and changes in project organisational structure led to the creation of institutional voids, and a group of change-agents were able to leverage this by slowly reinforcing the use of a set of Lean practices that then became ‘taken for granted’ practices on the project. By describing our narrative and enfolding the working of institutional voids as an explanatory theoretical lens, we attempt to both extend the theory and answer a primary research question – ‘What are some mechanisms that institutional entrepreneurs can use to implement new practices in the context of Lean Construction’?

CASE STUDY – INDUSTRIAL PROJECT

The study project involves the development of a Greenfield expansion of the manufacturing activities of the parent company. The parent company has a strong and unique traditional culture developed over a century, governing its working procedures and written and unwritten rules. This governs the way procurement is done, contracts are awarded, the working together of different divisions without encroaching upon each other's domains, etc. Being a Greenfield project the scope of work covers the entire gamut from synthesizing user/ client requirements through obtaining various approvals and land acquisition as well as Engineering, Procurement and Construction to commissioning of the project. Except the architectural and detailed engineering to be done by an external party, all activities including the main project management are managed by internal teams from the various divisions of the parent company.

The expansion is for the products of two divisions of the company, which are virtual clients for the project and the construction division is executing the overall project construction. The engineering and coordination for procurement and construction for the electro-mechanical (M&E) works are taken care of by another Division, which has traditional competency in this area, in cooperation with the Construction division. The site management acts as an overall coordinator for the multiple agencies involved, with loosely defined responsibilities and unwritten contracts. The overall corporate advancement is the common goal for all the divisions and the driving force cementing the various roles. Responding to the requirements of the Construction division for total Lean construction implementation, the research team, which was appointed as consultants for this purpose, devised a three-phase programme. This envisaged a transition from a heavy-training initial phase to a mentoring-for-execution third phase, with progressively lesser presence of the team. We first describe the organisational structure that was adopted and how this created a series of institutional voids. In order to avoid diluting the purity of the subject group's interaction dynamics and encouraging the development of self-motivation and spontaneous learning, the research team has taken up a stance of minimal interventions and guidance.

ORGANIZATIONAL STRUCTURE AND LEAN IMPLEMENTATION

The project witnessed an interesting interaction between the nature of the organisation structure and effectiveness of Lean implementation. This dynamic was exposed as the project progressed through its Lean journey.

The reporting structure

The various components of the project were implemented by different divisions of the same organisation. The construction division was responsible for the overall planning and implementation. Some specific components like M&E were implemented by a separate division of the organisation and a central procurement team/ division of the overall organisation was in charge of the bigger procurement items. Though the departments are directly engaged on the construction of this project, division they report to the top management of the organisation and not to the Construction division, on account of legacy organisation protocols. A Project Manager of the construction division was responsible for the entire project, but the peculiar reporting structure meant that the other teams working on the project did not directly report to him. Also, the planning, procurement and all other divisions were independent and had their respective heads. Such historically evolved reporting structure, which could not be changed just for a single project, created challenges for the project as often the team members had two or more supervisors. This also meant that the Project Manager was responsible for the project without adequate authority for the same.

The issue of the complex contract structures

The project also presented some peculiar contractual structures. The clients were internal to the organisation and the construction division became the general contractor for the project. The M&E works were then contracted to the electrical works division of the organisation (owing to their expertise in M&E equipment). This division thus became a contractor for the M&E works, but they would also be part of the client's team for maintenance of the same. Thus electrical division became a contractor and the ultimate client to itself. Similarly, while the procurement was handled by a separate division, some of the items were procured by the electrical division and some by the corporate procurement division owing to organisational policies. Such kind of complex structures precluded clarity on who would take decision on what matters till Lean was implemented on the project. When Lean was introduced, the periodic meetings and review of progress and causes for delay created situations where some decision should be taken on various items to move on with the project. Such situations enabled the project team to closely look at such contractual structures and make the right persons/divisions responsible for the decisions, with collective responsibility resorted to in some cases.

Tacit Contracts

A related issue was that there were no formal contracts between divisions. e.g., there was just tacit understanding that the construction division was responsible for construction and that the M&E work would be done by the electrical division. No formal contract was written between various divisions and the construction division. The relational contracting schemes here did not have any incentive criteria outlined. But as Lean was introduced and the teams started pulling work from the upstream, the divisions were forced to re-look at their work behaviour. This led to some turbulence in the team where some team members felt the pressure of such complexities for the first time. The peer pressure and imperatives created by the missed promises and low PPC counts acted as incentives for the other divisions to drive up their performance. Thus, it was possible to point out the need for better performance based on real data from not only other divisions but also from the vendors where formal contracts were present. The construction division started contemplating the inclusion of a "Lean Clause" in their future contracts where all the vendors would have to agree to work on Lean philosophy. As this section shows, the coordination and contractual practices adopted for this project were somewhat unique and non-standard. Coupled with top management commitment towards implementing Lean, there was a pressing need to customize project planning and monitoring practices for this project, thus giving rise to an institutional void in this space. The next section describes the dynamics surrounding the introduction of Lean philosophy on to this institutional void. This is done by discussing how Lean was introduced to the team members, the dynamics of team behaviour and the team morale across the phases of the project.

DYNAMICS OF LEAN PHILOSOPHY INTRODUCTION

THE INITIAL PHASE

Initial Deliberations

The senior management of the construction division of the organisation had extensive deliberations with the research team on ways to improve project performance by the introduction of Lean construction philosophy into the project. Fortunately, the core management team of the present project were also involved in the implementation of a previous project for Lean implementation along with the research team and hence had some expertise in Lean implementation.

Formation of "Lean Core Team"

After the initial deliberations, it was decided to have a "Lean Core Team" consisting of the head of construction, the project head, head of planning, the Project Manager and a Lean initiative champion. The core team was chaired by the head of the construction division

Initial Introduction of Lean philosophy to the project team

The Lean implementation for the project was initiated through a meeting with the various stakeholders covering procurement, engineering and construction functional people, the M&E division and the consultants for design. In this meeting the head of the construction division made it clear to the project team that Lean philosophy should be adopted in spirit and letter on the project. He asserted the absolute faith of the organisation in the Lean initiative and the importance of the current project to the organisation. The project would then form a template for Lean construction practices across different future projects by the organisation.

Introduction to Lean Construction

The research team then had a training session with all the team members, introducing Lean construction philosophy and the methodologies for implementation. The fundamental intuitions behind the implementation were discussed and some examples of Lean implementation and results from projects in India were shared with the team. Persons who were associated with the earlier flag-ship project implementing Lean talked about their Lean experience and benefits of the change.

CHANGE IN BEHAVIOUR

During the initial meetings the team was divided on the usefulness of this implementation. While some members saw merit in the implementation, others felt that this could become an additional overhead to their work. Some members expressed concerns on the rationale behind experimenting on a large and strategically important project as this. However, the team was given a clear mandate on Lean for this project. Further, the team wanted the project to move on and see some activity after the initial slump. Hence, the team agreed to embrace the change.

"Big Room" meetings

As an initial phase, "Big Room" meetings were agreed to be conducted each week. The engineering team, procurement team and the construction team were part of these meetings. The project concepts were still evolving at this phase and the master schedule was at a very macro level and lacked details on the project scope and the work methodology for various tasks involved, across the engineering, procurement and construction phases. During these meetings it was decided to evolve the look-ahead schedule for four to six weeks from the macro level "Master Schedule" and the task list for the next week in a collaborative way. The team would list out constraints from the look-ahead schedule and agree on the tasks promised for the week ahead. It was decided to calculate PPC every week and have root cause analysis performed on the promises not kept during the week.

From *"I will come back on this point*" to *"We will discuss this right here"*

Though the initial meetings had representatives from all the divisions of the project, the persons attending the meetings were not the ones who were actually executing the projects but the ones who were managing those persons. As the initial meetings kicked off and the look-ahead schedule was being evolved, the phrase which was quite often heard by the researchers in the initial meetings was, *"I will have to talk to my team and come back to you on this"*. Initially, the team was agreeing to wait, but the various players found it increasingly difficult to go ahead with the planning in the absence of timely commitments and information. Thereafter the phrase "*We have to discuss this item here itself and close this"* became quite common. The team representatives then brought along the members who could actually answer other team members' queries. In other cases, where the team members were not located in the meeting place, the representatives called them on phone to discuss the particular issues and understand the dependencies with other team members. One quote which signifies this change was by the team manager to one of the representatives. "*If she is not here, call her right now and ask how this will affect her work. Ask all your team members to have their phones with them switched on during this meeting time. We want such answers in the meeting itself*".

From *"This item will be done next week"* to *"I cannot do this item by this time"*

In the initial meetings, when some work was not done as promised, the bland reply used to be: *"Do not worry; this will be done next week."* People were not in the habit of coming out with the real root causes and were over-confident of their capabilities for achievement. But as the meetings progressed, the members started realizing that they were losing their credibility if they reneged on their promises. There was an invisible peer pressure to be transparent and honest and soon, the team members were proactively telling the team management – *"Look! I cannot perform those tasks in the next week or week after, these constraints we identified earlier were not removed."* and *"We should look deeper into this issue. I cannot figure out how to handle this constraint".* The root cause analysis was naturally taken up after some weeks of implementation by the team.

From *"What were my PPC items"* to *"Can you send these PPC items as quickly as possible to me"*

In the initial few meetings, people waited for the week's list of work items to be sent to them by email after the meeting and would inform details of action taken only in the next meeting. As the project progressed, the management started displaying PPC count for the whole project as well as for the individual teams (like engineering, design, procurement, vendors) separately. Then people started taking notes of their work items and proactively working on them. This led the management to use a workflow management software which would automatically send emails to the team members immediately after the meeting and also display the PPC count for the previous week. Further, the team members started sending details of their promises kept and promises not kept in advance to the team management with reasons why some tasks were not performed.

EMBRACING THE "PULL" PHILOSOPHY

The team was initially working only on those items listed from the master schedule which was still at a macro level. The initial look ahead plans and tasks for week ahead were also very macro in nature and had a lot of uncertainties and dependencies tied to them. The team members were over-optimistic in their estimates of productivity and often presented the best-case scenario to the other team members. But soon the "down-stream" team members started realizing that their work was getting affected severely due to this behaviour. A natural moderation occurred during the meetings where the down-stream members started correcting the team members about such promises. The unintended result of such interactions was that the entire processes of procurement and design in the organisation were examined in detail and also led to the evolution of time-bound *"Standard Operating Procedure*" for procurement and design for the organisation. Interestingly, the team started putting pressure on the planning team to come up with a good base-line and "realistic" master schedule on pull basis. The planning team then started co-ordinating with the Civil and M&E construction teams to prepare a schedule for construction and worked backwards through procurement to engineering. The procurement team and design team including the vendors and consultants were asked to draw up their plans realistically to be included in the master schedule. Thus, the master plan was prepared in a truly "collaborative-pull" based manner for the project.

TEAM MORALE

From *"This project was always like this"* to *"We are progressing well"*

The project had some initial doldrums on account of some preliminary issues and the team was used to slippages of deadlines and blockages in the earlier days. When the management conveyed their initial decision that the project was to be completed in a challenging time frame, many of the team members did not believe that could be achieved. During the initial weeks of Lean implementation, when the PPC numbers were low people thought that the project may get delayed and some actually put this project on a low-priority. However, with steady practice of Lean, the team slowly started realizing the significance of the new philosophy and the project climbed high on their priority lists. The team members started taking the responsibility collectively and when they saw some good initial progress in design and procurement which were out cold for a long time, enthusiasm started picking up. With the unfolding of pull-based planning, the team felt naturally responsible for the schedule and started working towards making it work. The team gradually started believing that they were progressing on the project.

From "*You*" to "*We*"

A significant observation to be noted here was that during the initial meetings there were prolonged discussions on responsibilities for tasks and responsibilities for delays. The reluctance for transparency was more for external consultants who feared contractual problems in case they came out with the real reasons. The word *"You*" was heard a number of times during the initial meetings. However, as time progressed, this behaviour changed and all the team members felt part of the team and openly discussed their constraints. The team felt collectively responsible for each task and started helping out each other. This significantly improved the morale of the team.

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DISCUSSION

This study shows that where the top management is very focused and keen to implement Lean and where the project context is unique leading to the existence of institutional voids, it is indeed possible through regulative fiat (enforcing Lean implementation) and normative pressures (increasing transparency, broadcasting PPC metrics and instilling a sense of shame into non-performing participants) to implement the Lean philosophy over the course of a project. Progressively the team members start wanting to perform on their own, without the catalysis of peer pressure. This is also in line with the earlier experiments in the Indian context where the research team had been involved. The initial stages of the project covering the conceptualising, engineering and procurement phases are usually the most difficult stages for Lean introduction. In this study this was also compounded by the problems of the diverse nature of the teams involved and their inexperience and inertial hesitations to embrace a new paradigm after having followed traditional and comfortable mechanisms for many decades earlier. Now that the project has entered the construction phase the implementation is becoming stronger and it has also been decided to bring in all the sub-contractors and vendors into the Lean fold. Even though the latter are traditionally much less inclined and capable than the main construction team to embrace a new field concept, the construction team is still quite confident that the experiment would be successful by deploying suitable training and motivation measures. The research team is closely watching the situation and providing guidance appropriately.

Organisational Issues and Involvement of Top Management

Since the project was highly strategic for the organisation and the top management of the organisation – to which the head of construction reported – was also keenly interested in the decisions relating to and the progress of the project. A few decisions regarding the design and scope of the project actually went high up to this level but because of other natural preoccupations of the top management decisions had to wait. However, by and by a mechanism was evolved in such a way that when a decision was put to the top management, the significance of the decision in terms its impact on the schedule of the project (and cost whenever it could be evaluated) would also be conveyed. This enabled the top management to prioritise and allocate time for key decisions. Earlier the team was not in a position to convey the impact, but after the set-in of pull- based planning based on Lean, they realized the significance of such decisions and were in a better position to convey the impact of various decisions. In the end analysis, we conclude that paradigm shifting innovations such as Lean may best be implemented on projects with unique technical, organisational and contractual characteristics since such projects are more likely to feature the presence of institutional voids, in comparison to more standardized projects. This can be a key insight to practitioners. In addition, the presence of a core team that can act as Lean entrepreneurs and can use specific mechanisms to bring about institutional change is critical. In this case, the core team used a combination of fiat as well as 'naming and shaming' techniques, coupled with more cognitive learning and evangelization sessions conducted by the research team at critical points to instil a new set of rules, norms and values surrounding Lean that then led to its adoption on the project.

CONCLUSIONS

For any new technology initial acceptance progressing to enthusiastic comprehensive adoption takes some time and all the more so in environments not permeated with organised systems. Though Lean construction concepts have been around for more than two decades now all over the world, their use is still not that widespread. Given the background of the Indian construction industry the permeation can only be progressive and slow. A few shining beacons such as the project cited as well as the enthusiasm of enlightened agencies such as the one covered in this paper are vital in the earlier stages for establishing the credibility of Lean construction as well as serving as path-breakers to be emulated by the rest of the construction industry. However, the initial learning process and acceptance of Lean were fraught with many hurdles. Inducing the concerned teams to enthusiastically take part in Big Room meetings, leveraging peer pressure, bringing around the team members to accept joint and several responsibility even in the lack of clear definitions of authority, carful management of the institutional voids, etc were some of the steps taken to further the development of the Lean culture. The Research team is closely working with the project team to study the evolving dynamics in a multi-stakeholder environment and the enthusiasm with which the various teams embrace Lean. As a next step, field implementation in construction sites almost always has many surprises deviating from the theory and availability of such projects for study present a golden chance to understand the appropriate introduction and implementation mechanisms which are to be followed for future applications

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LEAN MANAGEMENT PRINCIPLES AND STIGMERGY

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ABSTRACT

Stigmergy is a mechanism comprising a sensing agent that responds to the settings of the environment by performing an action. 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 the paper is to explore synergies between two seemingly distinct concepts. This is performed by investigating both Stigmergy and Lean separately, transforming each notion into its dynamic functional system, and comparing the functions of each against one another. Findings reveal that the natural mechanisms of Stigmergy can facilitate the operations of a Lean environment. Organizations can enhance performance by realizing and implementing some of the overlapping features between Stigmergy and Lean.

KEYWORDS

Lean management principles, Stigmergy, agents, environment, dynamics, actuators, sensors.

INTRODUCTION

Stigmergy and Lean Management Principles are two independent systems. The first describes a biological mechanism; 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. To what extent do Lean principles rely on natural mechanisms of Stigmergy? How can Stigmergy enhance the

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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.

The term Stigmergy roots from Greek words "stigma" and "ergon" meaning sign and action, respectively. Grassé, a French entomologist, defines Stigmergy as "a broad class of multi-agent coordination mechanisms that rely on information exchange through a shared environment." Theraulaz and Bonabeau (1999) state that Stigmergy offers a framework to understand coordination. This phenomenon explains self-organization at the level of societies. It mediates and regulates collective activities. This phenomenon explains how insect colonies look wonderfully organized and coordinated as a whole when every insect is naturally pursuing its own agenda without realizing the bigger picture.

Ant algorithms were derived from the Stigmergy phenomenon between insects. The algorithm is based on how ants choose between different pathways to get to the food source, for colony reparation or expansion purposes. For instance, Forcael et al. (2014) utilized ant colony algorithms to optimize evacuation models during Tsunamis to decrease chaos and evacuation time. From a broader view, this system can be also applied to solve complex problems within the field of civil and construction engineering for optimizing processes.

Although Stigmergy relates to insects, its importance exceeds these simple organisms to affect human beings. The significance for humans resides by how simple organisms are capable of constructing complex habitats only through their dynamic interactions. For instance, Parunak (2006) developed surveys of a wide range for human Stigmergy. Some examples of human Stigmergy mechanisms are the movement coordination that dictates humans to choose among existing trails, the market systems where prices govern the behavior of sellers and buyers, and joint authorship when each author is stimulated by what has been previously written or commented.

Other researchers aimed at studying Stigmergy phenomenon to employ it for construction (Petersen et al., 2011). Moreover, Stigmergy was applied using CAD 3D through a case study by Christensen (2014). The author shows that the work is subdivided into areas where actors (electrician, plumber, mechanical engineer, construction engineer) build upon each other to create the whole project (Christensen, 2014). Also, Ben-Alon et al. (2014) compared insects' building behavior to man's behaviors. Human projects are usually planned contrary to insects which have emergent construction. The study shows that social insects communicate indirectly through Stigmergy by responsiveness to natural simulation and sensation. However, people communicate through direct verbal contact, documents and models, and nonverbally through feedback. Moreover, simple insects' construction is self-governing and involves multitasking, while human projects have centralized control and defined professional roles.

Social insects' behavior is similar to core concepts of Lean construction Management. Koskela (2000) believed that waste in construction arises from focusing on the activity while ignoring flow and value. Understanding the dynamics of production, "the effects of dependence and variation along supply and assembly chains" is the most important goal of Lean management. Howell (1999) explains that Lean allows communication directly without having to rely on the central authority for the information flow, provides collaboration by involving downstream players in upstream decisions and reduces variability in work flow. Moreover, from a Lean perspective, burdens are shifted along supply chains and the ultimate aim would be to optimize the whole instead of just optimizing the parts.

The literature shows a few interesting scenarios of combining Lean and Stigmergy concepts. However, the relation of the two concepts was not spelled out clearly in any of the previous works. How are the two independent systems related? Can institutes utilize Stigmergy to facilitate Lean's implementation? This paper provides a thorough analysis of Stigmergy and Lean relation. Afterward, we present a thorough explanation of the two concepts separately. Then, we analyze the two concepts against each other to identify the areas where the Stigmergy mechanisms work in favor of Lean Principles and where one could hinder the other. Finally, we interpret the practical implications of the results of the analysis and conclude with some recommendations.

METHODOLOGY

The objectives of this paper are to 1) derive correlations between the two seemingly independent concepts: Lean and Stigmergy 2) utilize Stigmergy phenomena to achieve Lean work-environment. In order to achieve the objectives of this research, the following method was devised and followed: 1) define and understand Stigmergy 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.

STIGMERGY

As previously defined, Stigmergy is a stimulus-response feedback phenomena. Before explaining its mechanism, it is necessary to differentiate its components as: agent and environment (Parunak, 2006) . These two components are further divided into elements as shown in Figure 1.

First, an agent is the living organism experiencing Stigmergy. Agents have three elements at the core of Stigmergy mechanism: sensors, actuators and dynamics.

The sensor gives access to information available to the agent. It is similar to a router or to a capturer of the stimulus.

The actuator enables the individual to respond and to implement changes in the surrounding.

The third important component of the agent is its dynamics. Dynamics are the programs that translate the information received by the sensor into actions to be applied by the actuator.

If we consider that the agent is a human-being, they rely on listening, visualizing, smelling, or even inception of feelings or emotions to perceive stimuli. Actuators for human-beings can vary depending on the case from a response mechanism of the joints and muscles, to the ability of articulation, and even verbal and nonverbal communication. Man's dynamics can be understood by the control that happens at the level of the brain: interpretation of information and sending orders to execute actions.

Second, the environment is the shared medium in which the agent will be found localized or mobile and through which the interaction occurs. Environment can be understood through its two elements: state and dynamics.

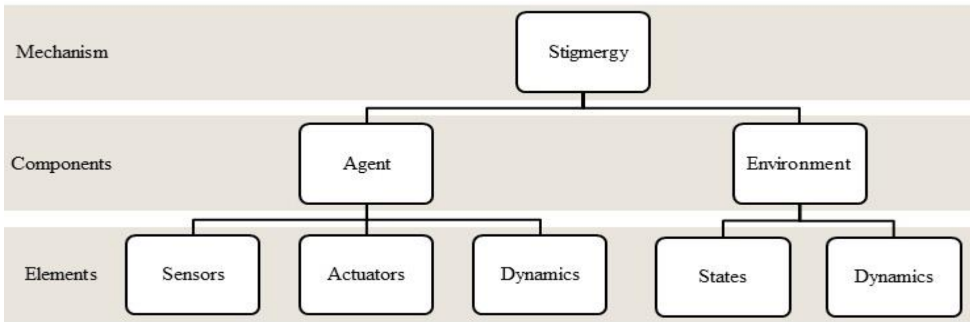

Figure 1 Division of Stigmergy mechanism into components and elements

The state has a deposit of stimuli that are eventually captured by the agent's sensors. The stimulus can be another agent's action, an inciting activity or structure, or even a provoking product like a chemical catalyst; for example, pheromones in the case of an ant-agent Stigmergy.

The environment's dynamics are the programs that govern its change over time (Parunak, 2006).

In case of humans, the state of the environment could be defined according to the situation; however, it shall be noted that the condition of the environment influences the inception of stimuli. For instance, in an enabling environment one will be able to sense and react upon stimuli better than in a suppressing one (Liker, 2005). As for the dynamics of a human Stigmergy, the evolution over time will be an enhancement, optimization, decay or maintenance of the conditions of a certain environment.

Figure 2 shows the mechanism of Stigmergy as the elements interact with one another. The environment is the medium through which the process happens. Agents and stimuli are found dispersed within this medium. The stimuli partly define the state of the environment and trigger the sensors of the agents. Once the sensors are triggered, sensory messages are initiated to feed the program. At the level of the program, the sensory messages will be analyzed and translated into instructions. Later, these instructions direct the actuators to act and execute changes in the state. The actions can be reflected in a corresponding change of the stimuli which might activate a loop of the described mechanism. On the long run, as the state follows a trend of changes, the environment will undergo a dynamic evolution that will affect its state including the stimuli and consequently the agents' reaction to them.

Parunak (2006) distinguishes Stigmergy phenomenon according to the stimulus type and the stimuli-response sequence. The differentiation according to stimulus type comprises two categories: a marker- based or sematectonic Stigmergy. The agent in a marker-based Stigmergy relies on special markers deposited in the environment (chemical or physical); whereas, the agent in sematectonic Stigmergy relies on current state of the environment. The other distinction which is based on the stimulus-response sequence divides Stigmergy into two types qualitative and quantitative.

Quantitative Stigmergy means that the stimulus is of the same type with a variance in the probability of the response of individuals to this stimulus. For example, humans are triggered by the car density to choose an optimal trail. The density of the cars interferes with the probability of the response to it; the higher the number of cars on a given route, the higher is the probability that the driver will be responsive by not choosing the trail with high traffic.

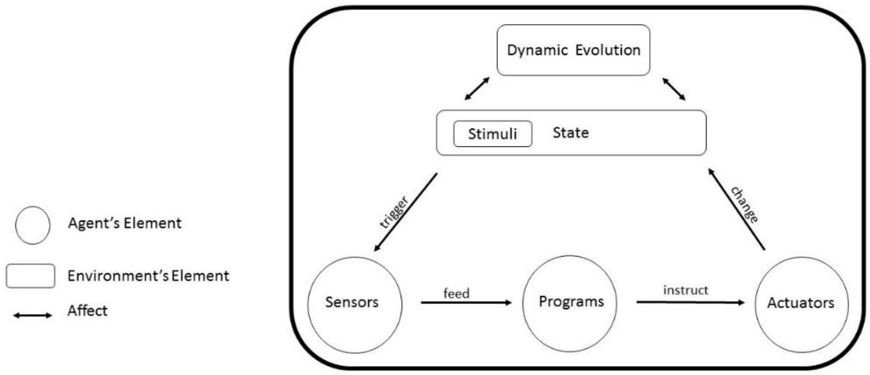

Figure 2 Stigmergy Mechanism and Elements

However, a qualitative Stigmergy means that the signal has a variable nature i.e. qualitatively varies. For instance, humans react differently to each of the traffic lights. Red light simulates the driver to stop his car; whereas, the green light triggers people to drive. It is worth mentioning that the two types of differentiations are not mutually exclusive. In other words, Stigmergy can be defined by the stimulus kind and stimuli-response sequence simultaneously (marker-based /sematectonic and qualitative /quantitative).

LEAN MANAGEMENT PRINCIPLES

Liker (2005) describes Lean management principles through Toyota's manufacturing process. The concept emphasizes waste elimination throughout activities and operations without compromising the client's value. Muda, Mura and Muri are the three kinds of wastes to be eliminated in a Lean process. Ohno views Muda as steps that do not add value to the product or process. Before eliminating wastes, the value in the eyes of the costumer must be identified. After identifying costumer's value and wastes, a continuous flow is to be created whenever possible; otherwise, pull flows are advisable.

Liker (2005) organizes the Lean management principles by a 4-P pyramid model at its base lies "Philosophy" then comes "Process" followed by "People and Partners" and on top is the "Problem Solving." All the pyramid's components hint to the existence of two main elements at the base of any Lean environment. These two elements are agents and system. Each of these elements possess a set of specific characteristics and are involved in certain interactions to constitute a Lean environment.

Starting with the agents of a Lean system, these are the individuals that perform actions required in an operation or a process. In Lean managed systems, the agent's work serves the ultimate goals of adding value; hence, these agents act according to specific characteristics summarized in the list below.

Working with wise eyes promotes the agent to proactively detect errors, to suggest improvements and to avoid wasteful actions.

Reason, creativity and passion help the agent develop critical thinking and an ability to solve problems.

By being trustworthy and ethical, the agents will perform well in collaborative teamwork and in interaction with outside players such as suppliers or clients.

An agent who possesses good communication skills can easily transmit his ideas to the teammates and other players.

Additionally, leadership does not only allow the communication of ideas with others but also gives the potential to influence and convince others.

Finally, a perfectionist agent will continuously seek improvement and will never settle for the best solution.

The second element of a Lean environment is the system. The system is the medium where operations and processes occur. The system which applies Lean principles shall also have a set of differentiating characteristics listed below.

A Lean system is one characterized by a long-term philosophy which is at the base of Liker's pyramid (2005). Long-term philosophy is similar to the True North; it sets the purpose of the business, process or operation. Hence, a Lean system does not only aim to succeed on the short-term key performance indicators but rather aims for sustainable growth and builds right relationships with clients, employees and suppliers for long-lasting benefits.

Enabling bureaucracy is an essential characteristic of the system. This characteristic gives accountability and a sense of responsibility to people while empowering them. Rules and procedures are facilitating and not limiting tools.

Lean systems are coupled with visual aids to help the employees detect errors and eliminate wastes. For instance, Andon signals the arousal of a problem. Andon is not the only used visual control, Kanban and A3 process are other examples implemented in Lean facilities and processes. For instance, Kanban serves pull systems and indicates the need for replenishing certain stations.

Lean systems are ones that utilize pull flows to avoid overproduction in operations. Continuous flow is the optimal requirement to expose inefficiencies in processes and to make it easier to track the cause/effect of errors. However, the pull-system flow is another possibility whenever continuity cannot be possibly incorporated.

The system is described through a set of standardized processes. The standards only serve as means to initiate further improvements and not to limit them.

Lean systems have levelled workload (Heijunka) to eliminate unevenness (Mura) in work distribution. As unevenness is eliminated, Muri (overburden) and Muda (wastes) will accordingly be alleviated.

Poka-Yoke is a necessary element of the system. It is the mechanism to draw human's attention in order to avoid errors. Poka-Yoke ensures quality-at-bay (Jidoka).

After dividing Lean principles into its two main components, agents and systems, we will explain the mechanisms between these two components. The interactions are categorized into three types (Figure 3) as follows:

1. Agent-related mechanisms: are actions initiated by agents who possess the set of Lean characteristic. These actions result in changes in the system. For instance, a creative employee offers suggestions to execute work in a better way.
2. System-related mechanisms: originate from the setup of the system to alter the agents' or its characteristics. For example, an enabling system helps the internal growth of leaders who are expected in turn to add more value to the system's operation or process.
3. Inter-agent related mechanisms: are actions initiated by agents who affect the behaviors of other agents. Collaboration in teams is an example of inter-agent mechanism.

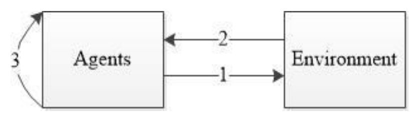

Figure 3 Lean components in dynamic interactions

COMPARISON

Defining Lean principles and Stigmergy each as a dynamic system allows their comparison. The two systems have common constituents, agents and environment. Moreover, these constituents interact dynamically either in Lean or Stigmergy System. Both systems interact similarly, Lean has three different types of dynamic mechanisms that form a dependent feedback loop; as well as Stigmergy where agents react to a stimulus that can be either an agent's actions or an environment's state.

The differences only lie in the nature of the mechanism and the makeup of the agents at the level of the two systems. For instance, in Stigmergy mechanisms, the agent has three components, sensors, actuator and programs that allow the interactions with the environment; however, in a Lean system the agent has to possess a set of characteristic to allow him to function accordingly. The environment for Stigmergy is defined by its states which are in turn a function of disposed stimuli and programs; however, a Lean environment has to possess a set of characteristics.

Having spotted the different nature of the two processes, one could not but conclude that the agent in a Lean system is one who possess Stigmergy elements actuators, sensors and dynamics. Lean environment is also instilled with stimuli forming states and dynamics dictating responsive mechanisms. Therefore, the two systems are related ones. Stigmergy interacts with Lean system to either synergize or inhibit the ultimate Lean objectives.

RELATION BETWEEN LEAN AND STIGMERGY

Despite being distinguishable concepts with different models, Lean and Stigmergy are comparable. It was deduced that the two systems are related and that Stigmergy can either have synergetic or inhibitory effects on Lean objectives. To spot these instances, we will discuss the intervention of Stigmergy in each of the three Lean mechanisms.

Stigmergy intervenes with the first Lean interaction-one through which the agent affects the environment- in several ways:

Stigmergy mechanism converges with the characteristic that requires an agent to have a wise eye. Sensing an error and accordingly taking an action ensures the occurrence of quality-at-bay in the workplace.

Through multitasking the agent can implement changes in the state of the environment around him. Multitasking is indirectly relevant to stigmergy through the agent's dynamic. An agent's program might allow multitasks; i.e., whatever the state appeals to the senses is integrated by the dynamic. The result of integration will be a corresponding action. This is how decentralization can be explained through Stigmergy.

Perfectionist agents will transform their environment into one which applies Nemawashi and Kaizen in their environment. Stigmergy meets the purpose of Lean interaction by continuously improving standards, solving problems by seeing for one's self and allowing decisions to go from downstream to upstream actors.

The second Lean interaction where the system influences agents is also affected by Stigmergy mechanism.

Affiliation of the environment with a long-term philosophy influences the agents to build their relations and to set their objectives based on the long-lasting benefit instead of the short term key performance indicators of success. This interaction entails the indirect convergence with Stigmergy at level of Dynamics of both the Agent and the Environment.

Lean environment is one that utilizes standards as a set point to develop further improvements. The agent's dynamic in Stigmergy mechanisms helps standardization. The agent seems to be programmed to optimize solutions to execute work. This optimization at the level of an organization is at the core of innovation.

Moving to the visual control characteristic, it has a direct relationship with the sensors of Lean agents. For instance, designers who work on a joint model are able to see what the preceding designer has accomplished; thus, will be able to interpret accordingly for the next step to be delivered (Christensen, 2014).

Levelling out the workload is indirectly related to the actuator of the agent. The actuator is the element performing the action. The relation resides in the fact that the less variability of the workload, the less will the agent witness overburdens. Therefore, equilibrium in the workload will require less effort by the actuators to execute action.

Stigmergy can either hinder or facilitate Jidoka, the quality-at-bay Lean characteristic. The agents might coincidently detect a quality problem as the type of stimulus might vary due to quality problems; hence, altering the resulting sensory message and the corresponding response. For instance, in joint modelling, collisions between different trade designs can be quickly observed and re-worked if the designs do not overlap (Christensen, 2014). In this case, Stigmergy facilitates the achievement of quality designs. Nevertheless, Stigmergy hinders Jidoka if a quality problem does not alter the stimuli; therefore, agents might not sense the problem and the feedback loop might only amplify the scale of the problem.

Lean environment only adapts reliable technology. Stigmergy mechanisms will bring on more efficiency when reliable technologies become the stimulus. For example, BIM technologies are useful because people can learn and work amidst the BIM model. If BIM model was not very helpful then people will be wasting effort and time to sense and react upon these technologies.

The third inter-action which is about agents affecting one another is a form of Stigmergy. For instance, in teamwork the team players use their co-workers for stimulus. A leader gives directions and signs, or shows the way which triggers his followers to take action. Collaboration in teams requires communication which is another form of Stigmergy. As one agent sends a verbal or nonverbal message, the other receives it and responds to it by feedback. Lean agents can strength their inter-actions if they utilize their sensors to anticipate what the team needs.

PRACTICAL FINDINGS

After listing the relation between the two dynamic mechanisms, we find some instances where Stigmergy and Lean concepts diverge. However, there are more numerous examples that reveal convergence and dependence of the two concepts on one another. This shows that although the two models function differently, in reality they are not but interrelated. As a matter of fact, Stigmergy is a natural mechanism that is applied within Lean environments.

Practically, this overall dependent relation between Stigmergy and Lean can be helpful for implementing a Lean workplace as per TPS (Toyota Production System). The elements of Stigmergy mechanism can be deployed for faster and improved Lean applications. For instance, the state of the environment that is represented by the stimuli can be devised in a way to trigger the agents to learn more and improve (Kaizen). Also, the more the agents receive the right stimuli, the less the occurrence of negative iterations. Once stimuli appeal to the agent little effort and time will be wasted. Moreover, proper environment dynamics of the workplace, such as an enabling bureaucracy, can promote the long-term thinking. Enabling environments allow actors to work as one unit through cooperation. In addition, it empowers people to hold responsibility and take decisions.

The agent elements (sensors, actuators and dynamics) shall also be catered for as organizations embark on TPS principles. The visual systems must be designed to the sensations of their agents. The actuators can be trained for better reactions; for example, explicit articulation, collaboration and communication within teams and cross functional teams. Challenging people develops the human's innate dynamics which eventually renders the employees attentive to arousal of problems. The agent's dynamics can enhance a fast shift in the culture as Lean principles become adapted within the agent's biological programs. For example, construction sites can apply Lean practices if they train the laborers to analyze the sensory messages around them and to use them as guidance for work. This will decentralize the control of the ongoing activities and will shift the responsibility from the superintendents and site engineers to every laborer.

CONCLUSIONS AND RECOMMENDATIONS

Stigmergy is described as the coordination of different mechanisms that involves information exchange between different agents in a shared environment. Their actions are initiated due to the stimulus received from the environment or from other agents. 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. We have discussed how the two independent systems are not but part of one another. The division of each concept into its elements or principles help us realize that Stigmergy and Lean interact in a positive net effect with one another. The mere realization of the natural Stigmergy mechanism can facilitate the incorporation of TPS and speed up the cultural shift required for Lean workplaces.

Future research can possibly utilize hardware technologies such as micro sensors for measurements of human interaction. Simulation techniques for design and analysis of human Stigmergy system are also recommended for future research. Is there an optimal pace of the Stigmergy mechanism to ensure a Lean workplace? What is the best Stigmergy type for development of Lean human culture? What can possibly hinder human Stigmergy interactions?

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PERCENT PLANNED COMPLETE: DEVELOPMENT AND TESTING OF A SIMULATION TO INCREASE RELIABILITY IN SCHEDULING

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ABSTRACT

This research responds to a perceived need to help construction management students and industry stakeholders develop a solid understanding of the impact of Percent Planned Complete (PPC) during their first exposure to the Last Planner System of Production Control™. Although the practice of implementing PPC is becoming more widespread, the benefits of its use are arguably not yet fully appreciated by industry practitioners. The QUESTION this research seeks to address is: How can the impact of PPC be clarified to those who are exposed to it for the first time? The PURPOSE of the research is to develop and test a new simulation to better understand how participants perceive the impact of using PPC as a tool to measure and subsequently improve reliability in planning. With respect to RESEARCH METHODS, a simulation was iteratively developed and a questionnaire was administered to participants both before and after playing the simulation to perceive any change in their understanding of the PPC method. The simulation was tested using students as subjects from two universities, as well as industry professionals, and questionnaire results were analyzed. RESULTS demonstrate that playing the simulation led to a 718%

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enhanced understanding of how applying PPC to schedule planning can lead to improved reliability of performance. LIMITATIONS include time constraints which necessitated a limitation in the number of test subjects, and the disregard of cultural differences in test subjects. Underlying the need for this work is the assumption that comprehending the impact of PPC helps facilitate application of it. IMPLICATIONS and VALUE of this work is that it has the potential to assist instructors and project managers to more effectively and efficiently transfer understanding of PPC and its capacity to measure (and therefore enhance) reliability, as part of the larger process of continuous improvement.

KEYWORDS

Percent Planned Complete/PPC; Lean simulation; Last Planner System of Production Control; Teaching Lean Construction

INTRODUCTION

Two major issues faced by the construction industry are time and cost overruns. These overruns are likely due in part to a lack of proper planning of schedule. Although collaborative planning helps industry professionals promise reliability, regular production evaluation and planning adds accountability and helps maintain an agreed timeline. Percent Planned Complete (PPC) has been shown to be an effective method of measurement of--as well as motivator for--production reliability. This paper addresses the need to transfer understanding of PPC as a way to increase reliability fundamental to continuous improvement processes.

For the Last Planner System of Production Control, the fundamental components of a planning system define what SHOULD be done, what CAN be done, and what WILL be done (Ballard 1993). Subsequently completed work should be compared to planned work (DID you do it?) to improve process planning. These concepts can be related to traditional project planning levels (**Figure 1**). The Last Planner System, developed by Ballard (2000), is a planning and control system based on lean production principles. This system strives to improve reliability in planning and reduce the negative impacts caused by variability by monitoring Percent Planned Complete on a regular basis.

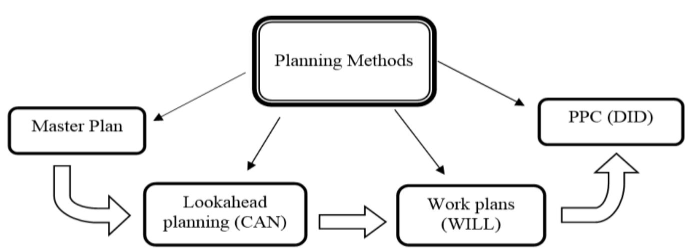

Figure 1: Project Planning Levels
Adapted from Ballard and Howell (1998)

The concept of PPC is integral to the Last Planner System by Ballard (2000). PPC measures the effectiveness of a planning system and is calculated as the ratio of work performed to work planned as a percentage. The reliability of workflow can be computed using PPC as shown in **Figure 2**. Regular tracking of PPC provides an excellent means to check the variability in project planning. It indicates the current status of work, and highlights areas which require more attention.

$$\text{Percent Planned Complete} = \frac{\text{Work performed}}{\text{Work planned}} \times 100$$

Figure 2: PPC calculation

Various studies suggest there is a positive correlation between reliability (PPC) and project profit, early completion, safety, and client satisfaction. From a more advanced perspective, highly reliable projects allow project managers to decrease batch sizes, reduce inventory on job sites, develop consistent workflow, and increase accuracy of estimation of planned durations (Skender 2012).

By measuring and monitoring the completion of activities, the variability of performance decreases, thereby increasing reliability. Ignoring the causes of variability reduces performance, which almost always brings a contractual penalty (Ballard 1993).

After implementing a plan, it is important to check the efficiency of the plan. Monitoring the progress of the plan helps identify drawbacks that can interrupt the smooth flow of the plan. PPC plays the same role in the Last Planner System. Throughout the duration of the project, PPC is tracked consistently and Production Evaluation and Planning (PEP) meetings are held involving all the Last Planners to discuss and evaluate the PPC of the project. The purpose of these meetings is to review and learn from the previous work periods and their respective PPCs. During these meetings, the 'root causes' for why planned work was not completed are identified. This is primarily orchestrated by front line superintendents and foremen who are directly responsible for plan execution.

This research investigates fundamental aspects of PPC, with the assumption that a better understanding can help project managers utilizing this technique improve project performance, thereby contributing to continuous improvement. The improvements realized from these discussions are not only made in the processes and functions at the Last Planner level, but also at the organizational level. PPC analysis can become a powerful focal point for breakthrough initiatives.

EXISTING SIMULATIONS ON PPC

Currently, there are few existing simulations related to the concept of reliability. Iris D. Tommelein, David R. Riley, and Gregory Howell designed the Parade of Trades simulation (Tommelein et al. 1999), with the intent to understand how variances in work flow affects the final productivity of the overall process. PPC emerged as a countermeasure to variability and is integral to the Last Planner System. However, there is still a need for a hands-on simulation to help understand and validate the usefulness of PPC.

ASSUMPTIONS

It was assumed that the lesson learned from the simulation can be directly implemented in the construction industry. The simulation was based on the postulation that PPC is the primary tool used to measure the reliability of the schedule.

LIMITATIONS

There are many other production planning systems to increase the predictable work flow and rapid learning in any project. This research only dealt with the Last Planner System of Production Planning™ formulated by Glenn Ballard and Gregory Howell. There are various factors that affect the work flow in a project. This research limited its focus on reliability as an influencing metric and PPC as its measurement tool.

RESEARCH METHOD

Figure 3 shows the methodology used for the simulation development and testing.

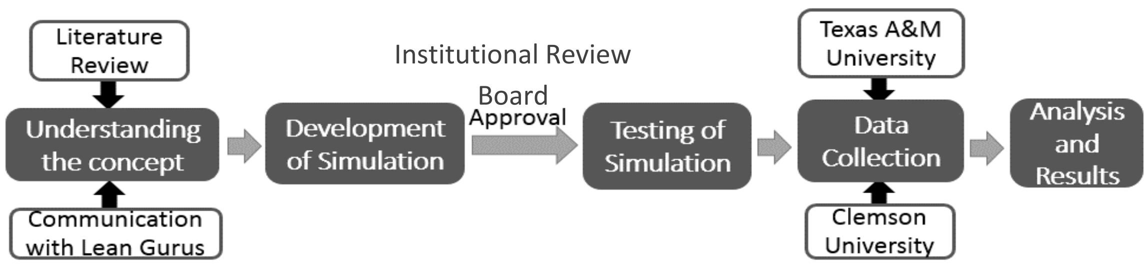

Figure 3: Research method used to develop and test simulation

SIMULATION

PROCEDURE AND SET-UP

Before the simulation, a questionnaire was administered to participants inquiring about their educational and work background, and their knowledge about lean and their previous participation in lean simulations. The participants were then introduced to the concept of PPC and reliability. Facilitators explained how PPC is measured and the importance of PPC. The participants were then presented a scenario where they, as construction individuals, were to provide an owner a supply of work units. This work unit consisted of a pyramid made with marshmallows and sticks as shown in **Figure 4.** The construction of these work units was divided into three 2-minute rounds.

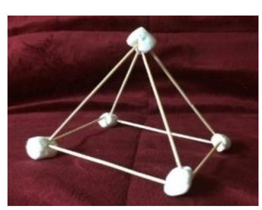

Figure 4: Structure made using marshmallows and sticks

DIVISION OF GROUPS AND SCOPE OF WORK

Participants were divided into groups of four, each group consisting of 1 General Contractor (GC) and 3 Subcontractors.

SCOPE OF WORK FOR GENERAL CONTRACTOR

- The GC independently prepared a work schedule for each subcontractor, supervised the work, and ensured smooth flow of the task.
- The GC was also responsible for documenting the amount of work done by each subcontractor and calculating the PPC after each round.

SCOPE OF WORK FOR THE SUBCONTRACTORS:

- At the beginning of each round the subcontractors estimated the amount of work they believed they would be able to perform.
- They performed the work of making pyramids during the time allotted.

MATERIALS AND HANDOUTS

After facilitators explained participant roles and responsibilities, each group was provided with the following materials:

1. Marshmallows to serve as joints and 5 inch mini skewers to serve as structural struts for the pyramids.
2. Schedule of work to be completed by the GC (**Figure 5**)
3. PPC calculation chart and graph to be completed by the GC (**Figures 6 & 7**)

	Estimated work for the allotted time
Subcontractor 1	
Subcontractor 2	
Subcontractor 3	

Figure 5: Schedule of work

	Work Planned	Work Performed	PPC=Work Performed/ work Planned x 100
Round 1			
Round 2			
Round 3			

Figure 6: Calculation of PPC

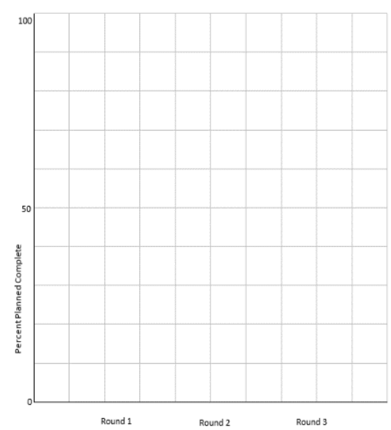

Figure 7: Plotting the PPC

SCHEDULE OF WORK

Before the rounds started, the GC estimated the capacity of work of each subcontractor and independently prepared a schedule of work for the project. Each pyramid was counted as one work unit as shown in figure 3. Incomplete units were counted as a half work unit as shown in the **Figure 8**.

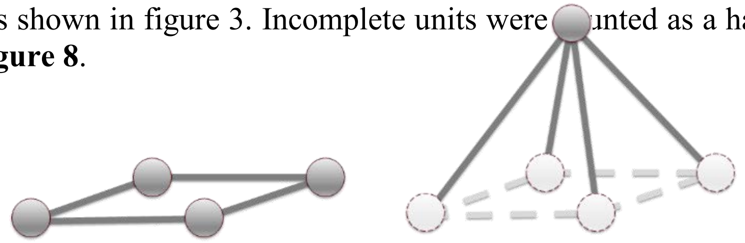

Figure 8: Figure showing half a unit

ROUNDS 1, 2, AND 3

The subcontractors declared the amount of work they predicted they would be able to perform for that round. The GC recorded the work planned by the subcontractor on the sheet provided. The subcontractors were then allotted 2 minutes to complete their planned work. At the end of the allotted time, the amount of work performed by the subcontractors was measured by the GC and PPC for each subcontractor was calculated and plotted on the graph.

DISCUSSION

The graph plotted during the entire activity showed the PPC of each subcontractor for each round. The graph showed an increase or decrease in the PPC with each round. The variation in their planning reliability in relation to each round was discussed and the participants speculated potential causes for variations. Finally, the participants were introduced to the application of PPC in the construction industry as a way to enhance schedule and to serve as a stepping stone toward continuous improvement.

RESULTS

EDUCATIONAL BACKGROUND OF THE PARTICIPANTS

The participants of this study primarily included students of Construction Science from Texas A&M University, College Station, Texas (60 participants) and Clemson University, Clemson, South Carolina (32 participants). Before the simulation was played, the participants were asked whether they had previously played lean simulations. 78 (85%) out of 92 participants stated they were playing a lean simulation for the first time.

WORK PLANNED VS. WORK PERFORMED

At the beginning and end of every round, the GC of the group documented the work performed and the work planned for each subcontractor. With each round, a difference in the gap between work planned and work performed was noted as shown in the figure 9. The gap between average work planned versus average work performed decreased with each round. With every round, the subcontractors became increasingly accurate about predicting their work capacity. This helped them plan their work better and subsequently decrease the gap between work planned and performed (**Figure 9**).

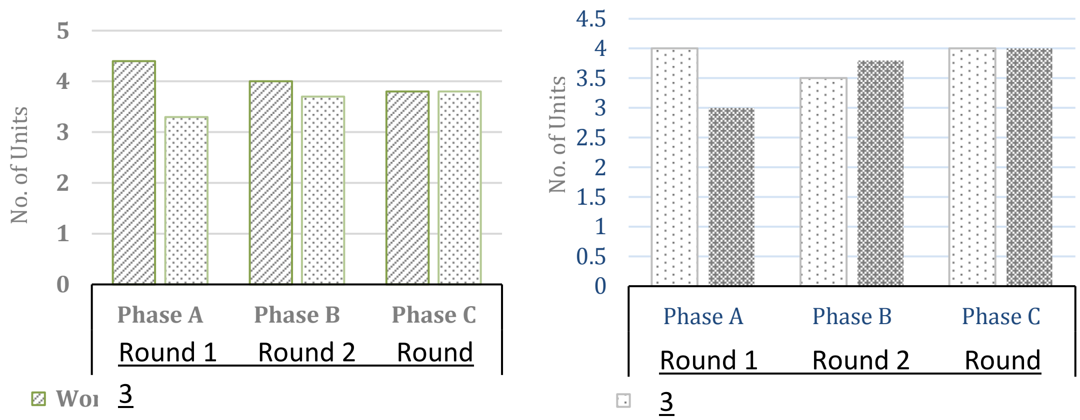

Figure 9: Work Planned vs. Work Performed

PPC BY ROUND

PPC was calculated and plotted at the end of every round for each subcontractor. A difference in PPC was noticeable for most of the participants as shown in **Figure 10**. The average PPC of the subcontractor approached 100% with each successive round as work predictions became increasingly accurate (**Table 1**). As the game moved through subsequent rounds, the subcontractors developed a better understanding of their work capacity and this enhanced planning reliability.

Table 1: Table showing data collected from each round

	Round 1	Round 2	Round 3
Min	33.3	50.0	75.0
Median	80.0	100.0	100.0
Average	81.5	105.6	100.8
Max	250.0	175.0	125.0

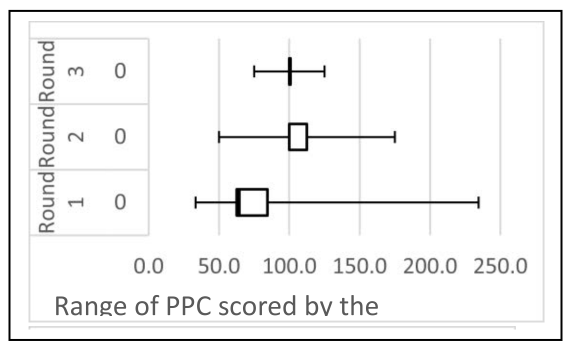

Figure 10: Box and Whisker plot showing the PPC scored by participants during each round

RELIABILITY OF THE GENERAL CONTRACTOR VS. SUBCONTRACTOR

The data collected from the simulation shows a difference between the work planned by the GC at the beginning of the simulation and the work planned by the subcontractor in each round (**Figure 11**).

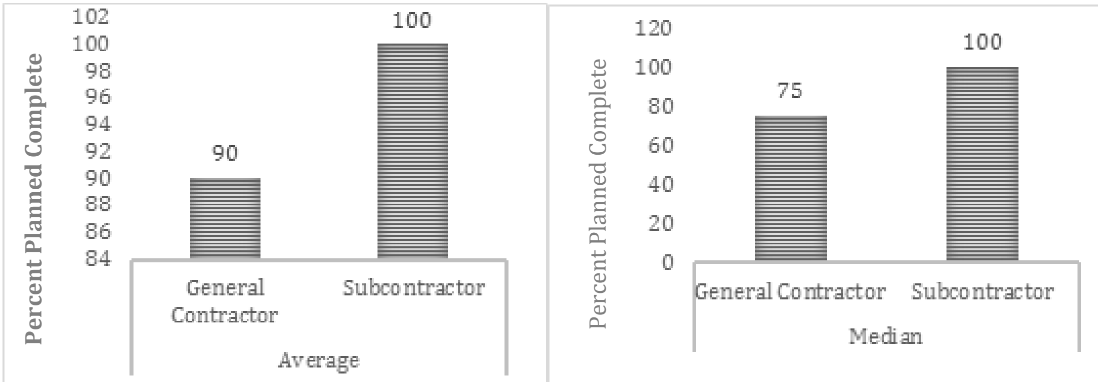

Figure 11: Reliability of the General Contractor vs. Subcontractor

Figure 11 shows the average and median reliability of the GC in comparison with average reliability of subcontractor. The results from the data show that the subcontractor's planning is more reliable than the GC's.

UNDERSTANDING OF THE CONCEPT OF PPC

A post-simulation questionnaire was administered to the participants to assess their comprehension of the term PPC and its use during scheduling in construction projects. Results are shown in **Table 2**.

Table 2: Understanding of the concept of PPC

	Before Playing	After Playing
Aware/Understand	11	90
Not aware/ Did not understand	59	0
No response	22	2

UNDERSTANDING THE CONCEPT OF LAST PLANNER SYSTEM

The questionnaire administered before and after playing the simulation also queried participants about their understanding of the Last Planner System. For example, participants were asked the question, "Who do you think can more accurately predict the time it takes to complete the task?" and they were asked to pick between "person who does the work" (Last Planner) and "an experienced scheduler." **Table 3** includes the results of the questionnaire. According to the data collected, the number of participants who picked "person who does the work" increased after the simulation. Thus, the simulation appeared to facilitate an increasing awareness of at least one key component of the Last Planner System among the participants.

Table 3: Understanding of the concept of LPS

	Before Playing	After Playing
Those who do the work	49	83
An experienced Scheduler	39	6
Both	4	2

RATING THE SIMULATION

At the end of the game, the participants were asked to rate the simulation based on the effectiveness in explaining the concept and application of PPC. On a scale of 1 to 10, a majority of the participants rated the simulations in the range of 6 to 10. The average score the simulation received was 8.3.

According to **Figures 12** and **13**, the simulation was successful in demonstrating that PPC helps in track the work performed and work planned, and increasing the reliability of Last Planners. Furthermore, it effectively explained the concept to the participants.

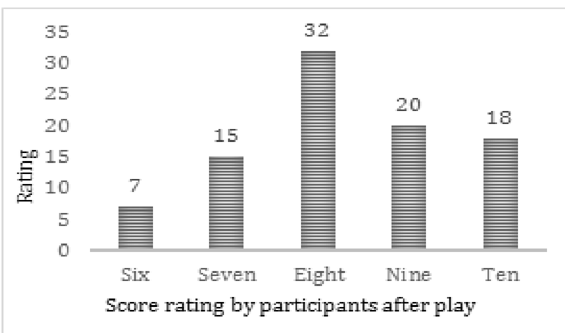

Figure 12: Distribution of the score

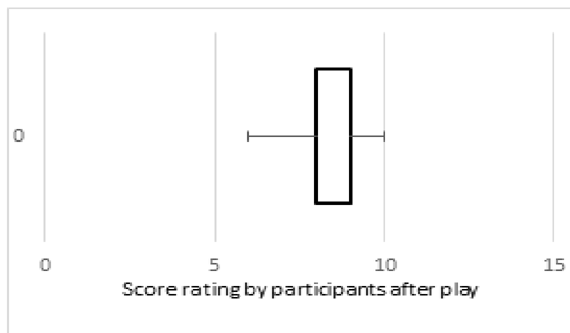

Figure 13: Box plot showing the distribution of the scores

DISCUSSION

During the analysis of the results, an observation was made about the measurement of PPC with each round. In the round 1, both the average and median of the PPC achieved by the participants was lower than 100%, whereas in round 2 the average PPC was lower than 100% and median PPC was higher than 100%. While the participants overestimated their capacity in the first round, it was observed that participants underestimated their capacity in round 2. Additionally, an interesting relationship between the previous exposure of the participant to the lean simulations and their observance of instructions was observed. The participants with less experience with the simulations were more willing to follow instructions. Moreover, the participants playing the role of the subcontractors pushed themselves to surpass the commitments they had made.

The current simulation concentrates on the application of PPC in projects and its direct impact on planning reliability with time. However, the indirect advantages of PPC such as smooth flow of the project, promotion of culture of trust, and its role in continuous improvement were not addressed. Therefore, a new dimension can be added to the simulation by introducing pre-requisite work by others for the subcontractor to start their work. Through this, the concept of inter-dependencies of work in the industry can be investigated. This exploration would usher in new dimensions to the identification of work-flow patterns and subsequently reliability in planning.

CONCLUSION

Reliability plays a fundamental role in project delivery. It is a key factor for improving project performance. Work reliability can be improved through PPC, a measurement tool promoted by the Last Planner System. The journey to improve project performance begins by recognizing existing problems. Measurement of reliability is a key tool for accomplishing this. This simulation helps reinforce an understanding among participants that measurement of work *and* work reliability is crucial to continuous improvement.

The simulation designed and developed though this project was used to investigate how participants perceived the importance of using PPC as a tool to measure and improve reliability. The results from the data collected through the simulation indicated a 718% increase in the level of understanding of the concepts of PPC.

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WHAT “MAKES” THE LAST PLANNER? A TYPOLOGY OF BEHAVIORAL PATTERNS OF LAST PLANNERS

Sigmund Aslesen[1] and Iris D. Tommelein[2]

ABSTRACT

This paper explains the role of the Last Planner and behavioral patterns observed in Last Planner meetings. We focus on the Last Planner as the person who serves as the coupling point between planning and production, whose key to success lies in the fine art of balancing what he or she really wants with the ways and means actually available for achieving it. We apply a sociological approach by introducing and discussing a typology of four types of planning behavioral patterns, the *Game Player*, *Gang Pusher*, *Yes Man*, and *Last Planner*. These types are derived from observing Last Planners on many projects and categorizing their behavior according to (1) the observed individual’s apparent level of commitment to using the Last Planner planning process vs. (2) the degree of conceptual understanding of the Last Planner System that they appear to exhibit. We conclude that no matter how good (or bad) the upstream planning is the real-time adaptation of and commitment to a plan strongly depends on the judgment, communication skills, and choices made by the Last Planner. Knowing what “makes” the Last Planner can be fundamental to the success of system implementation. By assessing patterns of planning behavior, focused training can be offered to help individuals and teams become more knowledgeable and fully-committed Last Planners.

KEYWORDS

Production planning and control, Last Planner® System, people, culture and change.

INTRODUCTION

Over the years, more than 200 papers have been written on the Last Planner® System (LPS) of production control in IGLC conference proceedings and elsewhere, too many to cite here. This paper sheds light on the role Last Planners play in planning meetings. According to Ballard’s (1993, p. 4) first publication on the concept he invented, what “makes” the

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Last Planner is the ability to produce "directives that drive direct work processes, and not other planning processes." Research papers on the LPS have shed light, e.g., on commitment planning, trust-building and behaviors that emerge from LPS implementation (Seymour and Rooke 2000, Fauchier and Alves 2013, Smith and Rybkowski 2013), linguistic actions and human concerns related to implementation (Macomber et al. 2005, Slivon et al. 2010), implementation barriers (Brady et al. 2011), learning and changes in behavior (Tillmann et al. 2014), and experiences of project managers and foremen using the LPS (Skinnarland 2012). However, the role Last Planners play appears to not have been the focus. One might find that to be paradoxical because, when applying the LPS, the priority is to bring all work processes under control. The strategy for achieving that control is to identify Last Planners, clarify their role and expectations, and enable them to be successful (Ballard 1993, p. 4). Indeed, whereas research in this area can be credited for describing efforts to enable the planner last in a chain of planners to act as a Last Planner, we find the main character somewhat hidden.

Our contribution in this paper is to explain the role of the Last Planner and characterize behavioral patterns based on observed practices. We view him/her as the coupling point between planning and production, whose key to success lies in the fine art of balancing what s/he really wants with the ways and means actually available for achieving it. We conclude that no matter how good (or bad) the upstream planning is, the real time adaptation of a plan greatly depends on judgments, communication skills, and choices made by the Last Planner. Knowing what "makes" the Last Planner can, in this way, be fundamental to succeeding with implementation of the system.

METHODOLOGY

We have found little in the literature that describes how Last Planners behave in certain ways at planning meetings and why their behavior may be so, yet each of our 10+ years of experience in deploying the LPS have provided us the opportunity to observe different behaviors. We have conducted numerous field observations by joining construction project teams both as planning facilitators as well as process observers at weekly planning meetings. At times having two researchers on our team made it possible for one to focus on facilitation and the other on observation. Post-meeting debriefs with planning team members (when we were coaching them to learn the Last Planner process) and between the two of us, offered richness in observation that would have been hard to capture so fully if a single researcher had attempted to do so. In addition, we also spoke with subcontractors (trade partners) before or after the planning meetings and checked in with them on site to hear how their plan got executed. That said, the characterization we here propose of Last Planners is but the first step on a path of research inquiry with many questions that demands more formal investigation and validation.

THEORETICAL BACKGROUND

SHIELDING PROCESS IN THE LAST PLANNER SYSTEM

In 1993, Ballard published his first Last Planner concept paper. In it, he expressed concern with the so-called "conversion" process model. Through his examples, one comes to understand that conversion model as depicting a way of managing construction projects based on sequential thinking. Ballard argued that the conversion model is outdated, in regards to projects in which engineering, procurement, and construction overlap in time. His apprehension derived from the observation that although so-called "fast-track" projects now are the norm in construction, project management practices are still very much dominated by the conversion process model. Ballard looked at what the consequences are for performance improvement strategies if the conversion process model is to be displaced with lean construction concepts and principles. A fundamental part of the strategy to make that happen is, in Ballard's view, to improve the production planning and control of construction projects. It is against this background that he outlined the basic elements of the Last Planner concept (later renamed and trademarked as the Last Planner®).

Why focus on planning? Ballard's response was that current standards for scheduling and budgeting construction projects assume poor performance and therefore include a tremendous amount of waste (Ballard 1993, p. 3). From a rational point of view, it seems to make little sense to plan in a way that makes projects less off. At the same time, why bother if projects get completed on time, on budget, and to the satisfaction of the customer? It is this particular reasoning that Ballard wanted to stamp out in the industry. He did so by pointing to the planners last in a chain of planners, named the Last Planners. Why the Last Planners? Ballard accentuated the Last Planner because s/he is the key to producing good assignments, yet the erratic delivery of resources to the construction site disables him/her from doing so. Instead, these planners spend a large amount of the time hustling resources and fighting fires (Ballard 1993, p. 5). This is not to say that it is the Last Planner's business alone to produce those assignments. Quite the opposite! Ballard advocated for "the deliberate creation of inventory surge piles" to shield the Last Planner "from an erratic flow of resources" (op. cit. p. 4-5). This "shielding" consists essentially of distinguishing what "should" be done, from what "can" be done, and what "will" be done. The Last Planner's job in this process is to approximate "should" within the limits of "can" (Ballard 1993, p. 3). The shielding process leads us to formulate the following first assumption:

1. What makes the Last Planner is the shielding process. The Last Planner's ability to produce good assignments is determined by the quality of this process.

ROLE OF THE LAST PLANNER

Ballard and Howell (1998) subsequently described the shielding process as the essential step in production control. Now, let us dwell a bit on the role that the Last Planners are there to fulfill, namely to produce good assignments. In Ballard and Howell's view, to make so-called "quality assignments" involves that certain requirements are met: i.e., that assignments are specific enough; that all prerequisites are in place such as materials, tools, design drawings, prerequisite work, space, manpower and other external conditions; that assignments have the right sequence and size; and, that learning takes place by tracking assignments not completed and identifying the reasons (op. cit. p. 3). Due to the existence of a shielding process, one may come to think of the Last Planner's role as being straightforward. Here too, quite the opposite is true if we follow Ballard and Howell's (1998 p. 7) substantial list of planning steps the foreman must follow on a weekly basis.

The plan where work orders or directives are released to the production units, often called a weekly work plan, is in Ballard and Howell's view a Commitment Plan (1998, p. 2). Committing here relates to the principle of producing only quality assignments. It goes back to the "will" in the shielding process and exposes the production units to the risks of not using available productive capacity and of failing to meet scheduled dates (op. cit. p. 3). Now, why would they do that? It is not certain that they will. This is probably why Ballard (1993 p. 3) is quite clear that the Last Planner's job is to produce assignments that are practical and to provide reliable input for the planning of interdependent work processes. Thus, a Last Planner's concern should be, not only with the practical feasibility of the assignment per se, but also with how that work relates to other work. This leads us to the second assumption:

2. What defines the Last Planner is his/her ability of judging what is possible and knowing how to achieve it. The level of commitment from the production units will depend on this.

COMMITMENT PLANNING, TRUST, AND MANAGING PROMISES

By using the term Commitment Plan, Ballard and Howell (1998) indicate that there are human concerns as part of doing production planning related to the social construction of trust and promises. A common problem or challenge with these human concerns is that they are so obvious they tend to be overlooked (Seymour and Rooke 2000, p. 1). A series of IGLC papers stress the human elements involved in making production plans. A substantial contribution is Slivon et al.'s (2010) paper that proposes a framework for situating the construction process in the world of human concerns. It does so by considering activities taking place on the construction site as expressions of human concerns or "interests," and not merely physical movements (op. cit. p. 3). In line with several other related contributions, the paper takes a language or linguistic action view to explain how the physical activity on site is a result of requests and promises having been made in the planning stage to align interests into a network of commitments (op. cit. p. 4).

A question then is: How do you manage to align interests into a coherent network of commitments? Macomber et al.'s (2005) answer is: By understanding the planning process as being about managing promises, and using the LPS to close in on the uninterrupted flow. Their paper further details how to achieve reliable promises in the construction context. What is not so much stressed in this paper, but which is a clear topic for another series of IGLC papers, is that of competitive tendencies appearing within the group of planners resulting in sub-optimization on relational sustainability. In one such paper, Smith and Rybkowski (2013) introduce the Maroon-White Game to illustrate the impact of trust, both earned and broken, as a way of teaching participants about the consequences of their actions in situations where cooperation is a possibility. The game makes evident that, given the option to cooperate with another party vs. look out for their own best interests the selection of a cooperative move is unlikely (op. cit. p. 990). This leads us to the third and final assumption:

3. Being the Last Planner is about making and receiving promises. Benefits from the planning process stem from the ability to make decisions based on a broader perspective than one individual's.

TYPOLOGY OF BEHAVIORAL PATTERNS OF LAST PLANNERS

The LPS provides a certain "programmable" pattern of action to reduce work flow variability as well as to complete the work. However, people are not easily programmable. Last Planners, last in a chain of planners, act in different ways for many reasons. In the following, we generalize their patterns of behavior by singling out 4 type descriptions. We crafted these, inspired by behaviors observed of Last Planners in planning meetings, but like movie producers we add the disclaimer: "The descriptions, all names, characters, and incidents portrayed in this paper are fictitious. No identification with actual persons, places, buildings, and products is intended or should be inferred." None of these types will be found in their pure form in real life. We made these types to help conduct useful analyses of how planning is performed in projects.

The types are categorized along two dimensions: (1) the apparent level of commitment of the planner to using the Last Planner planning process, and (2) the level of conceptual understanding of the LPS that the planner appears to exhibit. Regarding commitment, our focus is on the level of dedication or engagement shown by planners in the process of developing a plan. Regarding conceptual understanding, our concern is with the apparent aptitude these planners have in grasping the essence of what planning (and in particular the LPS) is. Figure 1 shows our four types, denoted in italics in the text: (1) the *Game Player* (high conceptual understanding, low commitment), (2) the *Gang Pusher* (low conceptual understanding, low commitment), (3) the *Yes Man* (low conceptual understanding, high commitment), and (4) the *Last Planner* (high conceptual understanding, high commitment).

Figure 1: Typology of behavioral patterns of Last Planners

		Level of Commitment	
Level of Conceptual Understanding		Low	High
	High	*Game Player*	*Last Planner*
	Low	*Gang Pusher*	*Yes Man*

What inspired the naming of each type? *Game player* is a term influenced by game theory (dating back to the 1920s) applied to social interaction in sociology, where attempts to explain how people interact are based on seeing their actions as strategies, involving winners and losers, punishment and rewards, profits and costs (Swedberg 2001). *Gang pusher* is a term Ballard (1993) used to refer to the front line supervisor or leader of a work crew. *Yes Man* is a term inspired by director Peyton Reed's 2008 movie by that name, about a guy who challenges himself to say "yes" to everything for an entire year. Finally, *Last Planner* is a term used in Ballard and Howell's (1998 p. 6-7) description of the planner involved in shielding and commitment planning. Next, we further distinguish these types.

Game Player: The *Game Player* is self-interest driven. S/he has a strong sense of what planning is about and comes well-prepared to meetings, yet strategically avoids committing fully to the planning process. S/he might indeed take an active part whenever planning touches upon issues that relate directly to his/her interests or concerns, but s/he will most likely also be passive for longer periods of time in the meetings. His/her self-interest may be driven by economic concerns. Have in mind here that a planner produces directives that drive direct work. Thus, decisions s/he makes, whether related to the use of labor, materials, or other resources, can have crucial impact on the outcome of the project for the contractor. Furthermore, self-interest as a quality might be misleading, since there is often a project manager standing behind him/her ("in the office", as they say) who follows up on the budget and whose role is to see to that all things go as planned and agreed on in the contract. This situation can work to limit the planner's propensity to participate actively in the meetings and instead disconnects him/her from the planning process, especially if s/he is also inexperienced in the planner role. We speculate—and suggest as a future research question—that the *Game Player* may be found in trades that use relatively long-lead time (e.g., fabricated) and costly materials and that have relatively little flexibility in terms of how they work, such as for instance plumbing or duct work, where the consequences of wrong decisions can be substantial.

Gang Pusher: The *Gang Pusher* is push oriented, and here understood figuratively-speaking as the archetypical foreman who shoves or pushes his/her crew around for work or pushes work onto his/her crew. S/he is the type of planner who operates with a short-term planning horizon only, and for that reason typically thinks of the shielding process as unnecessary or superfluous as the assignments in his/her opinion can be derived directly from the master schedule. This planner checks the quality of assignments in real time, while the work is ongoing, rather than beforehand as part of the planning process. The assignments s/he is used to are often poorly defined, decided opportunistically, typically including chunks of work rather than broken down pieces of work. As a result, s/he will find it hard to define assignments in a LPS's weekly work plan. Besides, when questioned about status or level of completion of tasks in the weekly work plan meetings, s/he will tend to give a blurred response as starts and ends of assignments are not always very clear to him/her. Being a pusher of work, this planner's focus is on getting things done to the point that work cannot wait for quality assignments to be produced. His/her dedication to the planning process is therefore low. His/her conceptual understanding of the planning process also being low has probably less to do with intellectual capacity and more with the kind of work s/he performs. We speculate that the *Gang Pusher* may be found in trades that are flexible in terms of which work can be done where, such as framing, dry walling, tiling, or painting, where the "push of work" or "push to work" thinking can be a quite logical approach—at least from that single-trade's perspective only.

Yes Man: The *Yes Man* is, as the name indicates, flexibility-driven. S/he is highly committed to the planning process to the point that s/he involves strongly in the meetings and is eager to contribute to a good plan. However, s/he has a hard time seeing what it actually implies to put an assignment *in* the plan, both when it comes to first making sure that all prerequisites are in place (materials, engineering drawings, etc.) and to agreeing that setting the start and finish dates for assignment really is the same as making a promise to the rest of the organization that the work will actually happen within this time frame. Failure or lack of willingness to understand this promise typically has as outcome that his/her assignments are taking longer than originally planned and even keep reappearing in weekly work plans until they are finally done (possibly weeks later). For reasons related to interdependence of work processes, a *Yes Man* may cause trouble in a project, but the extent of that misery depends on the nature of the work s/he does. For instance, if s/he happens to be an electrician whose work is pretty much everywhere in a building, but who at the same time can be quite flexible and used to working around others, the unreliability of his/her actions does not need to affect the other trades that much. This notwithstanding, being an electrician who experiences for example an unscheduled late delivery of light fixtures is likely to cause problems for other trades as well as the project.

***Last Planner*:** The *Last Planner* is pull oriented. S/he is highly committed to the planning process based on being convinced that coming up with a reliable plan will benefit him/herself, the contractor, all the other trades and the project in general. Pull oriented here means using the planning process to build up a backlog of sound assignments (including all necessary prerequisites) that s/he can pull from, down to the weekly work plan level and further out to the production units. Having that pull orientation usually involves considerable preparation ahead of meetings to make sure everything is in place for the upcoming week(s), as well as performing regular quality checks on site to control status and be certain that completed tasks really are 100 % done (done-done). When a *Last Planner* puts an assignment in the plan, s/he knows s/he is making a promise to the rest of the organization. For that reason, s/he will not hesitate to hold back an assignment that is not made ready, even though the overall plan dictates that the task should be done in the upcoming week. In the planning meetings s/he is also likely to point out if other *Last Planners* report falsely on the status of their work. Following the "go slow to go fast," a *Last Planner* is inclined to sacrifice some of his/her own unit's progress (as originally planned) for the sake of other units' progress—as long as it benefits the project. While we speculated earlier about planning behaviors possibly correlating with the nature of a trade's work, note that a *Last Planner* can be anyone on the team, independently of the nature of work s/he does. Ideally, everyone on the team should be a *Last Planner*. Note however that one does not become a *Last Planner* overnight. It takes time to learn LPS concepts and become skilful at using them. It is not unusual for a *Last Planner* to have had training and practice using the LPS on earlier projects. At the same time, success in planning in construction relies on more than an individual's mastering of certain concepts and skills; project context plays a huge role as well.

DISCUSSION

WHAT "MAKES" THE LAST PLANNER IS THE SHIELDING PROCESS

The output of the shielding process is a buffer of sound assignments (workable backlog), that shields production and not least the Last Planners from uncertainty. When such a shielding process does not exist, as was the case in more than one case study, one might expect various strategies appearing among the Last Planners to cope with the situation. The pull-oriented *Last Planner* is likely to establish his/her own lookahead plan. Furthermore, s/he will be eager to involve or otherwise communicate his/her plan to the other trades, in an attempt to make sure all interdependent work processes are coordinated before they "hit" the floor. However, to the point that some trades will lack a lookahead window in their plan, as may be the case for the *Yes Man* and the *Gang Pusher*, the *Last Planner* will get only vague or unreliable promises based on unsteady interpretations. Like the *Last Planner*, the *Game Player* may develop his/her own lookahead plan in a situation where no lookahead window exists that includes all the trades. His/her way of communicating the plan to the other trades is less based on involvement and more motivated by pushing them to finish the necessary, preceding work and "knocking them down" whenever s/he finds them to be in the way of his/her work. For the *Yes Man*, lacking a shared lookahead plan may lead to an intolerable situation, because s/he has no clear sight of what will go on, on site, in the near future and therefore will be much less able to know how s/he should work around the other trades' work. In contrast, for the *Gang Pusher*, working with no lookahead plan is more or less "business as usual". This is not to say that the situation will favor him/her or his/her production unit any more than others. On the contrary, it is likely that all trades will suffer in one way or the other from not having a shared look ahead plan.

JUDGING WHAT IS POSSIBLE AND KNOWING HOW TO ACHIEVE IT

We assume that the Last Planners' key to success lies in judging what is possible and knowing how to achieve it. The shielding process is crucial in this sense as it helps support assessments by determining what "will" be done against "can" and "should". In two case studies, lookahead planning was supported using a computer program. We will not go into the various functionalities included in such programs, but instead focus on how their use may affect the Last Planners in different ways. On the positive side, using a program to produce quality assignments enhances the standardization of processes and information input. For a *Yes Man* or a *Gang Pusher* that struggle to "take in" the planning principles and procedures, a program may offer a standardized structure for them to follow in order to provide more accurate information than they otherwise would. Also for the *Game Player* and the *Last Planner*, a program designed to facilitate the lookahead planning can work positively to improve the process, amongst others related to the structured information-gathering and not least for the fact that it can make planning meetings more efficient. As they normally meet up well-prepared and know the "drill" of the meeting, the use of a program can help reduce the risk of over-complicating matters that could be dealt with simply. At the same time, for all the Last Planners no matter the type, a potential problem in using programs is that one ends up seeing them as some sort of "calculus" that produces quality assignments for you, based on an optimum formula. In such a situation, *Last Planners* might end up as *Yes Men* in meetings, automatically replying "will" to all activities in the schedule without giving due concern to "can."

DECISION-MAKING BASED ON A BROADER PERSPECTIVE

We assume that being a Last Planner is about being prepared, continuously monitoring what is happening, improving, and being ready to adjust plans as needed. That being ready to adjust and improve almost inevitably is about making decisions based on a broader perspective than one individual's job. For example, one project had three pull plan sessions to hammer out one phase plan. The process failed all three times, to the point that no *complete* plan was ever developed for that particular phase. Nevertheless, several important clarifications were made during these sessions and tactics were agreed upon on how to approach the technically demanding and logistically challenging building process. For a *Game Player* with a self-interested approach to planning, the act of taking part in sessions like these with no outcome in the form of a concrete plan can be quite frustrating to the point that s/he is inclined to see it as a waste of time. For the *Yes Man*, however, the same sessions might be considered very valuable for the fact that more time than usual is spent defining the work which in turn may make it easier for him/her to understand his/her own obligations. A *Gang Pusher*, being focused on getting things done, spending time like this is really of no use as they perceive problems to be solvable as they turn up. Quite typically, this is also what keeps him/her busy during the planning meetings, being regularly interrupted by phone calls to "fix things." Finally, the *Last Planner* knows that planning as such is not only about issuing directives; it is as much about human and social dynamics. For complex work, multiple factors might intervene, which can be hard to even predict and put down in a schedule. Then, securing consensus among the involved parties for a solution or a tactic can be more appropriate than trying to nail the whole thing in one plan.

CONCLUSIONS

In this paper, we introduced a typology of 4 different behavioral patterns of Last Planners: the *Game Player*, *Yes Man*, *Gang Pusher*, and *Last Planner*. Each type addresses a certain pattern of behavior that might be found in a team of Last Planners on a project, depending on their apparent level of commitment to the planning process and the level of conceptual understanding of the LPS. What the typology explains, maybe more than anything else, is that there is not just one way to approach planning; people are driven by different motivations and exhibit various patterns of behavior.

The ideal situation is to have a project team of Last Planners behaving as *Last Planners*. All too often, we suspect, an implementation process starts by describing this ideal, future state. This is not to say that one should not strive to reach it, however, the reality at any time on a project may be far from it. Thus, ongoing training is needed to achieve greater in-depth use of the LPS depends on the patterns of behavior exhibited by Last Planners throughout the project. Furthermore, it is important to have in mind, when designing a training program that Last Planners may have good reasons to behave as they do: e.g., if a project suffers from a poor supply of drawings that creates work flow uncertainty, then behaving like a *Game Player* or a *Gang Pusher* can be about trying to make-do on a project that is not going well. For the very same reason, the types described in this paper should not be used to stereotype persons, as they address apparent behavioral patterns (rather than innate personal characteristics) that might very well be "symptoms" of a project run badly.

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TRAINATHON LEAN SIMULATION GAME: DETERMINING PERCEPTIONS OF THE VALUE OF TRAINING AMONG CONSTRUCTION STAKEHOLDERS

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ABSTRACT

This research was prompted in part in response to a recent study by the Associated General Contractors (AGC) that there is a shortage of trained, skilled labor in the construction industry and this shortage is increasing. The QUESTION this paper seeks to address is: Why aren’t construction stakeholders perceiving the value of training and development of employees? The PURPOSE of the research is to develop and test a simulation that will help identify the way building stakeholders view the impact of employee training on their long and short-term profit margins. The RESEARCH METHOD used was two phased: (a) a preliminary phase involving the iterative development and testing of a 50-minute table-top simulation using readily available materials; (b) a mature phase where results from a “perfected” version of the game were subjected to statistical analysis from a larger participant pool. The trials each team went through financially at each round were recorded and results recorded via cash flow diagrams. FINDINGS suggest that players tend to underestimate the importance of upfront training and its impact on long-term cash flows. LIMITATIONS of this research include a restricted sample size that was tested during this phase. IMPLICATIONS and VALUE for this work are potentially larger than that of pure research—i.e. as an opportunity to serve as a change agent as well since a number of respondents suggested that the simulation made them think about the long-term value of training, illustrating the first principle of *The Toyota Way*. This dual-role for simulations fits easily within the culture of lean construction which historically has used simulations both to understand impacts of certain types of stakeholder behavior as well as transfer comprehension of specific lean principles.

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KEYWORDS

Lean simulation; training; long-term value; skilled-labor shortage.

INTRODUCTION

This research was prompted in part in response to a recent study by the Associated General Contractors (AGC) highlighting a growing shortage of skilled labor in the construction industry. According to Loosemore et al. (2003) and Wild (2002) the construction industry exhibits a particularly dynamic and complex industrial environment. This creates a challenging situation for training and development (Loosemore et al. 2003; Raiden and Dainty 2006). The fast changing competitive environment requires effective development and management of human resources. Project Managers, executives and supervisors play a vital role in creating a positive impact by transferring knowledge to their employees (Jong et al. 1999). Nevertheless, literature about the construction industry indicates inadequate consideration is given to staff training practices (Tabassi et al. 2012).

DEFINING TRAINING

Training emerges from the realms of learning. "Training is an effectively outlined effort that develops knowledge, attitude, abilities and skills through learning experiences, helping people involved (trainees) to attain potent performance in an activity" (Garavan et al.1995; Reid et al. 1992). Training offers incremental adaptability and flexibility for employees and thus becomes essential for an organization to cultivate its proficiency (Tai 2006). Training and development practices must be recognized by companies as a vital means to enhance a company's level of achievement (Huemann 2010; Latagana et al. 2010; Raiden and Dainty 2006). It is critical for every construction organization to develop a learning environment for its employees (Raiden and Dainty 2006).

NEED FOR TRAINING

A survey conducted by the Associated General Contractors of America (AGC) involving more than 1,000 construction firms across the U.S. indicated that 83% of firms currently encounter a challenge finding craft workers (shown in **Figure 1**) and 61% of firms confirmed difficulty filling executive positions. This has increased from 74 % and 53%, respectively, as measured against the prior year (AGC 2014). Finding experienced workers in the industry is a primary concern for A/E (architecture and engineering) firms, GCs (general contractors) and specialty trade contractors. The literature on training and development in the construction industry offers a pessimistic view of investment in this area. In the construction industry, employee training and its benefits are undervalued, resulting in a lack of formal training practices (Kuykendall 2007).

RATIONALE FOR INVESTING IN TRAINING

According to a study by the Construction Industry Institute (CII 2007), a return of $3.00 is expected for every $1.30 invested on craft training; The US Department of Labor also confirms a productivity increase of 16% on ongoing trainings. Even though the return on investment is high, contractors remain averse to allocating time and money for worker training (Kuykendall 2007). Also according to research conducted by the Construction Industry Institute (2007), trained workers appear to have lower turnover and absenteeism rates than workers without training. The study reported that training appeared to be responsible for a 23%-27% decrease in rework and injuries. Moreover, a substantial decrease in absenteeism and turnover rates appears to lead to a 10% increase in productivity.

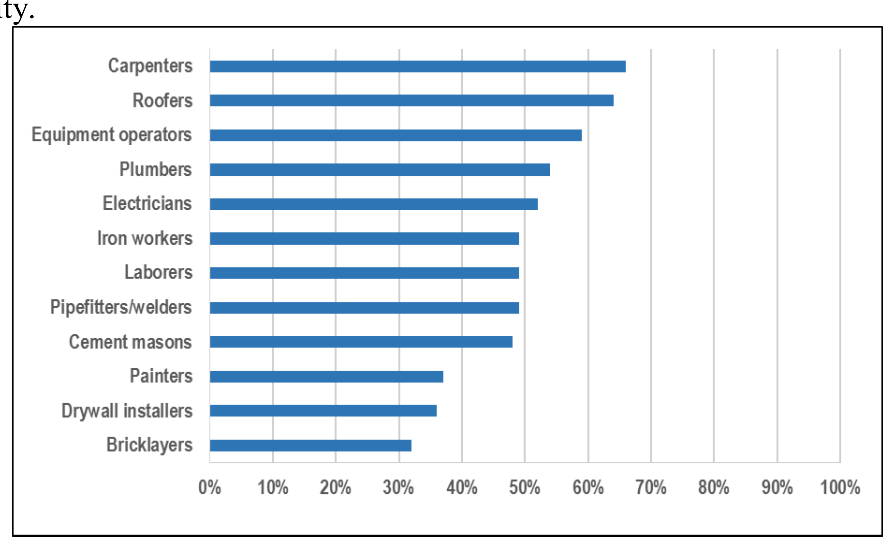

Figure 4: Craft workers shortage according to the survey conducted by AGC Adapted from Skilled labor Shortage (AGC 2014)

IMPORTANCE OF ON THE JOB TRAINING

An expansion of the construction industry during the last decade has led to the need for a workforce that is equipped with technical and managerial skills. McGraw-Hill Construction (2012) conducted a study on the use and importance of training by the A/E firms, General Contractors (GC) and specialty trade contractors. General contractors and specialty trade contractors rank on-the-job training as their top-most priority. Almost 64% of A/E firms and 67% of GC's indicated that on-the-job training is as important as a college education. A high score for on-the-job training reflects the importance the industry places on the value of practical, real-world experience. Also according to the McGraw-Hill (2012) report, the skilled labor shortage can be addressed by continuous education and training programs for workers to help sharpen their skills and update their familiarity with forms of innovative technology. According to Karen Holloway, Project Management Institute's Lead Instructional Designer, training boosts learning retention because when everyday work is combined with learning, the mind starts associating sights and sounds of the environment with skills under development (Gopanapalli 2014). Erina et al. (2015) argues there is a need to offer training to improve productivity on construction projects. Trainings should be designed to increase construction site productivity.

LEAN GAMES AND ITS IMPACT

The Lean Construction Institute (LCI) uses simulations to teach lean concepts (Rybkowski et al. 2012; Verma 2003). Simulations have played a crucial role in Lean construction (LC) by successfully demonstrating the practical implications of lean principles. According to Canizares (1997) and Walters et al. (1997), the simulated game environment helps participants to comprehend real world scenarios, enabling students to understand more easily lean concepts and their application to construction industry processes. For example, simulations such as the Lego® Airplane Game (Visionary Products 2008) and Parade of Trades simulation (Tommelein and Howell 1999) are regularly played by the Lean Construction community to educate participants about the impacts of pull, batching, and variability.

This simulation is an effort to help the participants understand how a company's decisions, if based on a long-term philosophy with respect to employee development, might prove costly initially but can benefit the company in the long-term by increasing its productivity. The simulation is also an opportunity for the authors to better understand the behavior of players confronted with weighing the short-term cost demands of upfront training against long-term benefits associated with that training.

RESEARCH METHOD

The purpose of this research is to develop and test a simulation that will help identify the way building stakeholders view the impact of employee training on their long and short-term profit margins. Trainathon lean simulation is a "perfected" version of a preliminary simulation concept that was developed in a Lean Construction class at Texas A&M University during the spring semester of 2015. Those involved in the development of the simulation's preliminary version included Krupal Bhatt, Yamini Bhatt, Sai Anirudh Challa, Rajath Padmaraj, Sachin Singh, Abhishek Shete, and Geethika Yarlagadda. The simulation was administered to graduate and undergraduate students in the Department of Construction Science between December 4, 2015 and February 10, 2016. The simulation was iteratively modified during successive trials. A total of 201 students was selected to participate in testing the mature version of the simulation.

To play the simulation, the following items were needed:

- Paper with 3 x 3 puzzle template
- Tokens with numbers written on them for each round
- Financial score cards (to record the cumulative cash flows and time taken in each round by the Project Manager; one per team)
- Pencil or Pen
- Stop watch
- Paper Tutorial (training to help solve the puzzle; one for each team)

The facilitator asked participants to form teams consisting of one Project Manager (PM) and two employees. The facilitator announced the objective of the game was to complete a given mathematical puzzle in the least possible time. The puzzle consisted of a 9 square (3 x 3) grid where each horizontal and vertical row must tally to a specified sum using individually pre-numbered wooden tokens (although paper tokens are also acceptable). The maximum permitted time in play per round was two minutes. The simulation was conducted in three rounds. The teams were able to earn profits and increase their net worth by solving their puzzles on time. The facilitator consulted a stopwatch to restrict the time limit to two minutes. At the beginning of each round the Project Managers were offered the opportunity to train their teams. The training was a tutorial that revealed how to solve the puzzle. The Project Managers were given financial score cards; they were responsible for requesting training for their employees and completing the financial score cards. For each successful attempt, the teams earned $1000. The initial amount given to every team at the start of Round 1 was $2000. Training cost $1000 per team and represented a onetime cost. The cost of labor per team per round was $500. The profit for each successful attempt was $1000. During each round, the tokens and sums were refreshed, but the mathematical strategy was the same and could be learned if teams had opted for training. The trials and tribulations each team went through financially during each round was recorded by the Project Manager. An assumption made for this study that undergraduate and graduate students in the Department of Construction Science at the university accurately represent future stakeholders of the construction industry. Their mindset is assumed to reflect the mindset of the industry.

RESULTS

The data collected for Trainathon lean simulation were evaluated using the financial score cards completed by each team. The financial score cards provided information about the cost and the time taken in each round to finish the project. Based on the financial trials of each team per round and the tendency of participants to request training upfront, 14 different scenarios were observed. **Table 1** shows the 14 observed scenarios. These were further evaluated using cash flow diagrams and bar graphs. The acronyms appearing in **Table 1** stand for the following: **NT** (No Training); **T** (Training); **NS** (No Success); and **S** (Success). Additional factors such as gender ratios, age, and participant experience were also recorded. The numbers of teams opting for each scenario are tabulated in **Table 2**.

Table 1: Explaining the 14 case scenario generated through the Lean simulation

	Case No.	Round 1 (R1)	Round 2 (R2)	Round 3 (R3)
	Case 1	T:S	S	S
	Case 2	T:NS	NS	S
	Case 3	T:NS	S	S
	Case 4	T:NS	S	NS
→	Case 5	T:NS	NS	NS
→	Case 6	NT: NS	T: S	S
	Case 7	NT: S	NT: S	NT:NS
	Case 8	NT: NS	NT: NS	NT: NS
→	Case 9	NT: S	NT: NS	NT: NS
	Case 10	NT: NS	NT: NS	T: S
	Case 11	NT: NS	NT: NS	NT: S
→	Case 12	NT: S	NT: S	NT: S
	Case 13	NT: NS	NT: S	NT: S
	Case 14	NT: NS	NT: S	NT: NS

Based on the frequency of occurrence, four case scenarios (case 5, case 6, case 9 and case 12) were selected for further focused analysis. From **Table 2** it can be seen the four selected scenarios constituted a total of 46.25% of all scenarios. The results for the simulation were analyzed using cash flow diagrams (**Figure 2**). While field testing the simulation, three demonstration rounds were conducted. The data has been extrapolated for the cash flow analysis.

One observation made by studying the cash flow diagram is that teams that opted for training after R1 (Round 1) broke even in R3 (Round 3) after which they started making profits, visible by a uniform positive gradient. Teams that delayed the decision to train, suffered losses and recouped from the loss only after Round 5; their profit margins decreased by $1000 due to their delay in adopting training. **Figure 2** represents the case scenarios discussed below:

- **Case 5: *"The Worst case scenario"* (1.49 % of all scenarios)**: In this scenario, the teams invested in training and were still unsuccessful in completing the project. These teams suffered a negative cash flow which is represented by the uniform downward gradient in **Figure 2**. It was observed that the training concepts were either not well understood by the teams or they failed to collaborate.
- **Case 6: *"The pragmatic case scenario"* (34.32 % of all scenarios)**: The majority of participants followed this decision-making scenario. In this scenario, after an unsuccessful attempt in R1 (Round 1), the teams realized that they needed to undergo training. The PM requested to train the team. This led to a loss of $500 (seen as a dip in **Figure 2**). However, this also led to positive cash flows and an increase in their profit margins during subsequent rounds. By the end of the rounds the teams ended up with $5000. This is $1000 less than the ideal case scenario. **Case 9: *"No Training, no success"* (5.97 % of all scenarios)**: Three observations could be made about teams that found themselves in this scenario:
  a) PMs were ignorant about training and the profits they could earn;
  b) PMs thought that the employees could complete the project without any training; and
  c) They were willing to go through repetitive cycles of trial and error.

In this scenario, teams suffered a negative cash flow which is apparent by the uniform downward gradient in **Figure 2**. In this case, the PM chose not to train the employees even though they were continuously unsuccessful in their attempts. In some teams, the employees asked for training but the PM refused.

- **Case 12**: ***"The Ideal case scenario"* (4.47 % of all scenarios):** It was observed that despite the PM never choosing training for these teams, the teams continuously completed their puzzles successfully. In other words, this case required no investment in training by the company. It was observed that the graph was uniformly straight and the team continued to earn until successful project completion. By the end of Round 9, the teams earned $6000, as shown in **Figure 2**. This case is an outlier as only 4% teams fell under this category. This scenario is an unexpected outcome so should be explored with caution when making decisions about whether or not to train employees in actual practice. It is also worth mentioning that although these teams succeeded without training, training would have likely reduced their time to completion.

One additional case is worth mentioning:

- **Case 10: *"Training in the second round"* (5.97% of all scenarios):** These teams opted for training after two unsuccessful attempts. Their double failure, declining cash flow and surrounding competition led the PM to ask for training for their teams. The teams in the end earned $4000, as shown in **Figure 2**, which was $2000 less than the ideal case scenario.

Table 2: The number of teams opting for each scenario

	Experiment #	1	2	3	4	5	6	7	Totals
	No. of teams	N = 10	N=11	N= 11	N=10	N=6	N= 8	N=11	N=67
	Total participants	31	33	36	31	22	26	22	201
	Cases	% Teams in each case							
	1	20% *(N=2)*	9% *(N=1)*	8.3% *(N=3)*	10% *(N=1)*			9.09% *(N=2)*	13.43%
	2	10% *(N=1)*	18.5% *(N=2)*	2.7% *(N=1)*					5.97%
	3					4.54% *(N=1)*			1.49%
	4				10% *(N=1)*				1.49%
→	5		9% *(N=1)*						1.49%
→	6	30% *(N=3)*	27.5% *(N=3)*	13.8% *(N=5)*	30% *(N=3)*	13.63% *(N=3)*	11.53% *(N=3)*	13.63% *(N=3)*	34.32%
	7						7.69% *(N=2)*	9.09 *(N=2)*	5.97%
	8	10% *(N=1)*			10% *(N=1)*	4.54% *(N=1)*	3.84% *(N=1)*	4.54% *(N=1)*	7.46%
→	9		9% *(N=1)*		10% *(N=1)*	4.54% *(N=1)*		4.54% *(N=1)*	5.97%
	10		9% *(N=1)*	2.7% *(N=1)*	10% *(N=1)*		3.84% *(N=1)*		5.97%
	11	10% *(N=1)*						4.54% *(N=1)*	2.98%
→	12		9% *(N=1)*		10% *(N=1)*			4.54% *(N=1)*	4.47%
	13	20% *(N=2)*	9% *(N=1)*						4.47%
	14			2.7% *(N=1)*	10% *(N=1)*		3.84% *(N=1)*		4.47%

The reasons stated by the teams for not asking for training were:

a) The PM estimated the project was easy and was not willing to pay for training. In certain cases, this attitude led to discord between the PM and the team.

b) The team members were challenged by the puzzle and wanted to try it on their own.

c) Few teams focused on the upfront cost of training and ignored potential long term profits.

The ones who took training in R1 were the most profitable teams in the end. The majority of people who took training after R2 were almost $2000 behind the ideal case scenario.

The ones with no training experienced a uniform downfall in gradient. **Table 3** illustrates the substantial difference in time taken by teams during each round. The teams who decided to train in R1 finished faster than the ones who took training in R3. The 95th percentile for the team taking training in R1 was 1.04 min., which is 0.23 seconds less than the team taking training in R3. This clearly indicates an increase in productivity for a trained employee. In other words, data from the Trainathon lean simulation trials suggests there is likely a substantial difference in the productivity of employees who take training in comparison to employees without training.

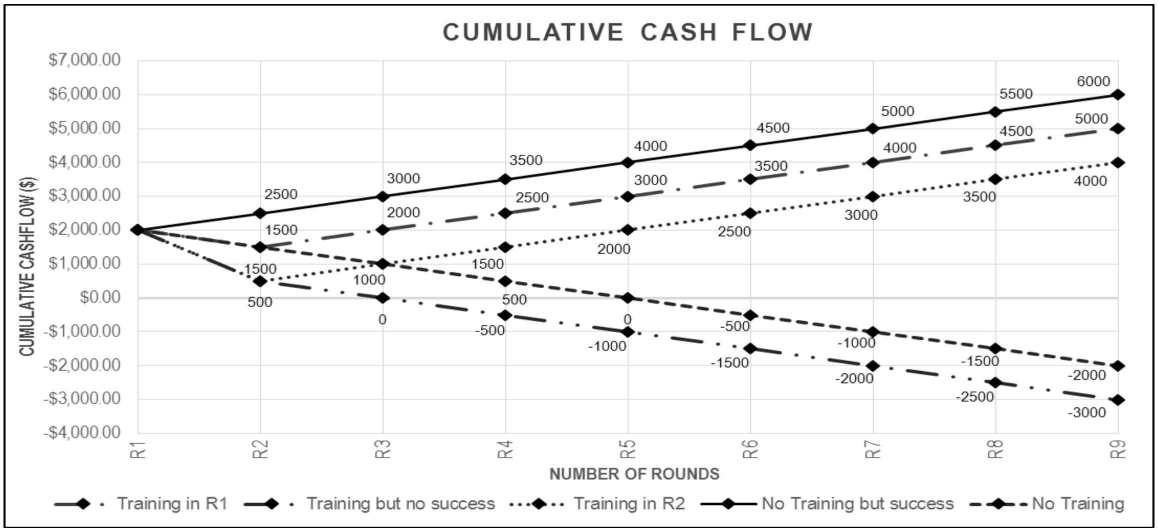

Figure 5: Displays the cash flow of each team at every round.

Table 3: The time taken on percentile basis

	Training in R1	Training in R2	Training in R3
P50	0.41	0.88	1.13
P90	1.05	1.15	1.47
P95	1.04	1.17	1.27

P_{50} stands for time taken by the 50th percentile of the participants;
P_{90} stands for time taken by the 90th percentile of the participants; and
P_{95} stands for time taken by the 95th percentile of the participants.

DISCUSSION

During the live playing of Trainathon several behavioral characteristics of participants emerged and these characteristics could be classified into "scenarios." Two are of special interest when applied to practice:

"The Ideal case scenario" This scenario was played out by participants who believed in themselves and felt convinced they could complete the project without training. Some teams did, in fact, manage to complete the project successfully without training. This population represented only 4% of the total sample size. This situation is found when employers seek the best graduates from premier educational institutions or among experienced professionals who do not require additional training.

"The Worst case scenario": These participants were forced to bear the decision made by their team leader to never purchase training. Team members in this scenario expressed feeling demotivated as they were never successful. Participants of teams in this scenario became increasingly demoralized as their competitors began performing with increased efficiency. For teams that found themselves in this scenario, there was a visible friction in the dynamics between the project managers and the team members. This mirrors actual scenarios where poor team dynamics can lead to productivity losses (Santorella 2011).

Overall feedback from the participants suggested, *"The simulation was challenging"*. It made them think about the "*long-term value of training."* Participants felt demotivated in cases where the PM did not train them. One respondent who did not receive training wrote, *"It was infuriating when the PM denied training as the people who trained finished their project faster while we struggled."* The simulation reinforces the notion that teams in the construction industry are varied and each team member exhibits personal strengths and weaknesses. Project Managers would do well to identify the abilities of each team member and consider offering training to supply specific skillsets that each individual requires for the task at hand.

CONCLUSION

As Trainathon teams postponed decisions to train, they lost $1000 repeatedly and this loss over time was recorded in cash flow diagrams. In the "real world," postponing a decision to train employees who do not already possess a critical skill can lead to a loss of millions of dollars on a construction project. Additionally, "trained" teams took 20% less time to complete a round, on average, than non-trained teams. It was observed that the majority of teams understood the concept of investing in training only after they failed once**.** After playing Trainathon, participants indicated they understood the lean principle associated with the simulation. The intent of this research was to develop and test a simulation to effectively highlight the value of training and its associated long-term benefits, thus helping to motivate increased productivity in the construction industry. According to Rybkowski et al. (2008), lean games create a "eureka moment" that enlightens participants about the effectiveness of a concept in a way that traditional presentations sometimes fail to do; This simulation was developed to create such a moment for stakeholders. But it was also developed to help researchers better understand the behavior of individuals confronted with options for upfront training. Student participants in this study were potential stakeholders in the construction industry and it would be worthwhile for a future longitudinal research project to investigate whether their understanding endures or is transformed as the student participants pursue careers following graduation.

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COLLABORATION THROUGH SHARED UNDERSTANDING IN EARLY DESIGN STAGE

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ABSTRACT

The complexity of the collaborative design process is related to the nature of the product and the processes, and also involves the social interplay that ultimately generates design. This fundamentally, affects the way people work, in the purposeful action of designing together. Low levels of collaboration are identified especially at early design stages, where the collective design creation is hindered by the lack of ability of the team to build shared understanding, embracing a multitude of expertise in the task. In this context, the research focused on how the concept of shared understanding can potentially support better collaboration at early design stages. This is based on a deeper understanding of collaborative design as a dynamic system of social interplay, in which the process to build shared understanding for concerted actions can be described as a system that combines mediated coupling and coordinated perception, in a context where division of labour exist. Based on a literature review, lean approaches that claim to support shared understanding between project participants are investigated. This paper contributes in discussing how shared understanding, as a process, can be the basis of the collaborative act, and how components of this process can be addressed through lean approaches.

KEYWORDS

Early design, Collaboration, Shared Understanding, Social Dynamic, Complexity

INTRODUCTION

The nature of multidisciplinary early design stage is challenging. Recent studies shown that early design usually present poor integration in the decision-making process between design disciplines (Adamu et al., 2015; Pikas et al., 2015). At this stage, decisions will have significant influence on cost, performance, reliability, safety and environmental impact of a product, accounting for more than ¾ of the final product costs (Hsu & Liu, 2000). This decision-making process involves large amounts of information, which are usually considered imprecise and incomplete (Hsu & Liu, 2000). In this sense, this dynamic nature of information will generally produce a sense of disorganised behaviour within a design

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team (Macmillan et al., 2001). Hence, design teams will spend a lot effort to coordinate individual processes of information processing, involving reasoning and thoughts, in order to reach shared understanding of the problem, mainly managing conflicts based on different interpretations of ideas, concepts and representations (Cross & Cross 1996).

This is particularly challenging for the management of teamwork in design, where an opportunistic exploration on the design space initiated by one member not necessarily is relevant to other members (Cross & Cross, 1996). According to these authors, those tacit iterations are not easy to track, and affect the understanding of design reasoning and decision-making in a group context. More importantly, there is a lack of knowledge concerning the concept of shared understanding in collaborative design (Van de Bossche, 2011). With no underlying theory of shared understanding yet developed, this topic have been superficially addressed on studies on social mind in sociology, and team cognition in psychology, which are based on the concept of understanding.

The discussion on shared understanding must be considered in the realm of social interplay in collaborative design. Specifically in construction the social system is complex, but it is often an overlooked part of the project setting (Bertelsen, 2003). The wicked nature of design has been misinterpreted due to lack of ability of the participants to articulate the holistic nature of the social interplay (Bertelsen, 2003), raising questions as how much the process of shared understanding affects collaboration in design.

This paper discusses how shared understanding, as a process, is in the basis of the collaborative act, and how some components of this process can potentially be addressed through lean approaches. The study is developed based on a synthesis of the literature, building upon definitions of collaboration and shared understanding in design and construction research. To build a model of shared understanding in collaborative design. The conclusions present main concepts and draw attention to some misconceptions that still hinders the process of shared understanding for collaboration.

COLLABORATION IN DESIGN

Schottle et al. (2014) differentiate collaboration and cooperation in terms of interorganizational relationships in the context of Lean Construction. According to them, cooperative actions do not demand a common vision or mission, resulting in independent organizational structures in the project team, which will depend on a project culture based on control and coordination to solve problems independently. On the other hand, according to the same authors, collaboration is built on a common vision with an organizational structure commonly developed by the team in a new project culture based on trust and transparency.

The level of interaction in a construction project will be influenced by the cultural element and will depend on coordination and communication (Schottle et al., 2014). Defining coordination as the planning or organization of different activities, Schottle et al. (2014) argue that coordination is not a separate relationship in a team. However, the authors introduce a prescriptive idea to coordination, as something that would happen before the action, in this case even the relationship, and it is not something that is intrinsic developed/evolved mutually during the task.

In Schottle et al. (2014), the difference between cooperation and collaboration relies on the level of integration of the participants and the organizational structure, which depends on the cultural continuum involving the development of trust and control. In design research, Kvan (2000) defines that the major difference between collaboration and cooperation is the creative aspect of working together that is related with collaboration. Kvan's (2000) definition is based in a different approach, in which is not important to state the intensity of the relationship based on organizational properties, but to recognize the purpose of the interactions. In this case, the question would be what is the purpose of the collective action?

In design, collaboration relates to the achievement of a holistic creative result (Kvan, 2000). In this sense, it demands a higher sense of joint working, and can be thought as joint problem solving, which means to embrace shared goals with the team working to produce shared solutions (Kvan, 2000, Aksenova et al., 2014). Collaboration involves the decomposition of the task; assigning roles and responsibilities; synthesis of information; and discussion and negotiation of shared representation (Qu & Hansen, 2008). Collaboration is also based on a full commitment to a common mission, enhancing the level of trust and compromising the group to higher level of risk sharing (Kvan, 2000). This commitment must be built in the situation context, in a process, which the authority is determined by the collaborative structure (Kvan, 2000), as an emergent property of the system.

One of the major challenges in collaboration is to develop shared understanding, which implies an overlap of understanding among design participants (Maher et al., 1996). Their particular view of the development of possible solutions as well as their understanding of the design problem must be overlapped by a common understanding of the group in the task about what should be achieved (Maher et al. 1996). However, the occurrence of undocumented design decisions and vague design descriptions, which are usually features of early design stages, can certainly lead to misunderstanding and confusion in a collaborative design environment (Maher et al., 1996).

SHARED UNDERSTANDING AS KEY TO COLLABORATION

In design research, the seminal work of Valkenburg (1998) discussed the importance of shared understanding on collaborative design, indicating that without it, decision-making processes will not be supported by all members and later activities in the design process can be hampered by different views of team members on fundamental topics. Hence, the lack of shared understanding causes unnecessary iterative loops (Valkenburg & Dorst, 1998) that can be correlated to the notion of waste in design.

More recently, Kleinsmann (2006) defined shared understanding as a similarity between individual perceptions on the conceptual content of design and the perceptions of how the systems work and who knows what. A more comprehensive definition is proposed by Smart et al. (2009), defining *shared understanding* as "the ability of multiple agents to exploit common bodies of causal knowledge for the purpose of accomplishing common (shared) goals". These authors also describe it "as the ability of multiple agents to coordinate their behaviours with respect to each other in order to support the realization of common goals or objectives." Seeing understanding as an ability, or "meaning in use" gives strengthen to the viewpoint that understanding is more than knowledge, because it involves reasoned action, thus it is not static, but a dynamic state (Bittner & Leimeister, 2013).

In lean construction, Pasquire (2012) suggest the interoperability between project participants is a form of common understanding. Accordingly, this common held understanding should be managed as flow through the project life cycle. Pasquire (2013) further explores the link between knowledge and understanding in construction, describing the tacit nature of the skills required and the complexity and specificity of the project outcome. Hence, the challenge in knowledge sharing is related to the ambiguity caused by the lack of understanding across the project delivery team.

In this exploration, Pasquire (2013) refers to Simon (1999) work on knowledge ambiguity, and the three characteristics on non-transferable knowledge: tacitness, complexity and specificity. It is interesting how those non-transferable features could be related to the ability of applying knowledge to certain situation. In stating that, the "non-transferable" property of knowledge may indicate a phenomenon of a different nature, cognitively. In this case, arguably the process of understanding.

The problem with the idea of knowledge flow is that it does not consider the evolving and constructive nature of the process of making-sense, which relates to understanding. Furthermore, it does not allow the consideration of the idea of shared understanding as a distributed process, in which individual understandings are complementary and not necessarily the same.

The idea of team cognition would emerge as an adaptive self-organization of teams (Cooke & Gorman, 2006) in the process to build shared understanding. According to these authors, heterogeneous teams setting, present specific and varied roles, with interdependence, which involves three parts: division of labour; mediated coupling; and coordination, as components of a dynamic interaction between agents performing a task. Under this approach, there is an emphasis on team members' interaction in the task to reach consensus on concerted actions (Cooke & Gorman, 2006).

BUILDING THE SHARED UNDERSTANDING PROCESS

Team interaction in a collaborative task allows us to design a model of the process of building shared understanding, which incorporates three main features: *division of labour, coordinated perception* and *mediated coupling* (figure 1).

DIVISION OF LABOUR AND *THE SYMMETRY OF IGNORANCE*

The first feature is a condition for collaboration and relates to the existence of interdependent agents from different specialties (i.e. *division of labour)* involved in the task. This can be correlated to the concept of *symmetry of ignorance* proposed by Rittel (1984) citted on Fischer (2000, 528). Accordingly, when people are engaged in activities, such as collaborative problem solving, they will experience a breakdown (i.e. a piece of lacking knowledge, a misunderstanding about the consequences of some of their assumptions). This condition for collaborative actions is related to the idea of *common ground*, i.e. a set of common values, mutually known facts, and commonly held presumptions, which is the starting point of social interplay, allowing communication between agents from different backgrounds (Koskela, 2015).

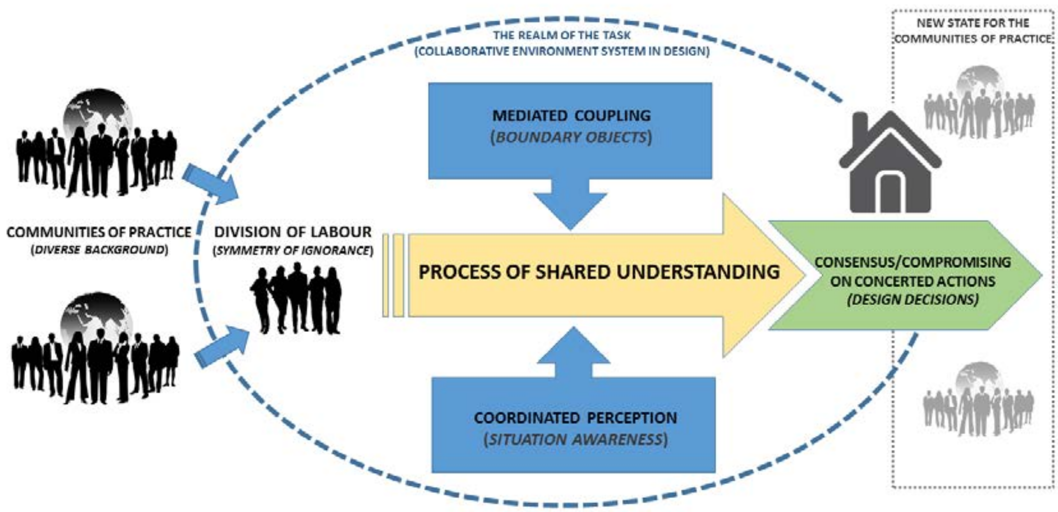

Figure 1: The process of shared understanding in collaborative design.

COORDINATED PERCEPTION AND *SITUATIONAL AWARENESS*

According to Cross & Cross (1996) and Fischer (2000) designers have a limited awareness and understanding of how the work of other designers within the project is relevant to their own design tasks. Therefore, an effective team task depends on the *situational awareness* among team members (Adamu et al, 2015), which is the capacity to perceive and comprehend the characteristics of an environment in a specific set of time and space supporting the realization of predicted futures aligned with a task or project (Endsley, 1995). This is important because it deals with what each worker knows about the understanding and workload of the co-worker, and how is this supported by intercommunication between them (Endsley & Jones, 2001).

MEDIATED COUPLING AND *BOUNDARY OBJECTS*

The process of building shared understanding forces the collision of ideas, and external representations are the means of negotiating shared understanding, in which the objective must be consensus on the meaning of representations (Qu & Hansen, 2008). Accordingly, understanding is achieved through explicit visualizations, comparing high-level overviews of common artefacts. In this sense, the research developed around the concepts of *boundary objects* and *mediating artefacts* (Carlile, 2004) address this component of the collaborative actions. According to Carlile (2004) these shared artefacts and methods provide concrete means of representing different functional interest, consequently facilitating the negotiation and transformation in the collaborative design product.

ANALYSIS AND DISCUSSION

Collaboration is a recurrent topic in Lean Construction, and approaches/methods/tools have been argued to support collaborative practices. In special, we analyse how some of them could be related to shared understanding in supporting multidisciplinary teams in early design stages. Each of them can be further related to the three main features of the proposed process of shared understanding.

COLLECTIVE PLANNING

In the Last Planner System (LPS), the production units are defined by those who will execute the work, which than feed the system that is built to control the workflow through the coordination of interdependencies in a time frame (Ballard, 2000; Spitler, 2014). Those interdependencies are elucidated in the work breakdown structure, which define planning hierarchies, inducing trade specialists to think of their work in relation to the trades adjacent in location and sequence (Spitler, 2014). The creation of a work breakdown structure is an essential early step to any project (Spitler, 2014), because this alignment could represent "shared understanding", in which a systemic view of the "project" systems needs to be collectively built with the team.

The problem is when the team fail to identify the key systems to coordinate (Spitler, 2014). For example, the Collaborative Design Management (CDM) case presented by Fundli and Drevland (2014) which was based on the LPS, the Start-up meeting seems to be key for establishing the relationship between the agents. The action towards connecting design tasks is related to the process of shared understanding, as it deals with the work breakdown structure. However, there is no clear description/explanation on how this is conducted, nor how this is represented in the phase schedule. In design, especially in early/concept design, the problems are ill-defined and demands the generation of a product and a correspondent production system, where there is no way of dissociating planning from doing. This represents incompatibilities for the use of phase scheduling as a collaborative managerial tool for concept design.

In LPS, coordinated actions are achieved through a complex network of requests and promises that are intimately personal (Ballard and Howell, 2003). This seems to represent a fragility of LPS hindering shared understanding in design. In this situation, the parties do not necessarily need to understand each other, in fact it is matter of believe and trust, which can be related to knowing. This is made clear in the phase schedule, where the focus is on describing specific goals (plans) and handoffs between stakeholders to achieve those goals, without necessarily sharing the reasoning process that support those decisions behind the goals. Furthermore, it could be argued that to build interdependencies in a sequential planning creates "knowledge" about the process but not necessarily "understanding". In this case, team members will know the operations sequence, but not necessarily understand why all that procedures were determined, limiting their ability to collaborate in the decision-making.

CO-LOCATION AND BIG ROOM

Collective coordination and mediating actions towards shared understanding seems to benefit from a shared workspace comprising the continuum space-time, where the participants find each other involved in the task and the social dynamic to reach consensus on concerted actions. Fundli and Drevland (2014), refer to the role of ICE-meetings and Big Room in making it easier to get clarification on issues. In the process of shared understanding, this actions towards "clarification" are key, and they seem to emerge in situations of collective problem solving (i.e. ICE-meetings), and are enhanced by the co-location factor (i.e. Big Room). Alhava et al. (2015) identified the increased task parallelism, as a benefit from co-location of participants, reducing the latency during design and reducing redesign.

SET-BASED DESIGN

Set-based Design starts with mapping the design spaces to define what decisions need to be made and establishing the available design options (Parrish et al., 2008). The set of alternatives or range of values are identified in this process (Ballard, 2000). According to Ballard (2000), this map of design space will define boundaries, in which all design contributors are free to develop their work. What Ballard (2000) describes seems to be more related to what Kvan (200) means with cooperation. Moreover, using the term "identify", indicates an effort for recognition (analysis) instead of creation (synthesis) in the action of mapping the design space. Considering the uniqueness of the project situation and the actions towards shared understanding it would be necessary to align it to a synthesis approach. The problem is that, it is not clear how the team should manage this action.

Each project participant must understand what is asked, articulating the levels of detail and accuracy required to define alternatives, taking into account the values and constraints that emerge from each member (Parrish et al., 2008). Those breakdown in communication highlights how important is to properly define the set in mapping the design space to articulate the input from the team (Parrish et al., 2008), which can be related to the process of *mediated coupling* presented earlier.

In Set-based design, Ballard (2000) also suggest integrating by intersection, which means to look for solutions within the intersections of sets, where the interface dimensions, for example, need to be based on shared values. The actions to work on the intersections, which means between boundaries, is a fundamental one in collaboration (i.e. "boundary objects"). At this point, is crucial to be able to engage in the Mediated Coupling process, in which the agents develop a combined representation to support negotiation and shared understanding.

Analysing the examples presented in Parrish et al. (2008), the different backgrounds of participants may affect some basic presumptions made on defining and working on the nature of abstract concepts in design, such as "*skin weight*", which consequently affects the understanding of the levels of detail and accuracy required by the other party in that design phase. In this situation, the emergent behaviour observed was that the affected party asked for clarification, in which the interdependent factors for decision-making were collectively understood through a breakdown, which can be related to the discussion on the *symmetry of ignorance.*

CHOOSING BY ADVANTAGES

Choosing By Advantages is a decision-making system that considers advantages of alternatives and supports comparisons based on these advantages (Suhr, 1999 citted in Parrish & Tommelein, 2009, 509). In comparing alternatives, participants will establish factors, which are dependent on their ability to discern unique advantages of the alternatives (Parrish & Tommelein, 2009). Factors are determined by a list of attributes, which must reflect facts wherever possible, postponing value judgment, making the process more transparent and defensible (Parrish & Tommelein, 2009). In CBA, arguments are built upon data that is relevant to a particular decision, providing stronger support and less ambiguity (Arroyo et al., 2014). This is an important feature of CBA, but it needs to consider the nature of knowledge and understanding. Providing the data/information that can be based in some knowledge structure, does not necessarily guarantee understanding. Since, understanding will be related to actions of synthesis, as an ability to make a proper decision. In this case, the use of logical reasoning, to describe and summarize the advantages of alternatives (Arroyo et al., 2014), may be examples of the use of causal knowledge and could be related to actions towards shared understanding.

At certain point, the group need to set the importance scale, defining the paramount advantage and assigning a degree of importance to advantages based on the multiple perspectives of the participants (Parrish & Tommelein, 2009). This could indicates a self-organized process of the team to support the coordinated perception of the project participants towards shared understanding on design decisions.

CONCLUSION

To better understand collaboration in design, there is a need to improve the theoretical foundations of shared understanding, which means to understand the dynamics of the social interplay to achieve consensus in concerted actions. We assume the definition of shared understanding as an ability to be collectively developed, contextually, in the realm of the project, which will be under the influence of many aspects of social interaction emerging to support team cognition (i.e., division of labour, coordinated perception and mediated coupling). More specifically, the process will involve two parallel abilities: one related to collective action for sense-making; and the second related to the collective coordination of interdependent perceptions between team members.

There seems to exist a problem of an epistemological nature, in which "knowledge" is considered as transferable. In this case, the general use of the term "ambiguity" is based on an idea of "sharing knowledge" and suggest an attempt to reach "common understanding". This interpretation supports the idea of a unique organisational knowledge (as a "thing"), which exists outside individuals mind. However, this is contrasting with the nature of project situations and consequent actions, as it was addressed in the paper (i.e. specific, complex and tacticness). Since, the need to share understanding is based on a situation of working together, a proposed solution to the paradox demands to rethink the nature of knowledge, in alignment with the idea of social construction of "knowledge", as a collective cognitive achievement, that cannot be dissociated from the situated action. In that sense, it can be argued that knowledge does not exist (or more precisely, could not be measured) prior or without the ability to articulate it as an action to understand as specific situation.

A preliminary analysis shows that Set-based Design, Choosing By Advantages and Co-location have the potential to address parts of this process engaging project participants in situations in which they need to build shared understanding. However, it is still necessary to investigate how this process happens in depth and how management strategies could be adopted to improve collaboration through higher shared understanding in early design stages.

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CHILEAN CONSTRUCTION INDUSTRY: WORKERS' COMPETENCIES TO SUSTAIN LEAN IMPLEMENTATIONS

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ABSTRACT

Lean implementations, especially Last Planner System - LPS, are facing various barriers along time losing opportunities to visualize its complete impact. The previous situation could be associated with lacking a more holistic approach; companies commonly deployed Lean tools from an operational point of view, without a clear vision of the future in complementation with strategic objectives. In a group of seven Chilean construction companies doing research in collaboration with the Production Management Centre of the Catholic University of Chile we observed these conducts. Research activities included four workshops with General Managers and Human Resources Departments, and semi structured interviews with some key positions. The present research's results provide competencies identification and definition for four key positions: Project Manager, Building Manager, Site manager and Technical Office, which will be part of a Competencies Dictionary. This instrument will work as a foundation for a training plan's development that companies will use as a backing of Lean tools' sustainability over time, especially Last Planner

INTRODUCTION

Based on Toyota's production system, Lean at construction sector seeks to make processes more efficient, design production systems that minimize resources losses, and face the issue of stagnation and low productivity in this industry. In Chile and the world, authors have identified that Lean implementations, LPS mainly, over time are facing barriers (Ballard and Kim, 2007; Hamzeh, 2012), slowing down its progress and provoking a setback to traditional practices. A possible reason is that companies implement Lean tools from an operational point of view, lacking support and without a clear vision of future

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aligned with their strategic objectives. In short, they do not consider a holistic perspective in the implementation of the new management's approach (Barros and Alves, 2007). The previous adds to common problems such as lack of knowledge (Sarhan and Fox, 2013), lack of training (Brady et al., 2009; Cerveró-Romero et al., 2013; Porwal et al., 2010), educational levels (Jara et al., 2009; Mossman, 2009) and the organization's lack of strategic maturity (Chesworth et al., 2010). A group of Chilean construction companies belonging to the Collaborative Group "Building Excellence" – GEPUC participated in a research, which focus was Lean practices' sustainment over time, particularly LPS, which was the common tool to all of them (Salvatierra et al., 2015). Results showed that although most managers considered Lean philosophy as central to the development of companies, the employees' skills have not been adjusted to this new thinking up to this day; also, there is no continuous training. Therefore, stage two of the research and this study shows it has as objective describe competencies for Lean tools' sustainability over time. For this purpose, we collected social competencies to design a dictionary for key positions: Project manager, Building Manager, Site Manager and Chief Technical Officer to be used by companies' Human Resources departments. Intending to visualize the associated competencies to the positions, we will take as an example the competency of planning; being this one to all companies a common activity. Furthermore, this competency highlights, as previously mentioned, that LPS is a common tool to the companies that participate in this study.

COMPETENCIES

WHAT ARE COMPETENCIES?

There is a varied literature about this notion yet it is difficult to define the concept since there is no unique definition (Serpell and Ferrada, 2011); this can be attributed, among many causes, to the models diversity and theoretical approximations on this matter (Pucheu, 2012). Based on recent meta-analysis, it is possible to say that a competency is a series of behaviors that are key to the achievement of specific performances or results (Bartram, 2002; cited in Bartram, 2005). Most definitions agree that these are behaviors implicating a conceptual or theoretical (to know) component, a procedural component (know to do), and an attitudinal or motivational component (know to be) (Optimal Education, s.f). Competencies are divided in two categories: of "threshold" and "distinctive", in accordance to the job's predicted performance criterion. *Threshold competences* are the essential characteristics (knowledge or basic skills) that someone needs in a job to be minimally effective; whereas *distinctive competences* refers to those skills that distinguish a person over others due to a superior performance, in contrast to the average (Spencer and Spencer, 1993).

HOW TO USE THEM?

Competencies' notion allows managing under a common language for all Human Resources systems, so its use allows managing in several ways a specific company's human capital. This notion enables an integration of diverse activities in People's Management matter (selection, training, others), and in turn, an integration of the department itself with the company's strategy, corporate values and business key processes (Soderquist et al., 2010). In other words, management by competencies allows to aligned Human Resources' practices with business strategy. We can use competencies in different contexts (for instance compensations) but for the present investigation's purpose, we will describe them to be used in the following contexts: Position profile settings, recruitment and selection, training and performance management, and career development. To sum up, it is possible to note that:

Position profile settings: the position profile is a description that includes the main functions and tasks of a specific position, plus the key competencies to perform properly (Rodriguez et al., 2002). Hence, the competencies dictionary enables us to update and perform settings in the position profiles selected and analyzed.

Recruitment and selection: management by competencies offers a way to evaluate a person's potential performance in a much complete manner than mere credentials revision (Rodriguez et al., 2002). In that sense, this study's competencies dictionary could serve as an initial step for selection tests production, such as the generation of assessment centers or individual and groups interviews.

Evaluation and performance management: This includes how it is measure employee performance, as well the necessary tools to increase it (Muchinsky, 2002). We can use the competencies dictionary to construct a questionnaire that permits evaluating and managing performance. Therefore, it is necessary to know what to do with high performance workers in terms of retention, and in low performances to offer opportunities to supply the areas for improvement.

Training people: comprises both workers' skills identification and strategies' formation necessary to developed these in accordance to the position requirements (Muchinsky, 2002). To be able to perform training plans that can be strategic with the business, it is necessary to establish the critical skills for the different positions. (Salas et al., 2012). In this way, the competencies dictionary allows establishing critical skills for a particular position, identifying who needs training based on pre-established levels.

Career development: It is a process where Human Resources' Management reaches a balance between the workers' growth needs and the company's needs. This is accomplished by establishing positions families and identifying the requested competencies among the different positions (Rodriguez et al., 2002) and the gaps between one position and other, recognizing necessary measures to supply the gaps in case of promotions. Therefore, this study designed' competencies dictionary allows to observe similarities and differences at skills levels among the studied positions being able to establish gaps in case of possible promotions.

SAMPLE AND METHODOLOGY

The sampling included seven companies of construction industry, from areas such as building extension, building height, industrial construction and mining operations – that currently are working in Lean tools implementation, mostly LPS. The total sample comprehends 26 professionals corresponding to the positions of Project Manager, Site

Manager and Chief Technical Officer. For a comprehensible description of the developed activities in this research, Figure 1 shows graphically the complete study process.

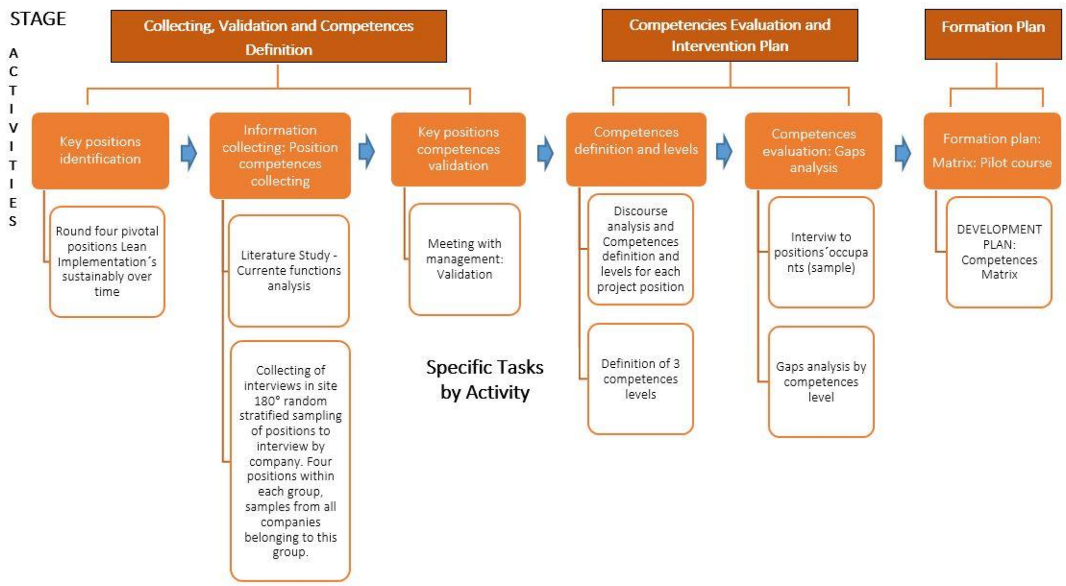

Figure 1: complete study process

Some methodological considerations of competencies mapping

At the start of the research, we considered relevant to analyze competencies by grouping the participating companies according to field and size, assuming meaningful differences among them. From this division, it was conducted a stratified random sampling of the company's positions to be interviewed. For this, we interviewed four positions within each group with samples from all the companies in that group, differentiating it by functions and required responsibilities for the position by the organizations. In these interviews, it was included the required competencies' perception by the superiors for the position's occupant, peers and subordinates. After interviews and bibliographic analysis, we held a management meeting with each company, with participation of Human Resources' members and projects participants and, in some cases general managements. This meeting aimed at sharing preliminary outcomes of competencies associated to each position, seeking to validate and amplify or include competencies. The collected information in interviews and the management meetings help to decide that even though companies belonged to different areas (Construction, Engineering, and Installation) and were of diverse size, there were no differences in the described competencies. Because of this, the research team made the decision of considering competencies by positions and not by type of organizations. From this point, we obtained the desired behaviors, definition and levels of each competency, searching a common language.

Stage 1: Collecting, validation and competencies definition:

We conducted a total of four round-tables or workshops with objectives, participants, contents and results as detailed below:

Round-table 1: Objective: Analyze the project participants companies' organizational mission and their alignment with Lean Management. **Participants:** General managements and the participating companies' Human Resources area. **Contents:** Mission analysis and organizations strategies and their improvement opportunities, discussion on the importance of strategic alignment to achieve a successful Lean management implementation**. Results:** Collaborative group's mission establishment, with the purpose to understand how to work in each company's missions**.**

Round-table 2: Objective: Alignment of the research objectives with competencies. **Participants:** Projects managements and/or Human resources and projects managers. **Contents**: Key position determination for competencies implementation. **Results:** a competencies collection for key positions.

Round-table 3: Objective: Review progress of competencies by position. **Participants:** Projects managements and/or Human resources and projects managers. **Contents:** First revision of competencies dictionary by Company. **Results:** Improvement proposals in the competencies dictionary.

Round-table 4: Objective: Improvements in the competencies dictionary, conceptual revision between competencies and performance. **Participants:** Projects managements and/or Human resources and projects managers. **Contents:** Competencies dictionary revision, conceptual analysis between competencies and performance. **Results:** Definition of competencies importance, improvement in the competencies dictionary.

Stage 2: Competencies evaluation and Intervention plan

To evaluate competencies each company was requested the selection of a project that met with two selection criteria (1) at least 3 months of implementation since its start and 3 months before its conclusion and (2) that the selected professionals in position had at least one-year of experience. We designed a semi-structured interview for each competency oriented to the four positions. From the results, two pilot workshops were designed with the aim of testing development techniques for a posterior formation plan's creation. To evaluate both workshops effectiveness, Kirpatrick model was used (1994; cited in Jiménez & Barchino, 2011), two levels specifically, namely, reaction level one, through a satisfaction poll and learning level 2, through ex ante and ex post polls.

Stage 3: Formation plan

Once performed the pilot workshops, it was designed a Formation plan in accordance with the competencies dictionary, this with the purpose of diminishing the detected gaps by level. We will present results of Stage 3 in a future paper.

RESULTS: COMPETENCIES DICTIONARY

TRANSVERSAL COMPETENCIES

For the purpose of this study, we understand transversal competencies as those valid to all the considered positions, listing, definition and desirable behaviors that are included in Table 1:

Table 1: Transversal competencies definition and desirable behaviors

Competencies	Definition	Desired behaviors
Quality orientation/ continue improvement (Kaizen)	Analyze processes trying to improve in permanent way, seeking to determine and eliminate the problem's root cause.	Analyze data, stage and dates (from planning) of past commitments aiming to find and eliminate the problem's root cause. Resuming each process seeking improvements, even when believed correctly established. Each improvement eliminates newfound wastes.
Change orientation	Flexibility in performing changes in the entire project process/projects, include work methods, adjusting environment conditions.	Adjust production rhythm to demand, when this one fluctuates. Deliver product to extend demanded and when demanded. Adjust programming, fitting to environment changes.
Internal/ external client orientation	Act proactively in front of the client (internal, external or supplier), keeping in mind his needs and incorporating them in the activity planning. (Adds value).	Planning activities based on clients and their necessities. Collecting information of the client's needs and incorporating them in plans and actions. Question during activity. Does it add value to the client?
Innovation	Generate ideas/ new processes or combine the existing ones through experimentation, to make an improvement by affecting the future performance.	Identify the problems affecting performance of one or several processes. Generate new ideas/processes or combine the existing ones creating a novel way to do it. Implement the idea/ new process evaluating the performance impact.

COMPETENCIES BY POSITIONS

Additional to transversal competencies, a set of competencies associated to position were identified (Figure 2). We established three levels with the purpose to categorize professionals and make a proper professional development plan in the companies.

Figure 2: associated to position competencies

Competencies of Planning, an example:

Intending to visualize the associated competencies to the four positions, the competency of Planning is going to be an example, being this one to all companies a common element. Additionally, the competency highlights LPS as a common tool to all the companies in this study. Definitions and associated behaviors of each competency are present from Table 2 to Table 3.

Table 2: Associated behaviors of planning competency for Project Manager

Position : Project Manager		
Level 3	**Level 2**	**Level 1**
Definition Managing several projects at the same time, considering short-term goals lead to long-term objectives, redesigning the programming if needed with the purpose to meet deadlines, costs and project's quality.		
Considers that short-term goals leads to meeting long-term objectives, redesigning programming when necessary for better compliance with deadlines , costs and quality . In addition, it takes concern about planning commitments made by posing strict control on them. Managing multiple projects simultaneously, setting tracking points and effective control, and coordinating with deadlines and commitments.	Considers that short-term goals leads to meeting long-term objectives, redesigning programming when necessary for better compliance with deadlines Managing multiple projects simultaneously, setting tracking points and control.	Considers important short-term goals only, not visualizing long-term objectives, not able of redesigning programming in opportune moments. Managing multiple projects simultaneously, not capable of setting tracking points and control.

Table 3: associated behaviors of planning competency for Building Manager

Position : Building Manager		
Definition: Managing the project considering that short-term goals lead to long-term objectives, redesigning their planning as required to achieve its objectives.		
Level 3	**Level 2**	**Level 1**
Have a broad vision of the project, minding weekly and intermediate planning, being able to anticipate bottlenecks and reprogramming when necessary, in addition to detecting cases of non-compliance. Managing multiple tasks simultaneously, setting tracking points and effective control, and coordinating with deadlines and commitments. Flexibility in reprogram to problems presented for better compliance of long-term goals.	Have a broad vision of the project, minding weekly and intermediate planning, being able to anticipate bottlenecks. Managing multiple tasks simultaneously, setting tracking points and control. Flexibility to reprogramming when necessary.	Prepare the weekly plan, without taking into account the variabilities associated with the project. It has a short-term vision. Managing multiple tasks at the same time, not being able to establish monitoring and control points. Little flexibility to programming changes.

Table 4: Associated behaviors of planning competency for Site Manager

Position : Site Manager		
Definition: Managing project planning with order and methodology.		
Level 3	**Level 2**	**Level 1**
Be neat and methodical in the control and monitoring of project planning, verifying compliance with deadlines, costs and commitments. Ensure and promote throughout the work team the good use of project resources, avoiding material losses, accidents or other. Possess a clear understanding of the work's master program, anticipating medium-term problems, lifting restrictions to achieve a smooth progress, and thinking on specific and innovative solutions. Adapt and efficiently overcome problems not seen in the work planning.	Be neat and methodical in the control and monitoring of project planning. Ensure the good use of project resources, avoiding material losses, accidents or other. Possess a clear understanding of the work's master program, anticipating medium-term problems, lifting restrictions to achieve a smooth progress. Adapts easily to changes in planning due to problems of the project.	Not anticipating to project problems, only reactively. Be neat in the project planning management without taking a rigorous control. Not ensuring project resources. Possess a clear understanding of the work's master program; however, there is no planning or medium-term vision. Not easily adapts to changes in planning.

Table 5: Associated behaviors of planning competency for Chief Technical Office

Position: Chief Technical Office

Definition: Take control of the project in an orderly and methodical manner.

Level 3	Level 2	Level 1
Supervise and control the fulfillment of agreed deadlines, always putting in front of difficulties. Establishing appropriate priorities differentiating the important from urgent, considering contingencies that may affect planning.	Supervise and control the fulfillment of agreed deadlines. Establishing appropriate priorities differentiating the important from urgent, trying to provide the necessary time.	Supervise and control the fulfillment of agreed deadlines, but is not able to control, letting dates pass and delaying the project. Not establishing priorities, making activities in a disorderly manner.

CONCLUSIONS

The study results are one-step more to go forward in Lean practices' sustainability such as Last planner from the participant companies. Past researches presented a gap associated to Human resources' management, where practices such as talent management, incentive structure, measurement system and performance evaluation are lacking a Lean approach, despite these companies are applying Lean tools to some extent. Therefore and accordingly to the results, there are not standardized Human resources management' practices in the participant organizations; being detected a models shortage or continuous training program that allows holistically integrate Lean philosophy. To sum up, it is strongly appreciated the philosophy's instrumentalization at the LPS tool with low incursions on other tools and, in Lean's philosophical and cultural aspects. These results provide the competencies identification and definition for four key positions: Project Manager, Building Manager, Site manager and Chief Technical Office, which will be part of a Competencies Dictionary that will work as a foundation for a formation plan's development that companies will use as a backing of Lean tools' sustainability over time, especially Last Planner. This dictionary includes four generic competencies for the positions: (1) Quality oriented/ continue improvement, (2) Change oriented, (3) Internal/ external client orientation and (4) Innovation; and a competencies set by position based on key positions' different activities. In this paper, we considered planning a transversal competency developed in different levels in accordance to positions. Competencies define areas in which a professional must be competent; these competencies through its interactions potentiate a proper management under Lean parameters. In this case, the dictionary as outcome of this research should be considered a basic tool for human capital's development in each organization. Nowadays, it is necessary to develop reflexivity regarding Lean tools' use and its competencies. For what? What relationship holds with its aims and missions? Accessing tools' use because or by tools? The latter will finally enable greater integration among the philosophy, cultures and technologies accomplishing a righteous convergence towards Lean tools' sustainability over time.

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A ROUTE MAP FOR IMPLEMENTING LAST PLANNER® SYSTEM IN BOGOTÁ, COLOMBIA

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ABSTRACT

In recent years, Lean Construction (LC) has come to be known among the construction industry in Colombia for its proven waste reduction potential, ability to increase value and improvement of project performance overall. The Last Planner® System (LPS) is one of the most valued and commonly used LC methodology in Colombia, however, there is not enough clarity about how it works or how to properly apply it. To this extent, this qualitative research proposes a route map for implementing LPS in Bogotá, based on a review of its current application, in order to guide companies toward a proper use of it. The assessment was carried out throughout a benchmarking process known as The Reading Model in which four of the eighteen competing companies that use LPS, were evaluated in terms of their commitment and scope in each aspect of the three main LC pillars: culture, philosophy and technology. The aim of the research is to identify possible improvements for the LPS implementation and to adapt the True North route map to the assessed context. Despite the fact that only four companies participated, it was found that all of them face similar barriers related to contractors' engagement, reluctance to change and lack of training.

KEYWORDS

Last Planner System, Lean Construction, Culture, Production Planning, Benchmarking.

INTRODUCTION

The Last Planner® System (LPS) of Production Control is a production planning method for construction projects (Ponz-Tienda, Pellicer, Alarcón, & Rojas-Quintero, 2015). This system was created by Glenn Ballard (1994, 2000) and Greg Howell (1998) in order to

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improve the predictability and reliability of construction production (Mossman, 2014). It has been implemented by numerous companies around the world for more than 20 years, which has allowed it to demonstrate its effectiveness in different cultures and work environments. (Daniel, E.I., Pasquire, C. and Dickens, G., 2015; Viana *et* al. 2010).

LPS was first introduced in Colombia in 2007 (Portafolio, unpublished data, 2008). At first, four companies started the implementation process, up to now, that number has increased to eighteen. (CAMACOL, unpublished data, 2015). Despite of the long track record LPS has worldwide, the adoption of this method has been difficult for Colombia, due to the high reluctance to change of the national construction companies. Moreover, there is almost no literature on the subject apart from informal unpublished university documents, undergrad and master´s thesis and one case study (Botero, L. F., Botero, F. and Álvarez, M. E., 2005). For this reason, an assessment of the LPS implementation in the city of Bogotá has been carried out to provide feedback for those constructors who have taken the initiative of applying this system. Furthermore, this study intends to promote the introduction of LPS in construction companies that still have not set it in.

LPS is not a Toyota's creation. The first appearance of the LPS concept in the construction industry took place in the 1990s. This method was created to promote and control the production in construction projects, through the management of the relationships, conversations and commitments. (Alarcón & Pellicer, 2009). LPS offers a realistic way to collaboratively manage project production, enables clashes to be identified and resolved before they turn into on-site problems and increments the possibilities that the work will flow and the projects will be completed on time. It is an essential link between logistics and assembly teams (Mossman, 2014).

BENEFITS AND CHALLENGES IN THE LPS IMPLEMENTATION

Several studies talking of the benefits and challenges of the LPS implementation have been developed in different countries, some of their findings are mentioned hereafter. Fernandez-Solis et al. (2013) point out the following benefits: smooth work flow, predictable work plan, reduced cost, reduced delivery time, improved productivity and greater collaboration with field personnel and subcontractors.

On the other hand, certain challenges faced when implementing LPS are: lack of leadership, organizational inertia, resistance to change, lack of training, contractual issues and lack of experience and knowledge.

There are multiple reasons that promote the adoption of LPS in companies and projects, some of them are to: deliver projects more safely, create a more predictable production program, reduce project duration, manage cost in a better way, reduce stress on project management, improve the overall production process, create trust among clients, establish clear and simple deliverables, improve communication and participants' integration, create transparency in the information and certainty about activities and finally motivate strongly team collaboration. On the other hand, some of the aspects that shall not be expected for implementing LPS are: directly earning more money, automatically delivering the project before schedule, replacing software with this system and reducing conflicts in some of them. (Ballard, 2000; Fernandez-Solis et al. 2013; Formoso, C. T. and Moura, C. B., 2009; Hamzeh, 2011; Mossman, 2014)

THE TRUE NORTH: A NAVIGATIONAL COMPASS TO GUIDE COMPANIES ON THE RIGHT TRACK

The True North concept evolved from Toyota. It is an absolute, fixed, immutable reference that serves as a guide towards the ideal way of how things should be done. (Smalley, 2015). As Rother (2010) said, besides of the application of a continuous improvement philosophy, a guide is needed. Thus, a long-term vision helps the company to navigate across this process until the goal is accomplished: the perfect implementation of LPS. In other words, the True North works is a compass for guiding companies from their current state to their target state, on the right track (Nesensohn, Demir, & Bryde, 2013; Nesensohn et al. 2013). Conducting a benchmarking process is a good methodology for a company who wants to find the appropriate path for improving LPS.

BENCHMARKING

Benchmarking is a tool designed for measuring the quality of organizations in terms of policies, programs, products and strategies, among others. Likewise, it is used for determining which improvements should be implemented, for analyzing how other companies accomplish high productivity levels and in such a way applying it.

As stated by Mohamed (1997), there are three different ways of carrying out a benchmarking process in the construction industry: internal, project and external. Internal benchmarking compares internal operations for producing a continuous improvement. Project benchmarking compares projects within a company looking forward to creating a data base for the management of future projects. Finally, external benchmarking attempts to adapt the best practices from other industries to a certain company.

Similarly, McCabe (2001) describes three types of external benchmarking: competitive, functional and generic. Competitive benchmarking compares a company with any of its direct competitors. Both functional and generic benchmarking are very similar and aligned to the external benchmarking definition.

Lastly, *The Reading Model* is a benchmarking model especially designed for the construction industry because the existing ones were too detailed or inflexible (Pickrell et al. 1997), and the construction industry needs a simpler and more flexible method (Garnett & Pickrell, 2000). This approach is based on the following steps: 1) recognizing the need for change, 2) deciding what to benchmark, 3) deciding who to benchmark against, 4) deciding what data to collect, 5) collecting the data and analysing it, and 6) putting the results into practice.

RESEARCH METHOD

For this case study, four companies that use LPS to some extend in Bogotá, were evaluated in terms of their commitment and scope in each aspect of the three main LC pillars: culture, philosophy and technology defined by Salvatierra et al. (2015). Contact was established with seven out of the eighteen companies that claim to apply LPS in Colombia; these seven were prepared for participating in the study, however, three of them withdrew for internal reasons. None of the four companies involved in this research had been applying LPS for more than three years.

Having in mind the purpose of evaluating the implementation of LPS, it was raised that the issues to be compared were all those which can be associated with a suitable implementation of the tool, and those which, according to the theory, a company who uses LPS has. Semi structured interviews, and open-ended questionnaires were performed to several members of each company. Also, the authors participated on these companies Pull Sessions and carried out on site observation.

The benchmarking was used to determine the quality of the LPS implementation in Bogotá. Particularly, a competitive benchmarking process with the purpose of adapting other companies' best practices to their direct competing companies was developed through the six step Reading Model.

DEVELOPING A TRUE NORTH FOR LPS THROUGH THE READING MODEL

Step 1: Recognising the need for change

Due to the reception of LC and the LPS method in Bogotá, many players, such as academics and managers, are worried and insecure with regard to the steps to take to accomplish the right LPS implementation. For this reason, the industry turned to the academy, inasmuch as they recognize the potential of this innovative philosophy versus the traditional management methodology (Pellicer & Ponz-Tienda, 2014) (Pellicer, Cerveró, Lozano, & Ponz-Tienda, 2015). They also have many doubts about how to apply it and this is why they demand a compass or route map for acquiring good practices and generating a continuous improvement.

Step 2: Deciding what to benchmark

Considering that LPS success depends on the Lean Construction principles being implemented, the authors have made their benchmark based on the Lean construction principles, tools discussed in the literature, and the globally reported LPS practice. (Ballard, 2000). Some of these aspects are: Pull Sessions, Look Ahead, Weekly Work Plan (WWP), Percent Plan Complete (PPC), changing the culture form push to pull, Kaizen philosophy and training among others. (Ballard, 2000; Mossman, 2014)

Step 3: Deciding who to benchmark against

As mentioned before, four companies that have started to introduce LPS in Bogotá decided to participate. While meeting with them, it was noticed that the chiefs of the Lean department were very motivated with the fact of being compared with other construction companies, who are their competitors, and of receiving a feedback about how to implement LPS in a better way.

Step 4: Deciding what data to collect

After performing an extensive bibliographic review, consulting experts and attending the first SEINCO-2015 (Ingeco, Universidad de los Andes, personal communication, 2015) it was concluded that the three main pillars for LC can also be claimed to be the life triangle of LPS: culture, philosophy and technology. For an appropriate and accurate implementation of LPS, these three pillars are needed. The lack or weakness of one of them may cause the failure of the method. (Salvatierra et al. 2015)

Step 5: Collecting the data and analysing it

Different subcategories were defined for the three main categories previously mentioned: culture, philosophy and technology. The presence in at least one Pull Session from each of the companies that participated was fundamental for the purpose of harvesting information, and for objectively observing which subcategories were applied and which were not. The obtained results are shown in Table 1, Table 2 and Table 3.

Table 4. Benchmarking LPS culture

CULTURE	Company			
	A	B	C	D
Just in time	X	X	X	
5 Whys	X	X	X	X
5 Ss	X	X		X
Pull Sessions attendance	X	X	X	X
Genba – See with your own eyes and in the real place	X	X	X	X
Hoshin – Each person is the expert in his or her own work			X	X
Kaizen thinking – Continuous improvement		X	X	X
Assistants participation	X	X	X	X
Pull Planning			X	X
Last planner			X	X
Acceptance of LPS by contractors				X
Acceptance of LPS by company's workers	X	X		X
Supervision of the LPS implementation by the head of the company		X	X	X
Philosophy application	X	X		X

Table 5. Benchmarking LPS technology

TECNOLOGY	Company			
	A	B	C	D
Software that allows them to calculate and evaluate the PPC	X	X	X	X
Software that allows them to see the project program	X	X		X
Software that allows them to see the evolution of the project		X	X	
Software that allows them to see the design of the project	X	X	X	X
"Value Stream Mapping"				
Hoshin Kanri – Strategic planning				
*Line of Balance		X		X
*IA3 report				
*IPD		X		

Table 6. Benchmarking LPS philosophy

PHILOSOPHY	Company			
	A	B	C	D
Clarify doubts	X	X	X	X
Well-defined and free activities	X	X	X	X
Commitments			X	X
External training		X		X
In-house training	X	X	X	X
Visual management			X	X
Milestones - direction – where are we going?	X	X	X	X
Look Ahead			X	X
Main Program				X
Phase Schedule			X	X
Weekly work plan revised/updated with daily data	X	X		
Restrictions worksheet			X	
Plus-Delta				
PPC	X	X	X	X
Publication of results in public areas		X		X
Pull Session			X	
Revision of the non-compliance reasons of the last plan			X	X
Revision of the PPC of the last plan	X	X	X	X
WBS			X	
WWP	X	X	X	X
Zones, areas, responsibilities and clients			X	X
Reverse phase scheduling			X	

Step 6: Putting the results into practice

With the previous results, the steps to be taken for generating a guide that serve as a compass for the implementation of LPS in Bogotá were identified. However, applying this route map does not guaranty that the best implementation of LPS will be obtained. There might be some extra steps that are not included in this guide and some others that might be useless. The important thing is that each company takes into account this recommendations and is willing to create its own path towards their goals and therefore achieve the correct implementation of LPS.

Figure 1 presents the fifteen steps that make up the compass for the Lean implementation proposed by Nesensohn (2013).

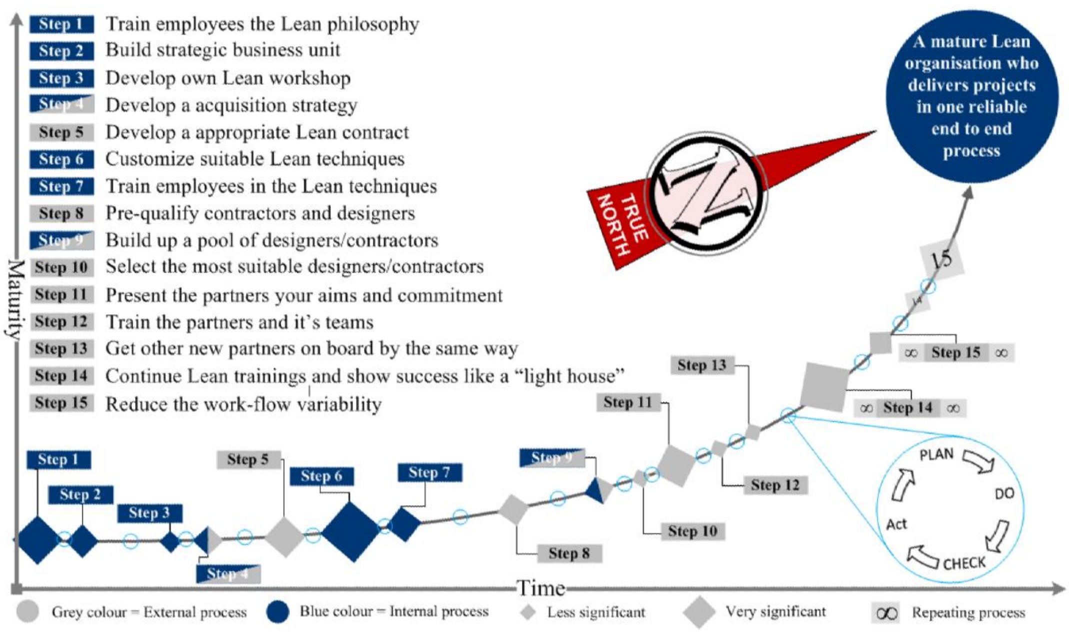

Figure 6. Compass for the Lean implementation. (Nesensohn C. et al., 2013).

For purposes of this study, the steps for implementing Lean proposed by Nesensohn were modified and adjusted in order to improve the implementation of LPS. The fourteen steps presented in table 4 are the achieved outcome of this adjustment and the suggested plan for the proper LPS implementation in Colombian companies.

Table 7. Steps of the route map for the LPS implementation.

	STEP
1	Train every member of the company the LC culture and LPS.
2	Create a Lean department, where the head is a LC and LPS expert with experience.
3	Hire an external consultant that verifies and supports the start of LC and LPS.
4	Train employees the LC and LPS technologies and philosophies.
5	Rate contractors according to if they do or do not apply LC and LPS.
6	Create a data base with the contractors that apply LC and LPS.
7	Select the accurate contractor according to the project.
8	Start the LC an LPS implementation with a pilot project.
9	Learn from the mistakes made in the pilot project and avoid repeating them on future projects.
10	Apply it in every project that starts once the pilot Project has finished.
11	Promote communication between projects to: inform mistakes from one and avoid them from happening in another, inform advances from one project and to apply them in another, and to facilitate mutual support among workers from different projects.
12	Continuous external supervision while the implementation of the LC and LPS culture, philosophy and technology is achieved.
13	Internal supervision (everyone supervises everyone). The owner or general manager should be the most involved one in the supervision.
14	Training and continuous improvement.

FINDINGS AND RECOMMENDATIONS

Companies who have been implementing the system for more than a year claim that they have seen improvements on the development of their projects, the worksite is more organized, waste has been reduced, and changes regarding the way in which the construction site was traditionally managed were noted. However, several barriers for the LPS implementation related to contractors' and stakeholders engagement, reluctance to change, partial implementation and lack of training were identified. Detected barriers are aligned with the ones reported in the literature by Hamzeh (2011), Porwal et al. (2010) and Viana et al. (2010). It was found that two of the companies that claimed to apply LPS assumed that caring out weekly meeting would imply they carried out pull sessions and were Lean.

The study was limited by the number of companies who decided to participate and by the quality and amount of the collected data, this due to the fact that a rating scale would have been better than a yes/no assessment for the benchmarking process. To this extend, further research is required to assess the maturity level of the LPS and the Lean implementation in Colombia.

Based on the previous findings and on the on site observations, the following recommendations were formulated: visual aids are vital to gain interest and understanding from the ones involved in the sessions. Being open to change is a must. Sometimes actions that may seem strange or against intuition are needed. Some of them may bring strong improvements to the company. Do not force assignments on contractors. It is crucial that they acquire commitments on their own to ensure an increased percentage of promises completed. Curb malpractices, continuous monitoring of the implementation should be done to avoid committing the already amended mistakes. Using the PPC is important for qualifying contractors, determining the non-compliance reasons and preventing them from happening again. Nonetheless, the PPC should not be used to punish contractors whose yields are low. A little is good, more is better, everything is excellent. Meetings participation should be a contractual requirement, in order to establish the Lean culture in every stakeholder involved in the construction site. Team members who resists change should be brought in with training and understanding. Companies' staff who participate in the Pull Sessions should be trained about the proper use of the LPS method, throughout the interaction with the academy.

CONCLUSIONS

While the assessment could not be conducted with the eighteen construction companies that currently implement LPS in Bogotá, it was found that they all face similar problems. The fact of passing from giving orders to contractors to encouraging them to assume their own commitments with the activities that should be performed was a very common difficulty. Some constructors claimed that if they allowed contractors to assume their own commitments, they would commit to do less than what they could actually do. However, the companies that applied it managed to see substantial improvements on the performance of the projects. It is important to understand that when the pace of change of the environment is greater than the one of the organizations, they tend to disappear. For this reason, it is essential that companies work hard in innovation and be open to change to maintain their competitiveness and in such way assure their existence.

For the accurate LPS implementation three fundamental pillars should be taken into account: technology, philosophy and culture. It is essential to understand that the lack or poor development of one of them leads to the failure of the implementation. It could be seen that construction companies have excellent software technology at their disposal, the majority of them understand the philosophy, but they fail on the adoption of the Lean culture. It is therefore appropriate to emphasize on its proper introduction, since if not everyone is willing to change, issues in the implementation will occur in the long and medium term. Along the study it was noticed that many people consider themselves as Lean for applying LPS. The truth is that to be Lean many tools and methodologies have to be applied bearing in mind the three pillars previously mentioned.

One of the main challenges in the LPS implementation is to train the members involved in the construction site. Learning and implementing new procedures in any process is relatively simple. Nevertheless, when the stakeholders are not ready to change, everything gets more complicated. Furthermore, it should be stressed that even though Lean construction is far more than LPS, the usage of this method enables the introduction of the Lean concept in construction companies. On this particular assessment, an absence of professional wroth possibilities for the people devoted to Lean Construction was perceived. This is why, very often construction professionals find unattractive the study of this management philosophy.

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INTEGRATED PROJECT DELIVERY IN PUBLIC PROJECTS: LIMITATIONS AND OPPORTUNITY

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ABSTRACT

One of the major challenges that the construction industry facing is how to improve the effectiveness and performance of construction projects which become more dynamic and uncertain. For this reason, more projects are adopting lean principles which focuses on collaboration and work flow reliability. Due to the limitations of current procurement practices including competitive bidding strategy and fixed price contracts, an innovative project delivery, so called integrated project delivery (IPD) or lean project delivery, has been adopted by project owners. However, most of public agencies have restrictions in choosing a project delivery. In fact, most procurement codes require public agencies to use competitive pricing and bidding, leading to difficulties in using IPD which encourages collaboration among project teams. In this paper, the researchers present the result of a survey aimed at investigating the benefits and restrictions experienced by project participants who have tried IPD or some principles of IPD in public projects. The research is expected to provide a practical view on the opportunities and challenges in applying IPD to their projects.

KEYWORDS

Integrated project delivery (IPD), public projects, survey

INTRODUCTION

In recent years, projects have become increasingly complex, dynamic, and fast (Ballard 2008). Integrated project delivery (IPD) has been proved to be an effective way to manage complex, dynamic, and fast projects (Ballard et al. 2011). The project integration requires

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more than just working together. It requires organizational integration, alignment of commercial interests, and management-by-means (Ballard et al. 2011). In addition, Kim and Dossick (2011) and Lee et al. (2013) reported that cultural alignment is also required to make a project integrated let alone management principles, technical support, and contractual arrangements.

Without integrated approach, construction projects (especially complex, dynamic, and fast ones) tend to suffer from adversarial relationships, low productivity, and process inefficiency resulting in projects being overrun and delayed (CURT 2004; 2007). In response to such problems of the current delivery systems, the number of projects adopting integrated approach has increased in recent years (Kent and Becerik-Gerber 2010). One exemplary delivery system is IPD.

IPD is a method of project delivery that is distinguished by a contractual arrangement that aligns business interests among a minimum of owner, constructor and design professional. IPD encourages collaboration throughout the design and construction process, ties stakeholders' success to project's success. (AIA/AIACC 2007)

IPD is an alternative project delivery that supports aligning interests, objectives and practices, and it explicitly promotes shared risk and reward and extensive collaboration between project parties (Matthews and Howell 2005). AIA (2007) defined IPD as "a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction."

Most notably, IPD distinguishes itself from other alternative project deliveries by supporting multi-party agreements with transparent sharing of project information between project parties (Cohen 2010), and by promoting a list of unique requirements as summarized in Table 1.

Table 1: Unique Requirements of IPD (Adapted from Lee et al. 2013)

Contractual Requirements	**Technological Requirements**	**Cultural Requirements**
• Multiparty Agreement • Shared Financial Risk and Reward • Early Involvement of All Parties • Collaborative Decision-making • Liability Waivers • Fiscal Transparency • Integrated Design	• Building Information Modelling (BIM) • Project Management Information System (PMIS)	• Mutual Respect and Trust • Willingness to Collaborate • Open Communication

As the number of IPD projects increases, IPD has gained interests of many public owners in that public projects could benefit from the principles of IPD. However, there are many obstacles for public owners to overcome in applying the principles of IPD to their public projects. To remedy the obstacles, IPD can alternatively be applied to currently available project delivery methods such as Design Build, CM at Risk, and even traditional Design Bid Build. (Sewalk et al. 2016). Projects that employ the principles of IPD with conventional delivery methods are called "IPD-ish" projects.

The objectives of the present study are (1) to understand the benefits of and obstacles to IPD implementation from the perspective of owners, engineers, and contractors who are working in public projects, and (2) to investigate how IPD or IPD-ish is employed in public projects.

RESEARCH DESIGN

This research investigated the perceptions that people have towards the implementation of IPD in public projects. The research specifically sought to identify the obstacles and benefits associated with IPD implementation in public projects. As the main research method, an online survey was distributed to professionals in different kinds of projects and data was collected by using a questionnaire that the respondents had to fill out. The respondents were contacted via emailing lists of lean construction communities including Lean Construction Institute. The questionnaire contained ordinal scale questions, in which the respondents selected the responses from a five-point Likert scale, where 1=strongly disagree, 2=disagree, 3=neutral, 4=agree, and 5=strongly agree.

The questions were divided into five major categories. First, general questions included the type of projects the respondents worked for, the role they had in the projects, and if they had direct experience with IPD contracts. Second, questions asked about the respondents' opinions about 19 different potential benefits and eight different obstacles associated with IPD in public project. The list of benefits and obstacles were developed based on extensive literature review combined with our collective experience that we gained from getting involved in IPD projects. Third, questions were asked to examine how IPD methods were implemented especially for those who had previous experience with IPD. Fourth, the respondents were asked about the delivery method of projects where the principles of IPD were employed. The researchers assumed that the most procurement codes do not allow multiparty relational contract (e.g., Integrated Form of Agreement). Lastly, the survey concluded with asking about the method of applying the principles of IPD to respondents' projects. The survey design is presented in Appendix.

RESPONDENTS

A total of 34 respondents participated in the survey. The respondents were all involved in the fields of architecture and/or construction. The majority of them worked in industrial projects (12), school projects (9), and healthcare projects (8). Alternatively, commercial buildings (2), residential buildings (1), and heavy civil works (2) accounted for the lowest numbers of respondents (Figure 1). Additionally, most respondents were owners or owner representatives. Architects (7) and general contractors (7) had the second largest number of representatives in the survey. Lastly, only one respondent represented an engineering firm. It should be noted that since the respondents were from different countries, this study does not aim to generalize the survey results to specific areas, rather focused on providing generalized insights on what industry professionals in public projects perceive for IPD.

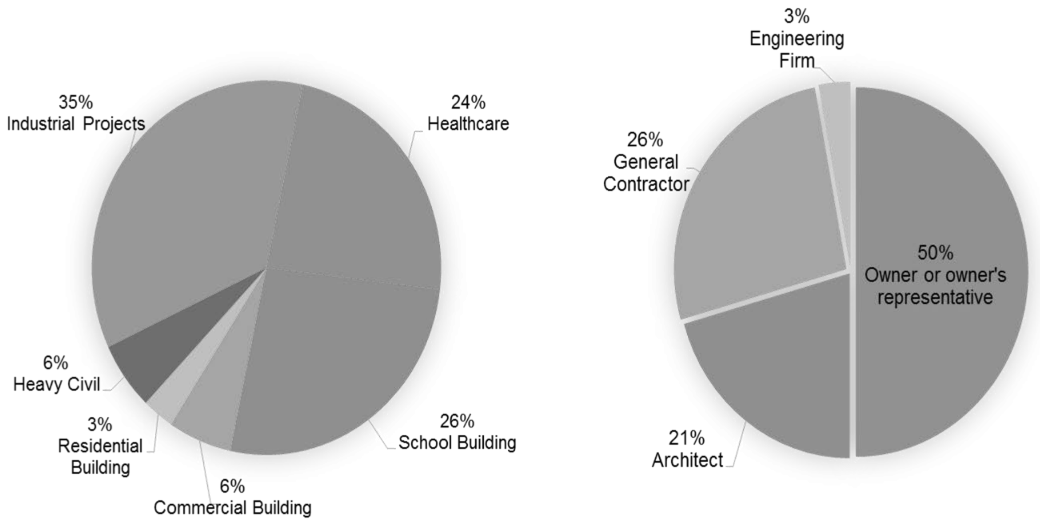

Figure 1: Demography of Survey Respondents

RESEARCH FINDINGS

PERCEIVED BENEFITS

In measuring the perceived benefits of IPD in public projects, the survey presented the respondents with 19 different potential benefits. For each of these benefits, the respondents were asked to select one option, indicating the extent to which they could achieve such benefit from IPD implementation.

The survey revealed a large number of responses with high scores in 15 out of 19 benefits, all of which outnumbered the negative and neutral responses for these perceived benefits. Based on these responses with high scores, it appears that most respondents considered IPD to provide those benefits, including improved communication on design issues; better communication between stakeholders; continuity in preferences and objectives in the construction process; a win-win process, early determination of project budget; improved administration; and improved project quality among other issues. Of these options, the respondents indicated that the most commonly perceived benefits of IPD are the reduced number of change orders, a win-win process, the continuity of preferences, and improved communication of stakeholders.

Top 10 benefits are listed in Table 2 based on mean value of each questionnaire.

Table 2: Top 10 Benefits

Rank	Benefits	Mean	Std. Dev.
1	Continuity regarding preferences and objectives throughout the design and construction process	4.09	1
2	Improved communication among stakeholders	4.00	1.13
3	Reduced the number of change orders	3.94	1.15
4	A win-win process: a gain-pain sharing mechanism encourages active participation in design decisions	3.88	1.09
5	Improved communication between owner and designer regarding issues of design	3.82	1.19
6	Improved project quality	3.82	1.11
7	Less chance of claims or litigation	3.82	1.14
8	Reduced project duration	3.79	1.12
9	Cost-effective design due to the designers access to construction information	3.76	1.05
10	Delivery of project within budget with less likelihood of cost overruns	3.74	0.99

PERCEIVED OBSTACLES

The survey also examined the perceived obstacles of IPD in public projects. As with the perceived benefits, the respondents were asked to indicate which obstacles they agree or disagree with the most, through the responses they marked on a scale attached to each obstacles. The survey presented the respondents with eight options, representing eight perceived obstacles of IPD in public projects. Of these obstacles, two had a significant amount of negative responses, which were collaborative decision-making and the involvement of key specialty contractors in the process of design. In contrary, three additional difficulties had a large number of neutral responses.

The perceived obstacles such as internal resistance, industry's resistance, and the selection of service providers without price competition received numerous neutral responses. This demonstrated that many respondents were not sure whether these issues were perceived obstacles to IPD implementation in public projects. Top 8 obstacles are listed in Table 3 on their mean value.

Table 3: Top 8 Obstacles

Rank	Obstacles	Mean	Std. Dev.
1	Multiparty agreement conflicting with the current public procurement law	4.09	0.87
2	Sharing profits and overruns (pain-gain-sharing)	3.59	0.99
3	Internal resistance (authorities do not like the idea)	3.53	0.93
4	Selecting a service provider without price competition	3.5	0.93
5	Lack of awareness or benefits	3.44	0.93
6	Involving key specialty contractors in design process	3.18	1.00
7	Industry's resistance (contractors and designers do not like the idea)	3.00	0.98
8	Collaborative decision making (design and budget) in design process	2.97	0.97

Numerous responses with high scores in the survey indicate that the respondents identified the majority of the perceived obstacles to IPD implementation. According to the result of the survey, three of the eight obstacles had the most respondents' agreement, which are: (1) the participants perceived multiparty agreement conflicting with current public procurement law, (2) internal resistance, and (3) sharing profits and overruns as the impediments to the implementation of IPD in public projects.

WAYS TO IMPLEMENT IPD IN PUBLIC PROJECTS

To maximize the effectives of IPD implementation, project parties especially in the private sector use multi-party contracting, to incentivize collaborative behavior, team risk sharing, and team decision-making process. Whereas in the public sector, such as federal and state projects, Design-Bid-Build is still the most widely-used delivery system that is used to deliver the public projects in many countries. Moreover, many public procurement laws restrict the use of alternative project delivery systems (Azhar et al. 2014), as is the case in the US.

When procurement codes do not allow for multi-party relational contracting (such as IPD) in public projects, public owners should seek alternative ways to implement IPD principles in their projects. Some of the alternative ways are: (1) use an addendum (agreement to implement IPD) to the main contract after the main contract is signed, (2) use an invitation to proposal or RFP/RFQ in which the intent to use IPD is addressed, and (3) use a project specification in which the use of IPD components is addressed. When using such alternatives to overcome the law restriction for IPD, it is called IPD-ish (AGC 2010).

According to the survey results, 17 of the respondents had applied the IPD-ish principles in their projects that were delivered through the following delivery systems:

Traditional Design-Bid-Build, Design-Build, and GC/CM or CM-at-Risk. Table 4 shows the percentage of the use of IPD-ish among the different delivery systems based on the survey. Although the survey has revealed that IPD-ish has been applied on DBB and DB projects, the majority of projects applied IPD-ish were GC/CM.

Table 4: Type of Delivery System where IPD Applied

Delivery Type	Number of Responses	Percentage
Traditional Design-Bid-Build	6	35.29%
Design-Build	4	23.53%
GC/CM or CM-at-Risk	7	41.18%

As to examine how IPD principles were applied in public projects while the procurement legislature impeded its implementation, participants were asked to identify the way they implemented the IPD principles in their projects without signing a pure IPD contract..

As a result, Table 6 summarizes how the respondents had implemented the IPD principles in their project contracts. Nine out of 17 respondents used an addendum (#1, #4, and #6 in Table 6) or IPD agreement to employee the principles of IPD in their projects. The invitation to proposal or RFP/RFQ documents was employed by six respondents. Two respondents ("others" in Table 5) chose other ways such as adopting lean principles throughout the construction phase without contractual arrangement.

Table 5: Implementation Methods of IPD on Contracts

#	Implementation Method	Number of Responses	Percentage
1	Use an addendum (agreement to implement IPD) only	4	24%
2	Use an invitation to proposal or RFP/RFQ only	3	18%
3	Use a project specification only	4	23%
4	Use both Addendum and RFP/RFQ	2	12%
5	Use both RFP/RFQ and Spec.	1	6%
6	Use both Spec and Addendum	1	6%
7	Use all three methods	0	0%
8	Others	2	12%
	Total	***17***	***100%***

DISCUSSIONS AND CONCLUSION

The findings of this study showed how industry professionals perceive the benefits and obstacles of IPD as well as how the principles of IPD are being employed in the project delivery methods that can be used under current procurement laws albeit the limited number of responses. The survey on the perceived benefits and obstacles of IPD identified various key issues related to IPD in public projects. Through the survey, the reduced number of change orders, a win-win process, the continuity of preferences, and improved communication of stakeholders were found to be the advantages that the majority of participants considered as the key benefits resulting from IPD implementation in public projects.

In contrary, the survey also found that many participants agreed that the multi-party agreement of IPD conflicts with the current public procurement laws, with sharing profits, and internal resistance, to be the main obstacles to IPD implementation. How to overcome such obstacles could be a key to making an integrated approach feasible in public projects.

Alternative ways, such as the IPD-ish approach, to the contracts has potential to eliminate the issue of the conflict between multiparty agreement and the current public procurement law. If IPD-ish is implemented, public owners are suggested to use RFP or RFQ to make clear their intention to use IPD principles, in order to minimize the possible resistance from service providers in signing the agreement after a main contract is awarded

Another challenge that IPD teams need to overcome is the sharing of risks and rewards. Though several alternative ways for such sharing mechanism exist, the industry needs to keep working on this issue because an alignment of commercial interests is a key component of IPD. In addition, the issue of internal resistance and the authorities who do not accept the idea of IPD can be resolved with training sessions to improve their understanding and perception on IPD principles in the projects. Future research is suggested for testing the efficiency and effective of such sessions.

This research also confirms that alternative ways to apply IPD principles should be devised in advancing the implementation of IPD in public projects, due to the inherent limitations of such projects. Using an addendum attached to the contract documents, addressing to use IPD by proposing that in the RFP/RFQ, and indicating and consisting to use IPD in project specifications are some of the suggested ways to overcome the restriction of the governmental procurement laws.

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APPENDIX: SURVEY DESIGN

Table 2: Survey Design

Type of Questions	Classification	
General questions	Type of project Party represented Experience in IPD	
Benefits	**Improved** communication between team members **Improved** communication among stakeholders **Continuity** **A win-win** process **Early** determination of project budget **Cost-effective** design due to the designers access to construction information **Delivery** within budget **No** detailed RFP process	**Improving** labour productivity **Reduced** construction costs **Reduced** design costs **Reduced** project duration **Improved** project safety **Improved** project quality **Improved** administration **Reduced** the number of change orders **Reduced** the number of RFI **Less** chance of claims **Single** point responsibility
Obstacles	**Conflicting** with the current public procurement law **Internal** resistance **Selecting** a service provider without price competition **Sharing** profits and overruns	**Lack** of awareness or benefits **Involving** key specialty contractors in design process **Industry's** resistance **Collaborative** decision making in design process
Delivery system that adopted IPD-ish	Traditional Design-Bid-Build Design-Build GC/CM or CM@Risk	
Method to implement IPD	Use an addendum (agreement to implement IPD) Use an invitation to proposal or RFP/RFQ Use a project specification	

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PROPOSAL FOR THE STRUCTURE OF A STANDARDIZATION MANUAL FOR LEAN TOOLS AND PROCESSES IN A CONSTRUCTION SITE

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ABSTRACT

The application of the concepts of Lean Construction appears as an important alternative to minimize waste, increase efficiency and generate more value for clients. The question that lead to this paper is whether a reduction of variability in the implementation of Lean tools and processes through a standardized manual is significantly going to improve applicability of Lean Construction. The main goal is to establish the structure of a manual to standardize Lean Construction tools and processes for further application in construction sites and to evaluate the proposed standards' implementation through the comparison between evidence obtained from Lean Audits conducted before and after the Practical Manual of Process and Procedures. The methodology of this paper consists on the characterization of lean practices and its difficulties at a construction company from Fortaleza, Brazil, the proposition of a manual's structure to standardize lean tools and processes and the conduction of Lean Audits in order to assess whether there was an improvement in the application of lean concepts. After compiling the results, it has been observed that the established goals were accomplished. It is believed that it will serve as guidelines for using the tools in the construction sites, thus facilitating knowledge management in the company and focusing on continuous improvements.

KEYWORDS

Lean construction, standardization, process, practical manual, audits.

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INTRODUCTION

The expansion of the construction market in the latest years already allows pointing to a number of changes in this industry. On that basis, the current scenario is composed of employees demanding better working conditions, customers becoming more critics and the other companies more prepared and competitive (ISATTO et al., 2000). Thus, it is crucial that builders seek differentials to remain at a high level. Based on this, Lean Construction emerges as an important alternative to achieve this differentiation.

Despite Lean Construction is based on clear principles, some difficulties of implementing it in a construction site are common, given that, as Ohno (1997) says, it is necessary not only to understand the concepts, but also to incorporate Lean philosophy within the organizational culture. In addition, the lack of parameters or certifications of Lean Construction combined with low qualification of employees, the lack of repeatability in the implementation of projects and the obstacles in the logistics suppliers are some of the factors that affect the implementation of lean practices (KOSKELA, 1992).

Based on this, the current paper will develop a Design Science Research in a company with 38 years in the market, in which applies lean philosophy as a management model for more than ten years. Thus, the company already has qualified employees, as well as tools and consolidated processes, built up through monthly audits proposed by Valente (2012), periodic training and its own routine.

Although the company already has maturity on lean work (Arantes, 2010), continuous improvement allows identifying that the deployment of tools based on the Lean philosophy is not enough. So, it is also necessary to establish standardized methods to ensure their correct implementation and continuity.

Thereby, this paper aims to propose the structure of a manual for standardizing processes and lean tools through analysis of previous audits, interviews with the technical management of the company, as well as tools and models adopted in the construction projects, seeking to establish the ideal procedures and providing inputs for application in construction. Thus, the established standards will be compiled for the company in manual format, which corresponds to a Policy and Standards Procedures tool.

Finally, it is believed that there will be contribution not only for academy, but also for the company, given that the standards set can serve as guidelines for using the tools in the construction sites, will facilitate knowledge management in the company, assist in stabilization of some processes to focus on incremental improvements, and can be used in other studies.

OBJECTIVES

GENERAL OBJECTIVE

The general objective of this paper consists on the proposition for the structure of a standardization manual for lean tools and processes used by a company in its construction sites.

SPECIFIC OBJECTIVES

The specific objectives for this study are to characterize the initial stage of Lean Construction within the company; identify which standards will be established; propose the structure of a Practical Manual of Processes and Procedures based on the company's Lean Audit checklist and criteria; and verify the implementation of the tools after defining the standards.

LITERATURE REVIEW

As Koskela (1992), just after the Second World War, much of the construction problems began to be understood, so that some solutions are now proposed and implemented, as investments in building technologies, total quality system, tools for control and planning, organizational methods and increase of productivity.

According to Isatto et al. (2000), construction problems come purely from managerial issues and concern to the quality of the product, to inefficiency in production processes and the dissatisfaction of internal and external customers. By inserting these obstacles in a highly competitive scenario, with the increase of demands from employees and external customers, it is necessary to search for new managerial philosophies that seek to improve production in construction.

Like other models of industrial production, the end product of construction comes from flow and conversion activities. According to Isatto et al. (2000), the flow of activities in the building industry correspond to the material flow, comprising transport, holding, processing and revisions. As Koskela (1992), despite the rework, reviews and repairs sound like insignificant when analysed on a small scale, but they have great impact when analysed the production system as a whole. Based on this, the application of the concepts of Lean philosophy has become interesting in improving the construction process.

Womack and Jones (2003) expanded the concept of Lean Production to the other areas of an organization and defined the concept of lean thinking, which is guided by five principles: define value, map value stream, create flow, establish pull and pursuit of perfection.

Despite this, some difficulties are common on implementing Lean philosophy within a construction site, in view of the uniqueness of each project, the low supply of skilled employees, the absence of lean culture in suppliers and the provisional nature of each. Despite these difficulties, Koskela (1992) states that the change in organizational culture is the key factor to overcome these obstacles. Thus, based on the lean production system, Koskela (1992) proposed eleven principles that would guide and optimize work with flow activities.

Dennis (2008) presented the Lean House, in which is possible to identify some elements and tools related to lean production. Some of them are already well implemented in the company object of this study (jidoka, poka-yokes, kanbans, 5S, A3, etc.). However, one of them is still beginning its application: the standardized work.

According to Liker and Meier (2006), the standardized work corresponds to an applied tool in repetitive processes and is based on the movement and work of the employee in order to eliminate waste. Within in construction industry context, standardization matches as an element capable to regulate services, reduce improvisations and wastes and optimize the development of activities (MEIRA, ARAÚJO, 1997). It is worth mentioning that the standardization process involves the reduction of variability, one of the eleven principles listed by Koskela (1992).

Standardization is one of the supporting elements of the Lean House, what highlights again the interdependency between the principles of lean philosophy and Standardization.

METHODOLOGY

The first methodological step consisted on the characterization of the company object of this research, the Lean Audits and the application of concepts and lean tools, based on technical visits, literature review and interviews with managers. This characterization intended to understand the history of Lean Construction within the company, evaluate lean practices at construction sites and the difficulties of working with Lean tools.

After that, it was analysed the results of Lean Audits of construction sites that were continuously evaluated by the checklist proposed by Valente (2012). The checklist was developed specifically for the company of this case study and it is divided into seven issues that contain general questions and specific company's features. The seven issues are Planning and Production Management, Kanbans, Jidoka, Flows, Production, Transparency, and Cleaning, Organizing and Safety and the goal is to obtain a 90% grade. The Lean Audit criteria are evaluated from zero to 3, being zero "None at Work" and 3 "Excellent". Each construction site is evaluated monthly and a report containing the audit final result and its analysis and observations is sent to the manager of the construction site. The complete version of the lean checklist is online (http://www.crolim.com.br/leanchecklist.htm) on company's website.

From the results of Lean Audits, it was fleshed out a comparative analysis of the grades and the applicability of each criterion evaluated for all of the construction sites and months of audits, in order to establish a standard for the most suitable month for the beginning and end of each parameter evaluated.

The third step was to define the standards of each tool for each criterion, based on what was discussed with the Work Managers, Lean & Green Coordinator and Technical Manager. Thereby, it was established the responsible for the preparation and monitoring of each tool, when and where each of them should be implemented, what would be the frequency of monitoring and how they should be put in practice.

Then, it was defined the models of tools and practices, which were compiled and then provided for each construction site. Thus, there was the standardization of documents and tools and, therefore, the most appropriate use of each, so that the comparison and benchmarking between construction sites were allowed.

The fifth step consisted on the analysis of the previous' audits results and, based on that, to develop a Practical Manual of Processes and Procedures for internal use in the company, which provides standards for the application of lean tools in the construction's development.

Finally, after the dissemination of the Practical Manual of Processes and Procedures in the company, it was presented the results of the Lean Audits in three construction sites.

Thus, it was analysed quantitatively the performance of the construction sites before and after the use of the Manual, in order to assess whether there was an improvement in the application of lean concepts.

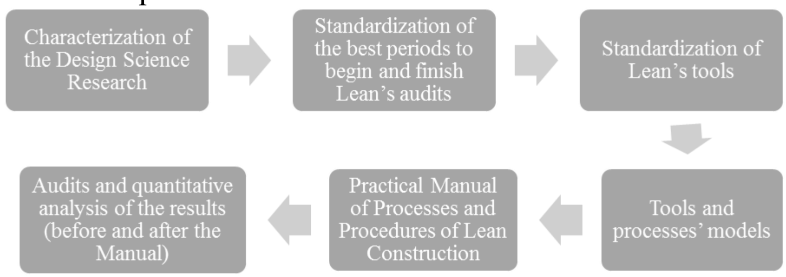

Figure 1: Methodology's flow chart

CASE DESCRIPTION

This study was conducted at a construction company from Fortaleza, Brazil, founded in 1975. The company has over 800 employees of its own (construction workers and administrative staff) and its expertise is exclusively property incorporation, specifically looking forward to Upper Class and Upper-Middle Class. The lean journey in this company started in 2004 and nowadays lean is the core of its management model.

It was analysed the results of Lean Audits from 3 construction sites in different construction phases. The Construction Site A is a residential project with 88 units and about 1.5 year under construction. The Construction Site B with 176 units and about 1 year under construction. Finally, the Construction Site C is a residential project with 23 units and about 6 months of under construction.

RESULTS

The standards for the application of lean tools and processes were organized in a Practical Manual structure, deployed internally in the company. Then, there were three Lean Audits in three construction sites, in order to verify if there was an improvement in the performance of the sites after the implementation of the Manual.

PRACTICAL MANUAL OF PROCESSES AND PROCEDURES

The Practical Manual of Processes and Procedures was drawn from the established standards and applied internally in the company. Thus, this document is structured into chapters (Table 1) and subdivided into tools. The Manual also presents the most appropriate periods for implementation of each criterion in Lean Audits, who is responsible for each tool, where and when they should be implemented and what should be the frequency of their accompaniment.

Chapters

The Practical Manual of Processes and Procedures was based on the criterions evaluated by Lean Audit proposed by Valente (2012), in view of the relationship between these criterions and the principles enumerated by Koskela (1992). Thus, the document was structured into seven chapters, named as the seven issues addressed by the Lean Audit checklist, as detailed in Table 1:

Table 1: Chapter's structure of the Practical Manual of Processes and Procedures

Chapter	Lean Audit criterions (Valente, 2012)	Lean principles (KOSKELA, 1992)
Chapter 1	Planning and Control of the Production (PCP)	Reduce the share of non value-adding activities; Reduce the cycle time; Increase process transparency; Focus control on the complete process; Continuous improvement.
Chapter 2	Kanbans	Reduce the share of non value-adding activities; Increase process transparency; Balance flow improvement with conversion improvement.
Chapter 3	Jidoka / Autonomation	Build continuous improvement into the process.
Chapter 4	Flows	Reduce the share of non value-adding activities; Reduce variability; Balance flow improvement with conversion improvement.
Chapter 5	Production	Reduce variability
Chapter 6	Transparency	Increase output value through systematic consideration of customer requirements; Increase output flexibility; Increase process transparency; Benchmarking.
Chapter 7	Cleanness, organization and safety	Increase output value through systematic consideration of customer requirements.

Periods to apply Lean Audits and definition of the responsible for each criterion

Based on historical analysis of grades and applicability of Lean's Audits criterions, it was determined the most appropriate periods to implement Lean Audits for each of them, as shown in Figure 2.

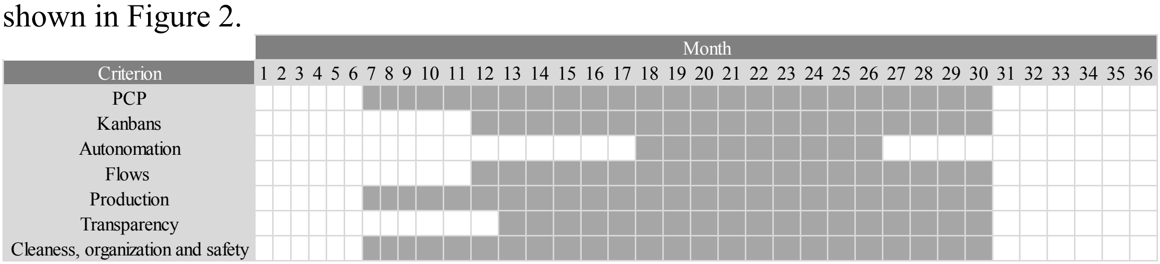

Figure 2: Ideal periods to begin and finish Lean Audits for each criterion

Based on observations of construction sites and after collecting information with Managers and Lean & Green Coordinator, it was possible to define who should be responsible for implementing and monitoring each of Lean's Audits criterions, as can be seen in Table 2. It is also important to notice that some of them have more than one responsible, what can be explained by the existence of different people as responsible for different tools in the same criterion.

Table 2: Responsibilities of each criterion

Criterion	Responsible for implementing	Responsible for monitoring
Planning and Control of the Production (PCP)	Project manager	Project manager
Kanbans	Project manager	Storekeeper and mixer operator
Autonomation	Project manager and Technician of safety at work	Project manager and Technician of safety at work
Flows	Project manager and Technician of safety at work	Project manager, Technician of safety at work and storekeeper
Production	Project manager and Production supervisor	Project manager and Production supervisor
Transparency	Project manager, Technician of safety at work and storekeeper	Project manager, Technician of safety at work and storekeeper
Cleanness, organization and safety	Technician of safety at work	Technician of safety at work

Definition of the places and moments to implement each criterion and the ideal frequency for the accompaniment

The moment suggested to implement each lean tool was defined with basis on the periods defined to start and finish Lean's Audits (Figure 2). However, these definitions have been adapted based on the demands of work and technical standards guidelines, so that established deployment times were very varied.

As well as the definition of moment, the places suggested for the implementation of lean tools were very diversified, based on observation in construction sites and in information obtained with Managers and Lean & Green Coordinator.

Despite this, the periodicity of accompaniment could be well represented in Table 3 and was also based on observations in the construction sites and in information obtained with Managers and Lean & Green Coordinator. As can be observed, some criterions had more than one periodicity, because of the variety of lean tools in each criterion.

Table 3: Periodicity of accompaniment of each criterion

Criterion	Periodicity
Planning and Control of the Production (PCP)	Weekly, Fortnightly and Monthly
Kanbans	Daily
Autonomation	Daily
Flows	Daily and Monthly
Production	Daily and Monthly
Transparency	Daily, Weekly, Monthly and Quarterly
Cleanness, organization and safety	Daily and Weekly

Evaluation of performance

The figure below presents the general grades of the three construction sites for one year. It is noteworthy that August represents the month immediately before the implementation of the Practical Manual of Process and Procedures, while September to December correspond to the period after the implementation of the standards. It is important to notice that in January, June and December the Lean Audits were not conducted because interferences such as vacations or strikes and the first Lean Audit at Construction Site C was conducted in August.

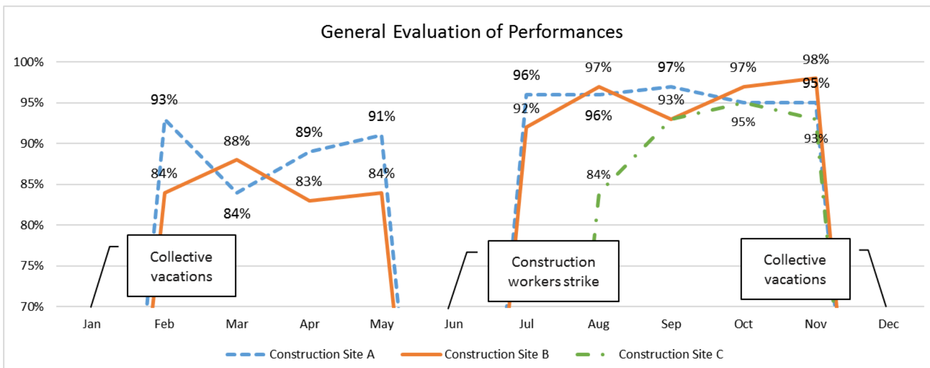

Figure 3: General Evaluation of Performances

The performance of Construction Sites A and B prior the Practical Manual of Process and Procedures had an average of 92% and 88%, respectively. After August, the average rose to 96% for both construction sites their performance did not change much during the period, so that, in general, the results were quite satisfactory. Because of the uniformity of the grades and because they are raised in the later stages of construction, it has become difficult to ascertain whether these performances were influenced by the Manual of Processes and Procedures.

However, it is also noteworthy that Construction Site C grades increased throughout the period, obtaining a 94% average. In this case, it is believed that the Manual have influenced these results, thus the Lean Audits were initiated in the first months of work, many of the processes were not yet well established, so it was possible to apply the suggested standards.

Anyhow, there are many qualitative results that should be taken into account. Before the Practical Manual of Process and Procedures, each manager of the construction site had its own pattern of documents and ways apply the lean tools. During the writing and developing process of the manual, all the good practices and tools used in each construction site were considered and adapted to fit each manager needs by unifying the controls. Thus, a set of documents were created and standardized for all construction sites.

Beside these documents, the processes and procedures described on the manual are an important source of research for current and new employees. The writing is very simple and it has many pictures showing how to use each tool, thus it may be understood by different management levels, from interns unexperienced to senior engineers. Also, the manual chapters and topics have been used as training method for new interns and employees and as refresher training for current production supervisor and other staff from the construction sites.

However, after a few months accompanying the Lean Audits, it was possible to observe that the team commitment had increased and the criteria's exigencies could be put in a higher level, thus Lean Audit checklist needs to be reformulated. The new checklist will define different weight for each criteria in order to require better performance in the practices, tools and controls believed to be most critical to the construction site management.

CONCLUSION AND SUGGESTIONS FOR FUTURES STUDIES

The current paper aimed to propose the structure of a manual for standardization of lean tools and processes and, after the implementation of these standards, audits were performed at construction sites in order to determine whether there was improvement or not in the applicability of the concepts and Lean tools.

Thus, based on the results obtained and the analysis performed, it is believed that the general objective has been reached, as well as the specific ones, in order that it was possible to characterize the Lean Construction philosophy in the company, the standards for the use of lean tools were set and the Practical Manual of Processes and Procedures was structured. It was also evaluated the application of the tools and procedures before and after the implementation of the Practical Manual, in order to verify that the document contributed to the improvement in the performance of Lean in the construction sites.

Despite the objectives have been achieved, it can not be ensured that the implementation of Practical Manual of Processes and Procedures has been the only factor that contributed to improve the application of Lean tools and processes, considering that the audit results were highly variable and difficult to analyse. Although it was expected that the building Construction Site C would be the better construction site to evaluate the implementation of the Manual, considering that its audits were initiated on the firsts months of work, the Lean Audit checklist was recently reviewed and it is not possible to compare the results. Anyhow, its Lean Audit results average is 90%.

It is also important to mention is that a long-term evaluation was hindered, because of the short time available for this study. Therefore, the "Post-Manual" period was restricted to only three months. In addition, stands out the peculiarity of the research, since it was established standards for lean tools used in a single construction company, which operates only in the residential buildings. Also, it is important to notice that further research and blending theory with practice will be conducted to improve the Manual’s benefits.

Based on the presented limitations and difficulties, it is suggested the following future studies:

Define the structure of a manual for the standardization of tools and Lean processes in a less restricted context, so it may be applicable in other industries;

Comparing the performance of two sites for a longer period of time, so that one of them is an older location, which has not been targeted by the proposed standards, and the other is a more recent one, so that it has the deployed from the beginning of its audits;

Propose a method of dissemination for lean standards in order to achieve the various hierarchical levels of construction sites.

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SECTION: 8 SUPPLY CHAIN MANAGEMENT AND PREFABRICATION

Peltokorpi, A., Seppänen, O., and Noorizadeh, A. (2016). "Project lifecycle approach to the perceived value of suppliers: A study of a Finnish contractor" In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.8 pp. 3–12. Available at: <www.iglc.net>.

PROJECT LIFECYCLE APPROACH TO THE PERCEIVED VALUE OF SUPPLIERS: A STUDY OF A FINNISH CONTRACTOR

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ABSTRACT

Systematic supplier evaluation, benchmarking, and development are parts of successful construction. However, there is a possible bias in supplier evaluations as in the early phase of projects, higher uncertainty about project success makes contractors potentially more critical of suppliers. We investigate whether contractors tend to favor suppliers of late project phases over suppliers in early phases. The analysis of 1,374 supplier evaluations revealed that in all 13 variables ranging from safety and schedule to quality the performance of the supplier was perceived lower among suppliers in the early phase compared to the late phase of the project. The evaluators recommended 92.8 % of the suppliers of late phases whereas they recommended only 86.1 % of the suppliers of early phases. When 12 other variables were taken into account, the contractor still tended to recommend more often suppliers that were active in the late phase ($p<0.01$). The paper contributes to the research on supplier management in projects by revealing novel insights about the effect of project phase on perceived value of suppliers. Contractors can utilize the findings by improving the objectivity of supplier evaluation systems. More research is needed to generalize the findings and to investigate the mechanisms behind the phenomenon.

KEYWORDS

Supply Chain Management, Supplier Evaluation, Perceived Value, Project Phase.

INTRODUCTION

Careful supplier selection has been recognized as a significant factor in maximizing customer value and eliminating waste in construction. As the competition usually occurs between project supply chains rather than between individual companies (Lambert et al. 1998), contractor's ability to develop its supplier network by evaluating suppliers' performance and selecting only best of them for the following projects is crucial in

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project-based business (Kumaraswamy et al. 2000). Existing research on supplier evaluation in construction has mainly focused on identifying characteristics of a good evaluation system. These characteristics include supplier categorization and comprehensive evaluation criteria (Biesek et al. 2008; Ho et al. 2007), proactive and periodic on-site evaluation (Maturana et al. 2004), combining evaluation to preferred supplier programs (Elfving and Ballard 2011) and to supplier development (Elfving and Ballard 2013), and use of appropriate analytics in the selection process (Bayazit et al. 2006).

From a contractor perspective, uncertainty about project costs, schedule and quality of the final product is highest in the early phase of a project (Chapman and Ward 1996). If suppliers have a remarkable role in the accomplishment of project's targets on time and on budget, it is logical to assume that uncertainty about the achievement of the overall targets of a project affects also contractor's perceptions of its suppliers: A contractor which is uncertain about the overall success of a project, may undervalue the performance of its supplier even if the supplier's performance has been objectively adequate. Construction project involves typically dozens of suppliers whose participation and activity in a project organization may concentrate on the specific stage of a project life cycle depending on whether their offerings are related e.g. to the planning phase, early execution phase or finalizing phase of a project. Therefore, evaluating suppliers at different times during project life cycle may unfairly favor suppliers whose activities take place in late phases (less uncertainty) compared to those who participate in the early phase (more uncertainty). Despite this possible bias in the evaluation systems of project suppliers, existing research about the topic is scarce.

This paper investigates the connection between the timing of a supplier evaluation during project life cycle and the perceived performance. More specifically we are interested in whether contractors tend to favor suppliers of late project phases over suppliers in early phases in their evaluations. In the next section we draw the hypothesis about the connection based on the existing research on project life cycle approach to supplier relationships. In the third section the method to test the hypothesis is presented. After results section, we conclude by discussing findings and their contribution on the existing research and practitioners. Finally, several avenues for further research are suggested.

PROJECT LIFE CYCLE APPROACH TO SUPPLIER RELATIONSHIPS

A construction project typically consists of several project phases which differ remarkably from each other both in their objectives and activities. Respectively, also critical success factors differ in each project phase. In execution phase, for example, project manager has to simultaneously manage several critical factors, such as mission, troubleshooting, schedule and plan, technical tasks, and client consultation (Pinto and Prescott 1988).

When the on-site execution is further divided into typical phases of building projects, such as foundations, structural work and interior construction, from project and supplier management perspectives, these phases have remarkable differences: In early execution phase, project organization is typically small, and contractor can easily evaluate the specific contribution of each supplier as the number of dependencies between tasks and sub-products is smaller than in the later phases of execution. The early phases of the project (Earthworks, Foundations and Structure) have fewer hand-offs because they have fewer subcontractors. In addition, several studies report that the finishing stages of the project are less well managed and often have poor quality, schedule overruns and hurry (Brodetskaia et al. 2010; Sacks and Goldin 2007; Seppänen 2009; Vasconcelos et al. 2012). Therefore, although there are more production problems in the end, they are very difficult to assign to an individual actor of the process because they result from cascading delay chains and cumulating quality problems. It is much easier to know who to blame in early parts of the project when just a few subcontractors are on site.

On the other side, relationships between client or contractor and its suppliers in construction are typically acknowledged to be poor. Especially in traditional procurement practices, such as in design-bid-build (DBB) contracts, overemphasis of low price leads to misaligned objectives between buyer and supplier and lack of patience to build long-term relationships (Davis and Walker 2003). Research about value suggests that relationship and engagement between customer and supplier is essential in value co-creation (Payne et al. 2008). Vice versa, when a supplier is engaged with the customer at the moment when the customer perceives to gain value, it can be argued that this engagement improves the relationship between the parties. We apply this phenomenon about customer value and relationships to a late project phase, and suggest that site managers' attitude toward late suppliers might therefore turn out to be positive even though they participated in cascading delay chains: "Although the sub-contractors who started early screwed up, these later suppliers were able to work as a team and finally to finish with us on time".

In summary, due to the lower uncertainty about the final value in the end of the project and higher uncertainly about the single supplier's contribution (or lack of contribution) on that final value, it can be proposed that in construction, contractors tend to favor suppliers of late project phases over suppliers in early phases. Therefore, the following hypothesis is proposed:

- ***Hypothesis:*** *Contractors tend to favor suppliers of late project phases over suppliers in early phases in their evaluations.*

We further divide our main hypothesis into two research hypotheses:

- ***Hypothesis 1A:*** *Contractors give higher evaluation grades for suppliers of late project phases compared to suppliers in early project phases.*
- ***Hypothesis 1B:*** *When sub-measures for supplier performance, such as achievement of costs, schedule and quality targets, are taken into account, contractors tend to recommend more often the use of the suppliers of late project phases than the suppliers of early project phases.*

The first research hypothesis highlights the objective nature of evaluation by claiming that suppliers in the late phase receive higher grades in specific project-related sub-measures, such as time, quality and cost. The second hypothesis, instead, underlines subjective issues in supplier evaluation and proposes that even when more objective performance measures are taken into account, alignment of the evaluation with customer's own value creation favors suppliers in late project phase.

METHOD

The hypotheses were tested by analyzing supplier evaluation database of a Finnish construction company. The company and its database were chosen for the study due to the company's long history in the development and use of systematic supplier evaluation, wide range of different construction projects in terms of their product, size and region, and easy access to data.

The supplier evaluation was made by project on-site superintendents. The evaluation system asked superintendent to fill an electronic evaluation form one week after the planned end of the delivery. The data included project-specific information (name, number, and region), basic information about the supplier (name, org id, and offering), and evaluation information (date, Likert scale grades (1-5) of 12 specific performance measures, and recommendation to use the supplier in future: true or false). The 12 specific performance dimensions included:

1. Supplier's attitude to occupational safety
2. Cleanliness, order, and consideration of environmental issues
3. Observance of safety regulations and guidelines
4. Activity in promoting safety
5. Supervision of work
6. Compliance with the agreed timetables
7. Additional claims in relation to the contract
8. Knowing the content of and compliance with the agreement
9. The quality of the product and service
10. Development activity
11. Billing and payment terms were timely and in accordance with the agreement
12. Response to possible comments and complaints

The original data consisted of 2,820 supplier evaluations made during the two-year period of 2014 and 2015 in 195 projects. For the analysis of this research, only projects in which the time period between the first and the last supplier evaluation was at least 30 days were selected. This also excluded potential projects in which all evaluations were made in the end of the project even if some suppliers' activity took place in earlier phases. After that the evaluations were categorized based on their timing during the project life cycle. As exact starting and ending times of the projects were not available, the categorization was made based on relative timing of the evaluation among all evaluations of the same project. The evaluations made during the first fifth of the time frame of all evaluations were categorized as '*early*' and the evaluations made during the last fifth as '*late*'. Evaluations made between these times were excluded. The final sample included 75 projects and 1,374 evaluations of which 577 (42.0%) were *early* evaluations and 797 (58.0%) *late* evaluations.

The hypothesis 1A was tested using ordinal regression analysis (Agresti 2010) in which a dichotomous variable about the project phase was used as an independent variable to explain each 12 performance dimensions and recommendation to use the supplier. The hypothesis 1B was tested using binomial logistic regression in which the project phase and all 12 performance dimensions were used as independent variables and binary variable about recommendation to use the supplier as a dependent variable. Spearman's rhos were first calculated to test the correlations between the independent variables. As the highest correlation coefficient was .778, all variables were included in the model.

RESULTS

The basic information about the projects and suppliers is presented in Table 1. The projects were very heterogenous both in their time span and number of suppliers. 44.9 % of the suppliers (n=167) were evaluated both in early and late phases depending on the project. On the other hand, 42.7 % of the suppliers (n=159) were evaluated only once, either in early or late phase.

Table 1: Basic information about the projects and suppliers

Variable	Value
No of projects	75
Time between first and last evaluations (days); mean (min; max)	204 (33; 693)
No of different evaluated suppliers	372
No of suppliers evaluated in the early phase	*262*
No of suppliers evaluated in the late phase	*277*
No of evaluated suppliers per project; mean (min; max)	18.3 (2; 130)
No of evaluations per supplier; mean (min; max)	3.8 (1; 39)

The results of testing the Hypothesis 1A are presented in Table 2. Share of non-recommended suppliers was 13.9 % in the early project phase and only 7.2 % in the late project phase, and that difference was statistically significant ($p<.001$). In nine of the 12 specific performance dimensions, grades given in the late phase were statistically significantly ($p<.05$) higher than grades given in the early project phase. The biggest difference in evaluations between the project phases existed in *timely and accordance billing and payment*.

Table 2: Comparison of evaluation grades between early and late project phase (significance evaluated using Ordinal regression analysis) (n=1,374 evaluations)

Performance dimension	Early phase (mean ± sd)	Late phase (mean ± sd)	Difference	Significance (p-value)
1. Supplier's attitude to occupational safety	3.53 ± 0.91	3.75 ± 0.90	0.22	<.001*
2. Cleanliness, order, and consideration of environmental issues	3.49 ± 0.88	3.74 ± 0.86	0.24	<.001*
3. Observance of safety regulations and guidelines	3.54 ± 0.91	3.77 ± 0.90	0.23	<.001*
4. Activity in promoting safety	3.21 ± 0.86	3.41 ± 0.95	0.20	.001*
5. Supervision of work	3.85 ± 0.95	3.92 ± 0.95	0.08	.150
6. Compliance with the agreed timetables	3.78 ± 1.09	3.91 ± 1.01	0.13	.061
7. Additional claims in relation to the contract	4.01 ± 0.96	4.20 ± 0.91	0.19	<.001*
8. Knowing the content of and compliance with the agreement	3.97 ± 0.84	4.13 ± 0.80	0.16	<.001*
9. The quality of the product and service	3.80 ± 0.93	3.95 ± 0.89	0.16	.001*
10. Development activity	3.55 ± 0.94	3.65 ± 0.93	0.10	.106
11. Billing and payment terms were timely and in accordance with the agreement	4.00 ± 0.91	4.34 ± 0.76	0.33	<.001*
12. Response to possible comments and complaints	4.01 ± 1.05	4.21 ± 0.96	0.21	<.001*
Recommendation to use the supplier in future (Share of recommended)	86.1 %	92.8 %	6.7 %	<.001*

*p<0.05

In testing of the Hypothesis 1B, the binomial logistic regression model was statistically significant, $\chi 2 = 496.42$, $p<.001$. The model explained 64.0% (Nagelkerke R2) of the variance in supplier recommendations and classified correctly 94.1% of the evaluations. When specific performance dimensions were taken into account, suppliers in late project phase were tended to be recommended more often ($p<0.01$) than in early project phase

(Table 3). The *quality of the product and service* had the strongest association with the supplier recommendation. Also *response to possible comments and complaints*, and *compliance with the agreed timetables* were statistically significantly ($p<0.05$) associated with supplier recommendation.

Table 3: The connections between variables and supplier recommendation (Binomial logistic regression) (n=1,374 evaluations)

Variable	B coefficient	Significance (p-value)	Exp(B)
Project phase (Early=0; Late=1)	.824	.003**	2.281
Supplier's attitude to occupational safety	.154	.549	1.166
Cleanliness, order, and consideration of environmental issues	.001	.997	1.001
Observance of safety regulations and guidelines	.195	.401	1.215
Activity in promoting safety	.108	.655	1.114
Supervision of work	.293	.090	1.341
Compliance with the agreed timetables	.452	.001**	1.571
Additional claims in relation to the contract	.254	.061	1.290
Knowing the content of and compliance with the agreement	.107	.580	1.113
The quality of the product and service	1.08	.000**	2.945
Development activity	.034	.862	1.035
Billing and payment terms were timely and in accordance with the agreement	.169	.320	1.184
Response to possible comments and complaints	.632	.000**	1.881
Constant	-9.980	.000**	0.00

*p<0.05; **p<0.01

The connections between supplier recommendation and product and service quality as well as compliance with timetables are illustrated in Figure 1. The figure shows that early suppliers received systematically lower recommendations than late suppliers with the same grades in quality and schedule.

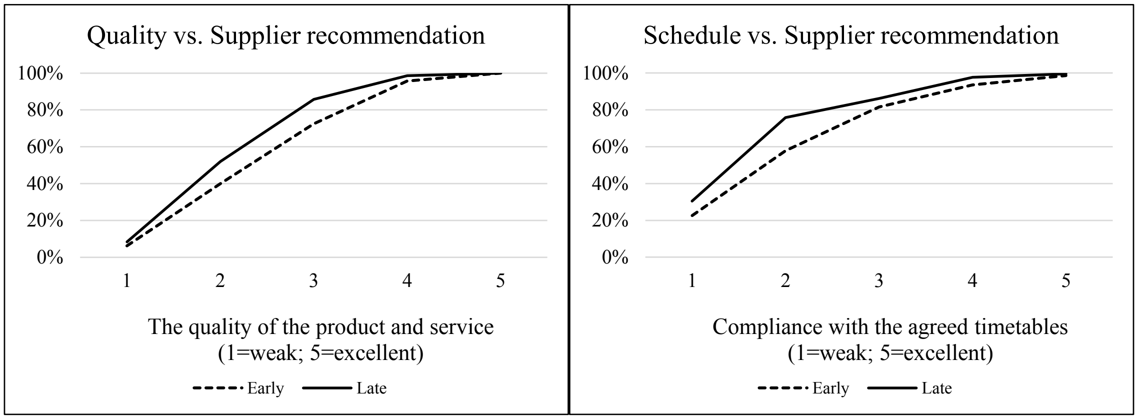

Figure 1: Share of recommenced suppliers compared to the grades of quality (left) and compliance with schedule (right) in early and late evaluations (n=1,374 evaluations)

As a summary of the results, the data confirmed the both hypotheses 1A and 1B and therefore also the main hypothesis. Based on the analysis contractors gave higher evaluation grades for suppliers of late project phases compared to suppliers in early project phases. That was confirmed as in 10 of the 13 performance dimensions the later evaluations were statistically significantly higher. In addition, when sub-measures of supplier performance were taken into account, the contractor tended to recommend more often the use of suppliers of late project phases than suppliers in early project phases. In conclusion, the contractor tended to favor suppliers of late project phases over suppliers in early phases in their evaluations.

DISCUSSION

The purpose of the study was to increase understanding about the connection between the timing of supplier's activity during project life cycle and the perceived performance.

The empirical analysis revealed that supplier recommendation was strongly connected with grades of typical project performance indicators, time and quality. Also response to comments and complaints was connected with recommendation. The findings indicate that contractors emphasize these dimensions in their evaluations. Therefore, minimum requirement for suitable supplier evaluation could be to incorporate three dimensions, schedule, quality, and treatment of complaints, into the system. Other dimensions, such as safety and supervision, may be important but not critical when recommending suppliers for further projects. The findings are mostly aligned with the existing research about critical dimensions (Biesek et al. 2008; Elfving and Ballard 2013), however, the role of cost was minor in this research. The reason might be that costs are rather fixed during the project but shedule and quality issues require more everyday attention from on-site superintendents.

The results supported the research hypotheses by indicating that in addition to time, quality, and treatment of complaints, also timing of supplier's activity and related evaluation impact on supplier recommendation: Superintendents tend to favor suppliers of the late project phase over suppliers in the early phase. The findings underline that supplier evaluation is highly subjective issue and that the perceived value cannot be fully explained by objective submeasures. Also context-related issues, such as project life cycle, affect the evaluation. Contractors can utilize this knowledge by improving the objectivity of their supplier evaluation systems. That can be done either by increasing consciousness of the phenomenon among project superintendents or by taking it into account in supplier selection process. With more accurate and appropriate supplier evaluation systems, contractors can develop their project organizations in order to collectively eliminate waste and increase customer value.

The study findings contribute to existing literatures about lean construction, projects and supply chains. The study contributes on previous lean supplier research by arguing that subjectivity in evaluating the value of suppliers might affect preferred supplier programs. To project management literature, the study highlights the role of project life cycle on relationships between project organizations. Although the empirical study could not reveal the exact mechanism behind the connection between project phase and supplier recommendation, the results support the argument about dynamic nature of uncertainty and complexity in projects and related dynamism in attitudes toward project suppliers. The findings also contribute to supply chain management and supplier evaluation literature by indicating that not only the life cycle of supplier relationship, but also the life cycle of the specific context of the relationship, project, affects attitudes about the relationship. In summary, the research increases understanding about supplier relationships in project context. Projects are specific and complex contexts in which the development of relationships may be more cyclical than in manufacturing and other more continuous and less uncertain production contexts.

CONCLUSIONS

The study indicates that contractors tend to favor suppliers of late project phases over suppliers in early phases in their evaluations. Contractors are more willing to recommend further use of late suppliers than suppliers of the early phases of the project.

The study has several limitations which hinder the applicability of the results. First, the study was conducted in a specific setting using data of a Finnish contractor. It is possible that the specific regional context affected the findings due to e.g. lack of markets in some offerings. There might be also problems in data accuracy. The date of evaluation was used to define a project phase, which might differ from the actual activity of a supplier. We also did not have data about projects' overall success, complexity or uncertainty. Therefore, the proposed mechanisms behind the identified empirical phenomenon are rather theoretical and more research is needed to clarify and justify them. This would require either a qualitative approach or prospective data gathering in which also other variables, such as project complexity, uncertainty or value are taken into account. It would also be interesting to look at the objective measures of project success (for example actual vs. budgeted costs and actual flowline diagrams) and compare them to subjective evaluations.

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EXPLORING 'LEAN' OPPORTUNITIES FOR IMPROVING SUPPLY CHAIN TRANSACTION GOVERNANCE IN SOUTH AFRICAN CONSTRUCTION PROJECTS

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ABSTRACT

Transaction governance dictates how members of a construction supply chain (SC) work together for the delivery of a project. This practice is the same in South Africa where many problems have stalled the achievement of expected value for the client. In an attempt to understand the problem better, an exploratory study that assessed 'how do transaction governance structures between SC members affect project delivery in South African construction' was conducted in 2015.

Using a single case study research design that was underpinned by the review of relevant literature as a starting point, it was observed that project parties in the case project have not moved away from the practice where the contract data form the basis of interaction among them. The study shows that optimum risk allocation approach that is evident in profit / reward sharing and collaboration is hindered by traditional view of transaction governance that is plagued with mutual distrust and antagonism. In other words, there appears to be a major scope for the introduction of integrated (lean) project delivery method that will foster collaboration and a culture of teamwork that favours improved project performance in South Africa.

KEYWORDS

Construction, Governance, Supply Chain, South Africa

INTRODUCTION

Reports in the last few decades indicate that the construction industry is failing to deliver as expected in terms of expected socio-economic gains due to problems in which the contributions of fragmentation is notable. Fragmentation in supply chains may result in financial problems, operational capital problems, delayed payment from clients, substandard designs and specifications, lack of technical proficiency, poor

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information sharing among supply chain members, production ineptitudes, poor work quality, work method issues, and project delivery reliability issues (Benton and McHenry, 2010).

For example, despite significant investments, promising construction projects often produce enormous wasted time and finance (Forbes and Ahmed, 2010). This underlines the rationale for the industry to change. Close to home, the construction industry lacks innovation or "out-of- the-box thinking" in South Africa (Rust and Koen, 2011). However, general construction problems are not limited to South Africa: the construction industry is facing challenges in developing economies (Ofori, 2012).

The world has adapted to tackling these issues through supply chain management (SCM), integrated project delivery (IPD) and building information models (BIM). To tackle the effects of division and adversarial relations, researchers and other experts in the construction industry have shifted their focus to SCM for the purpose of making the industry more efficient (Khalfan et al., 2004). SCM is applied to logistics, supply, manufacturing, and distribution needs in construction from a technological standpoint, which involves BIM (Dong et al., 2013). The successful aspects of integrated collaboration using BIM can be categorized as product information sharing, governmental roles interaction, and production activities coordination, conditions for teamwork and reference data-merging (Khalfan et al., 2015).

However, in South Africa, the use of technology is not adequate for improved performance because of the multiplicity of work culture in the industry (Emuze and James, 2013). This implies that better responsibility amongst all members within the industry needs to be the norm. Friendship has to be built between SCM members for collaborative information sharing and lasting partnerships. This research therefore explored the impact of transaction governance structure (TGS) on the management of supply chains by asking 'how do transaction governance structures between supply chain members affect project delivery in South African construction'. This is premised on the view that project processes require effective governance in order to deliver value to clients (Winch and Carr, 2001).

The paper provides an overview of TGS by highlighting what is it by showing the role it plays in an economic system. Thereafter, the method of the study is presented before results of face-to-face interviews are discussed. The paper closes with further discussions on how to take the research forward in South Africa.

AN OVERVIEW OF TRANSACTION GOVERNANCE

Research in construction supply chains using IPD principles has aided in the completion of high performance projects through the creation of a collaborative system; which can be used to address traditional construction procurement issues (Akintan and Morledge, 2013). The construction industry is currently specialized to such a degree that no single firm is capable of providing all the specialized expertise needed; thus there are numerous firms focusing on different disciplines to meet varied and complex demands. Therefore, understanding what TGS is and its role in the industry is important in practice.

What are transaction governance structures?

TGS is defined as the legitimate systems of governance that apply to various types of transactions and the organizational and administrative precautions that parties assign to a transaction (Ring and van de Ven cited in Zhang, 2006). A TGS is created during each society's evolution. It has a distinctive blend of market, social and legal attributes, which has influenced studies on it move from traditional competitive, "arm's length", buyer-supplier relationships towards longer-term, more complacent relationships where buyers and suppliers view one another as partners. The movement is taking place because the essence of partnership is a commitment to a collaborative exchange where parties mutually share project risks and opportunities (Patterson et al., 1999).

Transaction cost economics (TCE) is an essential anchor for studying an extensive series of economic and organizational problems (Zhang, 2006). TCE framework governs exchange of goods and services among technologically separable interfaces based on two assumptions: resourcefulness and confined rationality (Williamson, 1979, Williamson, 1981). The basic insight of TCE is that in order to economize on the total cost of a service, production costs and transaction costs have should be aggregated (Winch, 2001). Winch (2001) noted that TCE focused on understanding the drivers of transaction costs. The elaborate transaction governance framework in Winch (2001) shows how the right choices of transaction governance mode are affected by three contingency factors (uncertainty, frequency and asset specificity). These contingency factors interact with each other. As an illustration, the absence of uncertainty would allow contracts to negate opportunistic behaviour that may arise from asset specificity (Winch, 2001). When asset specificity is removed from a setting, negotiations to handle unforeseen events can proceed when they occur; and frequency determines the return from investing in transaction-specific modes. However, differences in institutional context often shift the interactive space between these contingency factors (Winch, 2001).

What is the role of TGS in a supply chain?

TCE centres on the body of transactions that take place each time a good or service is transferred within a supply chain. When transactions are domestic, costs implied by such transaction consists of managing and coordinating personnel and acquiring contributions and capital equipment. Similar to the norm in construction, the transaction costs of purchasing the identical good or service from an outside supplier can consist of source selection (bid process), contract administration, performance evaluation, and dispute resolution, as a result, TGS have an influence on transaction costs (Williamson, 1979, Williamson, 1981).

However, TGS is deviating from hierarchical (vertical) integration to a greater amount of outsourcing. It is diverting from self-ruling market rivalries to partnerships. The deviation is against the backdrop of outsourcing, which is one of the principal requirements for integrated SCM in construction (Benton and McHenry, 2010). This, however, poses its own set of questions: single versus multiple sources. The principal advantage of multiple sourcing is the creation of a competitive supply base. It is generally accepted that competition has a direct correlation with driving costs down. The other factor is that multiple supply sources assure undisrupted stream of material. The principal advantage of single-sourcing is that the supplier is more comfortable with reducing the cost per unit; another benefit is cooperation and communication which leads to win-win relationships among buyers and suppliers.

The time requirement and the comprehensiveness of contracts is another aspect of TGS. An all-inclusive and enforceable contract is challenging to compose, particularly when the intent of the transaction is complex. If contracts are intrinsically imperfect, parties might notice possible gains from unprincipled conduct, even in a construction enterprise (Pryke, 2012). Therefore, care must be devoted to more diverse governance devices so that gaps in agreements could be bridged, and conflicts could be resolved in unexpected situations (Zhang et al., 2004). Clear management of TGS involve negotiation and multi-dimensional communication among members to accomplish integration of monetary undertakings that are cooperatively held and to address problems that cannot be supervised through autonomous activities or implicit coordination. Implicit coordination takes place when a company activity is spotted, predictable, and matched with activities of other companies (Zhang et al., 2004).

METHODOLOGY

The study aimed to understand the relationship between TGS in the supply chain and project performance in South Africa. To comprehend the issues around the aim, a case study was conducted in Bloemfontein in South Africa. The project involves the construction of an outdoor cafeteria, consisting of two adjacent vendor stations with a covered seating area in the centre. A qualitative research method is often used for SCM research in construction (Tennant and Fernie, 2012a, Tennant and Fernie, 2012b). This is also evident in the SCM papers that have been dissemination within the IGLC community (Emuze, 2015). Such case studies, similar to this study, often try to emphasise the understandings within supply chains by focusing on decisions, interactions and actions of different actors. Thus, the method is arguably well placed to illuminate the actions of actors, and their functions regarding TGS in the supply chain (Yin, 2013). Amongst the various data collection methods used in case studies, the face-to-face technique was used in this study that was conducted in August 2015. However, the use of a single data collection method among the many known methods in case studies is a clear limitation of this research.

Nevertheless, all interviews were tape recorded, transcribed and entered into field notes where necessary. The selection of the participants was unstructured but focused on the SCM team in the selected project. While ten members of the SCM team of the project agreed to participate in the interviews, there was only opportunity to conduct six interviews with two quantity surveyors, one principal agent, one contractor, and two professionals working for the client. The total number of interviews was therefore six, which made the data collection somewhat less rigorous. However, since in qualitative studies, interviews range from 5 to 25 in number (Yin, 2013), a decision to proceed with data analysis was made by the researchers. Rather than generalising into a population sample, the aim of the study is to explore and if possible attempt analytic generalisation (Flyvbjerg, 2006). In demographic terms, the interviewees were all university graduates that are exposed to business and project aspects of construction management. One of the interviewees, who hold a director position in a quantity surveying consultancy and a PhD degree, has been in the industry for over 40 years. The junior quantity surveyor that was interviewed has been in the industry for four years. He holds an honours' degree in quantity surveying. The interviewed principal agent has been in the industry for over 20 years and he holds a masters' degree in Architecture. The acting deputy facilities manager that was interviewed has been in the industry for 16 years. He holds a bachelor's degree in Building. The assistant facilities manager however has four years of industry experience. The interviewed

Site Agent has over 12 years of industry experience. He holds a National Diploma qualification in Building.

The interview protocol was semi-structured with open ended questions. Section one enquires about demographic information while section two addressed the research questions of the study. The use of such semi-structured protocol is suitable because it unfolds in a conversational way that offers interviewees the chance to explore issues based from their experiences (Longhurst, 2009). The collected interview data were examined by focusing on the central question of the study in terms of the approach to the representation of data.

RESULTANT TEXTUAL DATA

The central research question guided the six interviews. Despite the guidance, the interviews were unstructured so that the interviewees could freely elaborate on each questions based on their knowledge and experiences. As a start in each interview, descriptions of SCM and TGS were made to focus the discussions. Broad questions of the interviews are used to present the analysed data as follows.

Question 1: How is transaction governance structured within your company?

Question one focuses on the channels through which transactions amongst parties flow from the top tier of management to the lowest tier in the organisation structure of the project. The question was asked in order to gain a better understanding of how the SCM members interact with one another and how these interactions are governed. For instance, the client used a predetermined internal policy that guides the supply chain team on how consultants and contractors are appointed and governed as shown in Table 1.

Table 1: Observed procurement structure of the client in the case study

Estimated value	**Procurement Method**	**Authorization**
<R 10 000	One quotation from preferred 'supplier' list	Deputy Director of Facilities Management
R10 001- R 100 000	Two quotations from preferred 'supplier' list	Deputy Director of Facilities Management
R 100 000 – R 500 000	Three quotations from preferred 'supplier' list	Deputy Director of Facilities Management, with approval from the Director of Facilities Management
>R 500 000	Selected tender procedure from preferred 'supplier' list	Deputy Director of Facilities Management, with approval from the Director of Facilities Management and Deputy Vice-Chancellor

This system does not apply to appointments only, but also it applies to payment certificate approvals. This internal policy determines the way in which parties within the client organisation interact with one another. During construction projects, this policy and the Joint Building Contracts Committee (JBCC) principal agreement govern exchanges amongst the client, consultants, and the contractor. The contractor's system was interesting as the site manager is in complete control of all transactions on site. For example, he appoints suppliers, approves payments, and is the only channel of communication. This observation aligns with the JBCC principal agreement, which explain that all transactions related to subcontractor work flows through the contractor. The quantity surveying (estimator) firm policy follows a standard two-tier organisational structure that is governed by employer-employee policy in conjunction with the principal ethical and professional standards laid out by the Association of South African Quantity Surveyors (ASAQS). For example, estimate format, and standard system of measuring builders' work follow the ASAQS guidelines. These professional guidelines are augmented with standard documents to help monitor employees in completing their obligations, which are the standard system of measuring builders' work, standard preambles to trades, and the elemental guide to estimating builders' work. The policy directs the internal transactions of the firm, and also governs interactions with external parties through the use of the quantity surveying - client agreement. The architectural firm, however, has no formal policy, which governs its internal interactions; instead it has what is called an 'open door' policy. There was no mention of whether an architect - client agreement is used to govern external transactions; instead the interviewed architect stated that the JBCC principal agreement was the TGS followed.

Question 2: How does this structure affect/influence your supply chain?

This question focuses on how the individual system of each member of the supply chain in the project impacts the success of the team. The majority of the interviewees stated that the TGS employed has a positive impact on the supply chain. The JBCC principal agreement is the main contract that guides all transactions in the project. The JBCC gives a detailed description to what has to be done by each party, how much it costs, when and who receives payment; and how and where it must be done in order to deliver a complete project on time and within budget. This positive response of the interviewees is mainly based on enforcement / compliance to the terms of the contract document as opposed to collaboration / partnership.

Question 3: How would you describe the relationship between transaction governance structure and integrated project delivery?

This question focuses on how the TGS provides a basis for an integrated delivery system. The majority of the interviewees had a negative view on the IPD system. All of them, who are operating under the current procurement system, were of the opinion that the tendering system has no room to cater for the integration of contractor in the early stages of the contract. The contractor, however, expressed enthusiasm for the idea. The quantity surveyors stated that South African contractors lack the knowledge to manage a site properly without 'checks and balances', which makes the client vulnerable to risks. The quantity surveyor, however, recognized that the JBCC principal agreement is structured in such a way that risk is placed with the parties who should be responsible for the risk. None of the interviewees were able to answer this question in a robust and insightful manner, but enough information was obtained to draw a conclusion.

Question 4: How have different technological tools improved team decisions and overall project delivery?

The question focuses on how technological advances have improved project delivery. Most of the interviewees stated that technology has made construction progress faster, as all supply chain members are available at the click of a button. The most popular technological advancement mentioned is the email. The interviewed architect stated that Revit and AutoCAD programs have revolutionise the design process as it easier to make changes to construction drawings. Revit's three-dimensional rendering has made it easier for the client and end-user to visualize the proposed building. The quantity surveyors stated that Dimension X program has made measuring much easier and quicker.

Question 5: Who has the inputs into the project decisions?

This question focuses on who are the major decision makers within the project. All the interviewees stated that the majority of the decisions are made jointly by all the supply chain members, but all decisions that affect the contract price and delivery date must be approved by the client through the principal agent.

DISCUSSION

The central question of the study tends towards two objectives that are used to discuss the findings of the study in this section as shown below:

Objective 1: Establish transaction governance structures

Based on the responses provided during the interviews, the TGS utilized in the case project can be described as a framework of rules and regulations, which are recognized by law and relevant professional bodies in South Africa. The framework dictates how supply chain partners within an agreement interact. In construction, the interactions between parties of the agreement are often controlled through a set of terms and conditions set up within the contractual agreement. The most preferred contractual document used in South African construction is the JBCC principal agreement (Othman and Harinarain, 2009, Richards et al., 2005). However, the JBCC does not cater for the establishment of a collaborative working arrangement that is aligned with the intentions of an integrated TGS that is supported by an appropriate contract form (Lowe, 2013). The supply chain structures in Southern African construction, which include countries such as Malawi and South Africa are often fragmented because of the focus on contract data and other people related issues (Emuze et al., 2015).

The establishment of an alternative governance structure that promote SCM ethos is vital for the continued improvement of the construction industry in South Africa and other countries in which construction is a major contributor to gross domestic product (GDP) (Dainty et al., 2001). Instead of setting up multiple contracts with various actors within a supply chain, multiple-party agreement based on partnership could be established as clearly explained in the literature (Forbes and Ahmed, 2010, Rubrich, 2012). These partnerships will establish 'true' information sharing mechanism. For example, where information is being exchanged, the contractor would be fully aware of the actual budget of the project, and consultants would also be fully aware of how the contractor built-up his rates, etc. If necessary, a confidentiality agreement could be incorporated in such contract agreement. Additionally, risk-sharing will be possible, instead of risk being transferred to different parties according to their duties (Hallikas et al., 2004). This risk-sharing will lead to rewards / profits being equally transferred, as IPD promotes early contractor involvement (Rubrich, 2012). This means that the conventional payment structure of the case project would need to alter to a certain extent, if the parties are convinced about the benefits of IPD. As an illustration, milestones need to be established by the project team at inception, and in achieving these milestones; all parties could receive an incentive bonus. In other words, a TGS based on partnership could eliminate the need for a single gatekeeper through a contract data – the JBCC in this case. The parties forming the IPD will not only protect clients' interests, but also, they would have an interest to act appropriately regarding a dispute resolution medium (Forbes and Ahmed, 2010).

Objective 2: Determine how transaction governance structures function within a supply chain

As shown in this case project, in South Africa, consultant-contractor relationships are plagued with mutual distrust and antagonism. Perhaps, the JBCC principal agreement may be unintentionally promoting a situation where intricate surveillance and control centered on construction programs, certification of milestones, bill of quantities, and cash flow schedule, is compensating for the absence of trust between project parties. This in turn generates many hidden transaction costs. For example, there is a need to pay specialized staff that must operate all control systems. The relationships is such that all risk for non-completion is placed on the contractor, while the professional team bears little risk, but receive substantial percentage of professional fees prior to start of construction; this removes the anchor keeping most of the professional team completely interested in the project from beginning to end. Hence, a TGS that should aim to minimize risks and maximize successful completion of the works is evidently lacking in this case project in contrast to practices advocated in the lean construction research and practice community (Sakal, 2005, Kent and Becerik-Gerber, 2010). A construction contract should function in a supply chain as a cost-controlling mechanism, risk minimizer, and a template for project delivery (Pishdad-Bozorgi et al., 2013). This is not the case in the researched project. Therefore, the case project requires a platform in which an integrated TGS can be applied, especially with the use of lean construction techniques so that culture and orientation may be positively altered to improve the decision-making process and client satisfaction.

CONCLUSIONS

An exploratory study on TGS and opportunities for 'lean' is the foundation for this paper. The nature of contracts employed to monitor transactions among supply chain members in the case study hinders the implementation of an integrated SCM structure, and is contributing to antagonistic relationships within the chain. There is a chance to look at lean IPD for improving the status quo. Regarding the central query of the study, TGS does affect the supply chain in South Africa. The industry should however move away from this TGS practice, which promote one-off relationships where parties protect individual interests. Rather, the industry should adopt practices, which provide a basis for IPD. As opposed to technology such as BIM, the lean IPD that promotes collaborative communication, joint risk-reward sharing, and withdrawal / assignment should be considered.

Based on the perceptions of the interviewees, SCM members in the project interact with one another based on signed contractual guidelines. The interaction is governed by the JBCC that is used for engaging the services of everyone involved in the project. The traditional tendering system, which is supported by the JBCC that is used to govern contracts is failing to promote collaboration. This realisation from the exploratory study requires further assessment of how different transactions that take place in a construction project life cycle are coordinated and controlled so that client's requirements are met. There is a need to find out how SCM principles could be used to govern project teams in favour of reduced reliance on complex contracts. Similar 'how' questions should form the basis of future research on TGS and SCM in South Africa?

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INTEGRATING LEAN INTO MODULAR CONSTRUCTION: A DETAILED CASE STUDY OF COMPANY X

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ABSTRACT

Value stream mapping is a valuable tool in the lean toolbox that truly uncovers hidden waste in a process. Recent researches have focused on process improvement in various construction domains, but more research need to address precast concrete operations at the plant. This paper seeks to investigate the integration of lean principles in the fabrication phase of modular construction by using value stream mapping. The research focuses on the plant processes used to produce precast concrete pre-slabs and on means of improvement. It presents results from a case study of Company X’s precast plant. Data describing the current state of pre-slab casting was collected from plant visits, the current value stream map is drawn, and a future state map is then recommended. Indeed, alongside some effective lean concepts that are applied at the plant such as preventive maintenance and autonomation, some weaknesses are identified such as sizeable raw material storage, large batch sizes, considerable final product inventory and lack of “shine”. Appropriate remedial measures are recommended such as reducing batch and inventory size, creating FIFO lanes as well as applying 5S across the plant.

KEY WORDS

Value stream mapping, lean principles, modular construction, precast operations.

INTRODUCTION

For the past three decades the construction industry has been adopting successful practices from the manufacturing industry in an attempt to achieve a quicker, cheaper, and better quality construction. The principles of the Toyota Production System (TPS) were welcomed by modular construction academics, and the consequent research on lean construction has been paving the way for smarter methods of construction. One of the links between the TPS and the modular construction industry is that a lot of the items needed on site are manufactured in factories and delivered just in time. This process, therefore, highly resembles the production process of any built-to-order item similar to the process used by Dell computers, where each product is created according to customer’s specifications.

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In markets where loans are low, manufacturing size is small, and customers are hesitant, contractors become hesitant about stocking any pre-fabricated items due to the low and unstable demand. Initially, large companies would be comforted by their economies of scale, but smaller companies would feel the need to take drastic changes to reduce their stock and adopt smarter methods of production and delivery in order to reduce waste (Nahmens, I., & Mullens, M. A. 2011).

Hence, lean manufacturing principles have been integrated into the field of modular construction at a decent rate. Several researchers have targeted the benefits that could be drawn from such a step. Early work by Ballard, Harper, and Zabelle (2002) aimed at illustrating the impact of applying lean concepts to the fabrication of precast concrete. Their experiment showed noticeable improvements in demand management, cycle time, productivity, workforce involvement, revenue, and profitability. These improvements were realized using existing technology and operations with little capital investment emphasizing the high efficiency of lean processes.

A more recent pilot study conducted by Manufactured Housing Research Alliance (2007) proved that lean techniques incorporated in factory home building could significantly increase efficiency and quality. The study subsumed nine different home manufacturing plants each of which has witnessed remarkable improvements in various areas. Over 100% increases in efficiency were recorded in some production departments. As for quality, an 85% overall reduction in defects was achieved in a certain process. Different plants also experienced ameliorations in work moral and communication between management and workers.

One way to efficiently implement lean principles in modular construction would be to first map material and information flows, the value stream. In fact, value stream mapping (VSM), a tool that has been frequently used in the manufacturing industry, was used in a few construction related research. Simonsson et al (2012) showed how VSM can help visualize the workflow in a construction project and the effects of the improvements or modifications made to the workflow. In another study in a Brazilian construction company, VSM allowed detecting problems and identifying the proper actions for improving the masonry process in construction using lean tools (Pasqualini & Zawislak, 2005).

This paper uses Company X as a case study to explore the process of modular lean construction. This company is currently producing precast pre-slabs for the construction of a big mall. The paper will seek to evaluate where the company stands from a lean perspective by drawing the current value stream map. Then, the study will seek to further enhance the company's performance by drawing an appropriate future state map and providing pertinent recommendations. Further recommendations will be provided for a more advanced lean process in the far future.

VALUE STREAM MAPPING (VSM)

A value stream map (VSM) is the visualization of all the processes involved in the production of a certain product. It takes into consideration a range spreading from the time the order is made by the customer till the time the product is received, also included in this range are the aspects of design from concept to operation. Value Stream mapping mainly consists of information gathering, current state map drawing, and future state map drawing followed by an implementation plan (Rother & Shook, 1999).

The advantage of a VSM is the ability to focus on the problems hindering progress from a broad perspective and, accordingly, improve the system as a whole by tackling the root causes, instead of only tackling the problems by independently optimizing stations.

The “door-to-door” analogy is used in VSMs to show how processes are separated and how transitions occur between working stations/departments. This enables process planners to make further connections between suppliers and working stations. It may also eliminate other doors by merging several processes to achieve a rhythmic flow.

This process is mainly aimed at optimizing the flow through finding the sources of waste, linking all manufacturing processes to one visual language, and enabling companies to learn from each other. It also links the flow of information and material and allows the manager to create a visual representation of the production process while on site (*Rother, M., & Shook, J. 1999*). This leads to the desired future state map that would show beforehand the effect of making these changes on the production speed and efficiency. Furthermore it creates a roadmap that would direct towards a more efficient process in the future. A key to continuous improvement would be then to go through this process of information gathering, current state map drawing, future state map drawing, and implantation plan setting in a continuous cycle

METHODOLOGY

First of all, the study identifies the actual state of the system through a current state map. The authors conducted visits to the Company X’s factory (the Gemba). Observing the processes alongside meeting with the workers and managers, the authors gathered information on the production process. On one hand data is gathered describing information and material flows in the factory (internal flow), mainly focusing on the following parameters: equipment and tools, number of people, available working time, uptime, cycle time, storage time, and inventory (raw material, WIP, and finished goods)

On the other hand, information on the factory's customer demand and material procurement (external flow) is collected describing the following:

Material requirement planning

Customer demand (size and rate)

Product delivery (size and rate)

After collecting the required data, the current state map is drawn focusing on both material and information flow.

In order to take the exercise to its full-fledged goal, the authors then identify waste in the system and seek to improve the process. A future state map is then drawn incorporating waste eliminations as well as system improvements. Finally, long term future recommendations are proposed with the goal of making the process even more lean.

CURRENT STATE MAP (CSM)

The scope of the value stream map will be limited to the Company X plant, starting from the materials storage and ending at the finished product inventory, while incorporating nonetheless materials supply as well as customer demand.

FINAL PRODUCT DEMAND AND MATERIAL SUPPLY

First of all, the VSM starts with Y Enterprise who contracts Company X for the fabrication of 600 m^2 of 0.1 m thick pre-slabs/day.

After being contracted by the client, the production control unit in Company X's plant office contacts material suppliers. For fine and coarse aggregates as well as for cement suppliers, it provides a monthly forecast (since they have daily deliveries). Production control also makes daily orders of fines and coarse aggregates, bi-daily orders of cement (since their suppliers are local) and steel coil orders once every 5 months (since the supplier is overseas). The quantity of fines, cement and coarse aggregates ordered is based on keeping a material storage that is enough for the upcoming 30 days, using a "Go See" mechanism. Therefore, material storage is closer to a supermarket approach than to a "push" schedule. Nonetheless, material storage is considerably high, but it is required in order to keep the plant running in spite of material shortages.

GENERAL FRAMEWORK

While ensuring the required raw material, production control also specifies the weekly schedule that is communicated to the general foreman at the plant who then schedules placement and pre-tensioning, pouring and curing in order to meet the set deadlines. The plant operates from 7:00 AM till 4:00 PM, with a l-hour lunch break at noon, and so the calculated total work time is 28,800 sec. The unit of flow in our VSM was taken to be 1 m2 of surface area.

PROCESS STEPS

The different process steps are as follows:

Cable Placement and Pre-tensioning at the plant of Company X is preformed using standardized formwork which is 140 m long, 1.2 m wide and 0.1 m thick (168 m^2 of surface). A single form allows the production of a batch of slabs. The steel cables are placed using a machine, operated by 2 workers, that was tailor-made for the process at the Company X's workshop adjacent to the precast plant. After placement, the cables are tensioned. Then, pieces of wood and cork are installed transversely at certain points throughout the 140 m long slab in order to decompose it into slabs of smaller spans (i.e. to prevent the concrete from being poured monolithically by providing a discontinuity). All in all, this takes around 21 sec/m^2, back-calculated from measuring the total time of about 60 min that was required for the whole (168 m^2) slab. At the plant, the concept of preventative maintenance is well followed. Consequently, the pre-tensioning machine has an uptime of 100%, with very rare breakdowns.

Concrete mixing is completed in batches of 0.5 m^3, which covers an area of 5 m^2 (since slab thickness is 0.1 m). Then, the batch is transported from the mixer to the formwork location in a movable metal basket automated on elevated rails (also made in-house). The process of mixing and transporting the batch to the pouring location requires about 3 min. by calculating the time required for 1 m^2, we obtain a cycle time of 36 sec. This 5 m^2 batch will be considered Work-in-Progress (WIP) during its transport phase.

Concrete Pouring is then done by a machine that moves along the 140 m formwork and pours the concrete inside the mold at a specified rate. After repetitive mixing, transport, and pouring, the 140 m pre-slab is cast.

Measuring the time required to pour the whole slab (2 hours), the cycle time for 1 m^2 is 43 sec. However, in spite of the preventive maintenance, the pouring machine still breaks down in some rare instances and needs repair, resulting in an uptime of 98%. Moreover, pouring in the plant is messy since some concrete spills over the formwork and, along with the rubble laying around in the plant, it has serious drawbacks. In the plant, several lines of formwork are available for parallel use. However, a team will only move from one line to another once it has finished its work on the previous line. Hence, each team moves to the 2^{nd} line after finishing the 1^{st} line, and this process is then repeated.

Accelerated Curing is preformed to speed up the production in the plant. Using steam curing, only 12 hours are required for concrete to reach the required strength, and only 2 workers are needed for the process. However, a certain setting time is required before curing can start in order to preserve the concrete mix's water-cement ratio. After pouring 3 slabs, curing is done for the 1^{st} one, and there are usually 2 shifts of workers that monitor curing. Uptime is usually 100%.

Cable Loosening and Cutting is done after curing. After curing, 2 workers remove the wood and cork separating different spans, and the pre-tensioned cables are slowly released. Finally, the steel cables still connecting separate spans are cut. This requires around 20 min for the whole 168 m^2 slab surface.

Staging is the final process in the plant. The finished product is moved by a crane to the storage area for delivery or customer pick up. However, the storage area is excessively full with around 5000 m^2 of finished pre-slabs equivalent to 8.3 days of production. Because of contractors delay in pick up, several pre-slabs may be left in storage for months before they are actually withdrawn. Unfortunately, this causes serious waste. Not only do they occupy space and result in storage costs, but they can be damaged due to weather conditions or to storage loads (since they are piled up on each other). This makes the pre-slabs unusable, thus leading to rework or waste.

The current state map is displayed on the following page. Lead time is 1288 hrs. while processing time is 12.4 hrs.

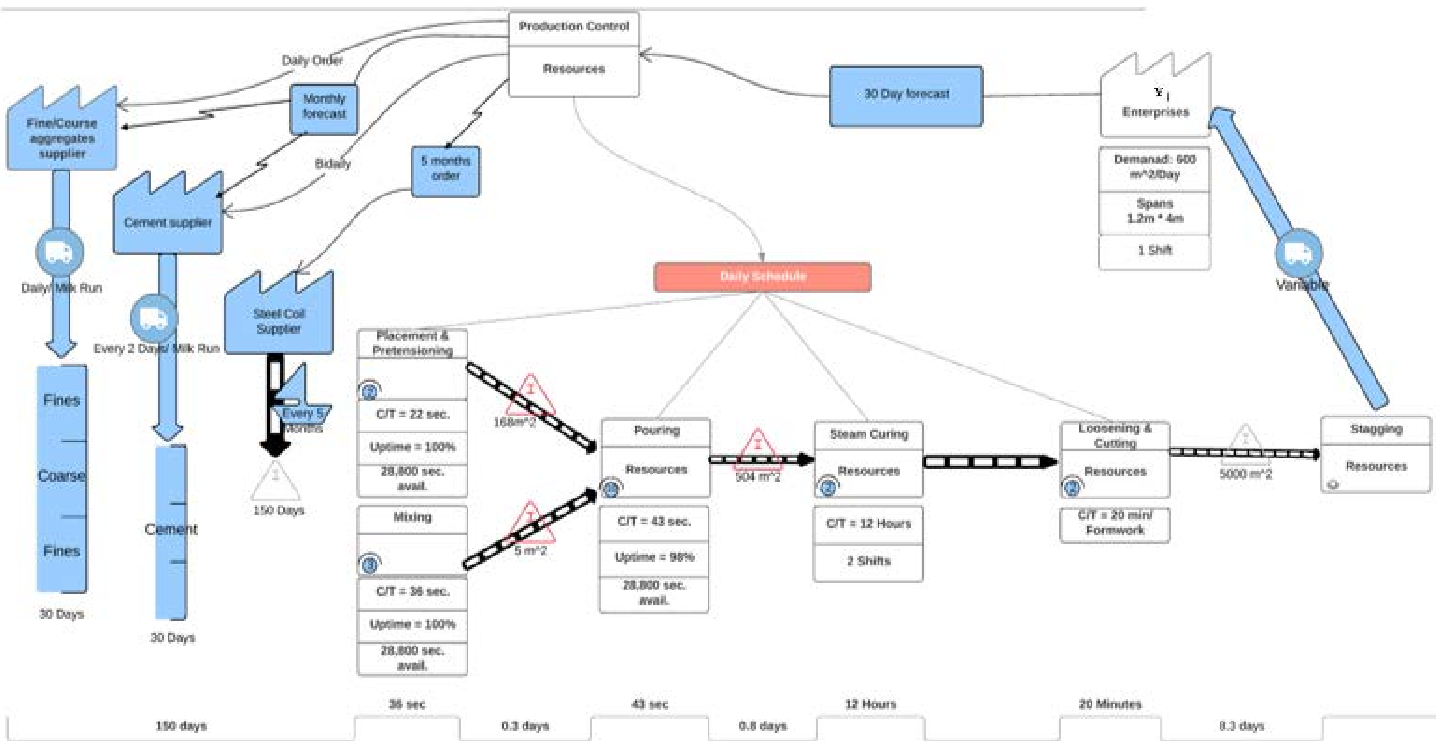

Figure 2. Current State Map

FUTURE STATE MAP (FSM)

After analyzing the CSM, a FSM is developed incorporating modifications deemed necessary for a lean value stream. These modifications aim to optimize the system using existent technology, simple additional or modified tools, and lean principles. The aim of this exercise is to use lean principles in order to improve manufacturing process without incurring considerable costs.

As a first step, Takt time (customer demand rate) is determined in order to identify the pace at which the production process must be running (Rother & Shook, 1999). Takt time is calculated as follows:

$$Takt\ Time = \frac{Available\ Working\ Time\ per\ Day}{Customer\ Demand\ Rate\ per\ Day} = \frac{28800}{600} = 48\ sec$$

The CSM shows that all of the processes, except for curing, loosening and cutting cables, have a cycle time that is below Takt time. Yet a good practice is to try to reduce the difference between different cycle times and, consequently, reduce the quantity of work in progress (WIP). For this purpose and some others, discussed below, the following improvements are made to the current state map:

Kaizen-1: Knowing that there should be a certain quantity of mixed concrete ready to be poured, concrete mixing and concrete pouring cannot be incorporated into a one piece flow. However, we can run the two processes at equal rates (43 seconds) if we maintain a certain buffer between them. In this sense, concrete would be equally withdrawn and replenished. This would impose a limit on the quantity of mixed concrete.

Kaizen-2: In order to further control production of mixed concrete, FIFO (First in First Out) will be used. FIFO could be conceived as a lane that once gets full signals to the supplying process to stop producing (Rother & Shook, 1999). In this case, a part of the bucket of the pouring machine in which concrete is placed could function as a FIFO. If FIFO gets full under certain circumstances, the production of concrete is triggered to stop.

Kaizen-3: The cycle time of placing, pre-tensioning, and tying cables will be increased to match that of pouring (43 seconds). Slowing down this process would reduce the waiting time of the machines involved in this process but cannot reduce the amount of work pushed to the downstream process (Pouring). This is because pouring cannot start until cables along a whole formwork (140 m in length) have been tensioned. This inventory is conceived as necessary waste and cannot be reduced unless the length of formworks used is shortened.

Kaizen-4: The formworks will be made 30 m in length. Using 30 m long rather than 140 m long formworks (as an initial goal) would not only reduce the quantity of inventory between the processes but also time wasted while waiting for a prerequisite activity to finish. The quantity of inventory between cable tensioning and pouring would decrease from 168 m2 to 36 m2. A FIFO can be introduced between the two processes to ensure that the quantity of inventory does not exceed 36 m2, the minimum necessary waste (i.e. as soon as cabling is finished, pouring starts).

Kaizen-5: Considering a setting time of 4 hours and pouring time of two hours for a whole formwork, curing the first formwork cannot start until two other formworks are poured. Thus, under these conditions, the quantity of WIP (504 m2) between the two processes is deemed necessary and cannot be reduced since enough time must be devoted for concrete setting after pouring. Yet FIFO will be used to create a pull mechanism and prevent overproduction under any circumstances.

Kaizen-6: The variable final product inventory will be replaced by a FIFO lane that will limit its size and provide a pull rather than a push mechanism. The stock will match demand for 2 days, reducing the production lead time by 6.3 days. In order to achieve this goal, reliable promising and close communication are required with the contractor on site so that the exact time of pick up can be determined realistically. This would greatly reduce the quantity of product that might not be eventually sold due to damage or changes in customer demand. Consequently, rework and overproduction are reduced.

Kaizen-7: Although scheduling is a must when it comes to shipping material from one country to another, a lead time of 5 months is considered an excessively long period. We must reduce the size of the steel coils batch to overcome the problems resulting from storing steel for a long time. Instead of ordering 30 tons of steel coils every 5 months, we can order 15 tons every two and a half month.

Kaizen-8: In spite of the preventative maintenance procedures followed at the company, uptime of the concrete pouring machine must be increased to 100%. This could be done using the "5S programs." These programs consist of eliminating waste that could result in defects and even injuries in the workplace (Liker, 2005). Particularly, shine (cleanliness), one of the 5S, reveal pre-failure conditions that cause machine failure. This will allow for a more efficient preventative maintenance. It will also ensure a safer working environment for workers.

Finally, having a plant operated using FIFO, pull is prevalent all throughout the process. This eliminates the need for the daily schedules previously assigned to each process. Rather, the work will only need to be communicated to the first process, and the rest will flow. Incorporating these changes into the current state map, a future state map is presented below. The total lead time is 636 hours while processing time

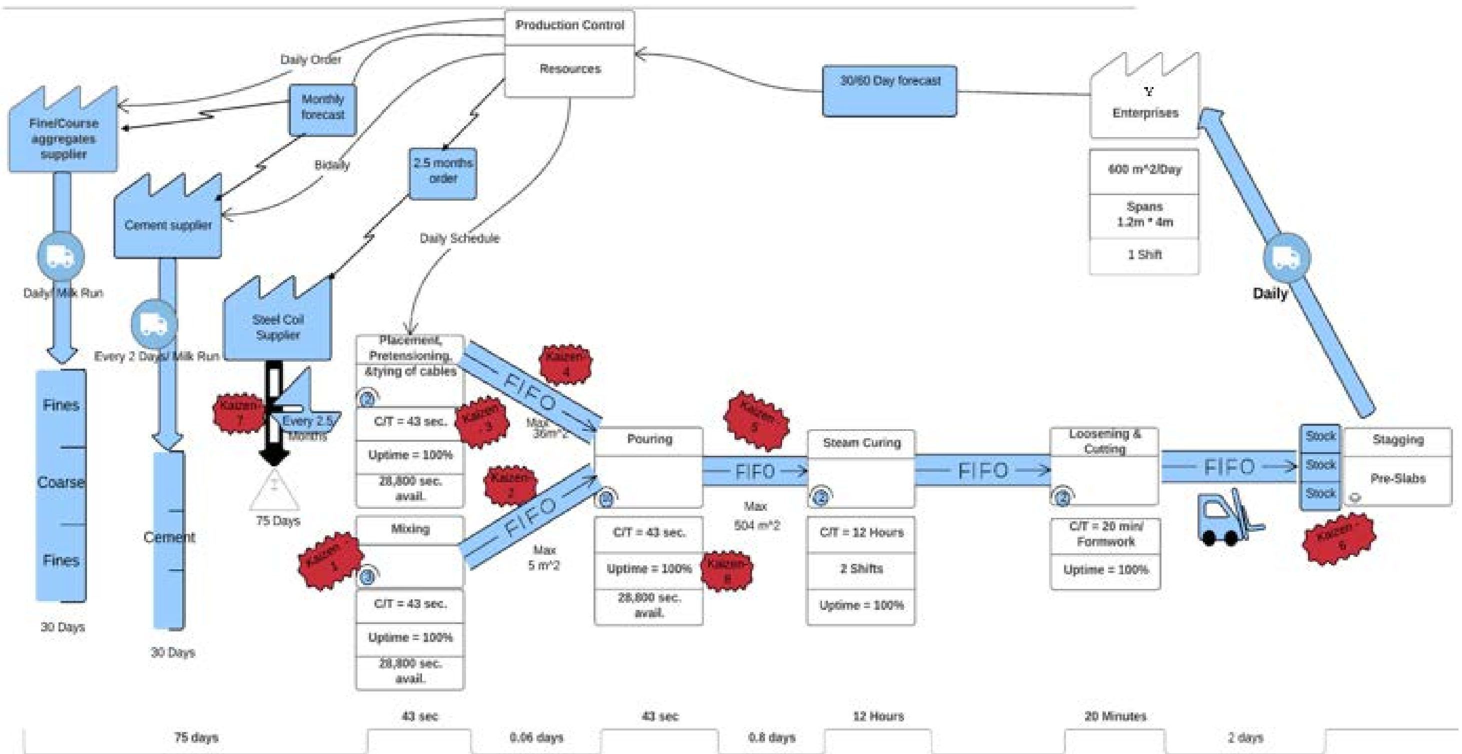

Figure 3. Future State Map

is 12.4 hours.

NECESSARY IMPROVEMENTS FOR A MORE LEAN PROCESS

For Company X to achieve the material and information flows visualized in the FSM, the following improvements must be realized in the process:

Reduction in the rates of concrete mixing and cables tensioning processes to match that of concrete pouring (43 seconds) by properly reallocating resources.

Use of FIFO between different processes to control production and avoid unnecessary waste at each process.

Reduction in the formwork length from 140m to 30m to considerably reduce batch size.

Replacement of the final product stock with a 2 days FIFO lane, relying on reliable promises and close communication with the client.

Reduction in the batch size of steel coils from 30 tons ordered every 5 months to 15 tons ordered every 2 and a half months.

Integration of the 5S programs.

These modifications would have a minimal financial impact in the short term. Moreover, they would cut costs in the long term mainly as a result of reducing batch size and inventory. Hence, there should be no major challenges that could hinder the implementation of the FSM. This could be further emphasized by the fact that, during data collection, the managers acknowledged the deficiencies their process suffer from and the need for change.

LONG TERM FUTURE RECOMMENDATIONS

One of the most important lean principles is continuous improvement in the pursuit of perfection (Liker, 2005). Bearing this in mind, once the proposed future state map is properly implemented, great efforts must be dedicated to go through a more challenging value stream mapping cycle. The more one approaches perfection, the harder the identification of possible means becomes. Yet what is firmly determined is that the ideal goal is based on maximizing value in the eyes of the customer while eliminating waste (Liker, 2005).

In a more lean scenario at Company X, formwork could be constructed to tightly meet the specifications determined by the customer. In the case study described above for example, this imposes further reduction of formwork length to only 4 m. This would significantly reduce the amounts of necessary waste between different processes. Moreover, this could even eliminate the need for the cutting process. On another note, the available quantities of raw materials should be further reduced. Regarding steel coils, the company could search for another supplier that is geographically closer and requires less shipping time to deliver, maybe even a local one. This would allow the company to buy raw materials weekly or even bi-daily instead of buying very large batches and stocking them for months. By doing this, the company would not only reduce the total lead time by 73 days (in case of bi-daily delivery) and free up space in the plant but also save cost usually wasted on steel coils damaged due to storing. Hence, deeper analysis would continuously reveal room for improvement, advancing the lean aspect of Company X.

CONCLUSION

The state of Company X's manufacturing process is investigated in this paper using value stream maps that break down the sequence of ordering, manufacturing, and delivering into delimited processes in order to help visualize the entire progress of work. A detailed analysis of the company's current production process revealed certain lean aspects, including preventative maintenance, supermarkets of material supply (except for steel coils), and tailor-made equipment and tools. Yet room for improvement is also identified at the level of overall lean philosophy. With the aim of creating better flow of material and information, waste such as raw material inventory, work-in-progress and final goods inventory were tackled. Fundamental lean concepts and tools, specifically kaizen and continuous flow, were suggested: FIFO lanes, reliable promising and 5S programs are all suggested for inclusion throughout the process. Furthermore, previously imposed necessary waste is reduced by reducing formwork length.

As an outcome of the near future state map, production lead time is reduced by 50.6% from 1288 hours to 636 hours. Moreover, different types of waste including inventory, overproduction, waiting, and rework are reduced. Finally, safety is improved as a result of reducing health hazards. Cost savings and efficiency improvement are evident consequences of reducing waste and lead time and improving safety.

The case study of a successful company with 16 years of experience proved that there is always a definite possibility for continuous improvement and proved the importance of a new perspective to overcome the perceived optimum state. Long term improvements that were suggested prove this assertion, coming closer and closer to the lean ideal: Instant delivery with zero inventory in stores.

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A DECENTRALIZED AND PULL-BASED CONTROL LOOP FOR ON-DEMAND DELIVERY IN ETO CONSTRUCTION SUPPLY CHAINS

Patrick Dallasega[1], Carmen Marcher[2], Elisa Marengo[3], Erwin Rauch[4], Dominik T. Matt[5,6], Werner Nutt[7]

ABSTRACT

Engineer-to-Order (ETO) process chain types with a successive installation on-site are common in plant building and the construction industry. Usually, the core processes Engineering, Fabrication and Installation are disconnected, which creates high levels of Work in Progress (WIP) and long lead-times. Furthermore, up to date information about the construction progress, as prerequisite for an on-demand delivery of ETO-components is always difficult to obtain. Usually, to prevent a lack of material on-site, costly intermediate storages are used, which extend the delivery time. Well-known approaches in research, like the Last Planner System (LPS) or the Location Based Management System (LBMS), increase collaboration on-site and improve the reliability of construction schedules, but have a limited impact on synchronizing the supply chain to the construction progress. The approach presented in the paper describes how off-site and on-site production can be coupled, to reach short construction lead-times without wastefully intermediate storages. A first IT-prototype, based on "Industry 4.0" principles, was implemented and tested in an Italian medium-sized ETO construction supplier.

KEYWORDS

Engineer-to-Order, Just-in-Time, Supply Chain Management, Control Loop, Industry 4.0.

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INTRODUCTION

Engineer-to-Order (ETO) processes with a successive installation on-site are very common in plant building and the construction industry. Here, every project is engineered, fabricated and installed according to a specific customer order. Traditionally, the Engineering, Fabrication and Installation departments work in separated silos, making the overall project optimization difficult. Big job orders are released, which induce high levels of Work-in-Progress (WIP) and hinder a parallelization of the three phases. Very often and especially in small and medium sized construction projects, the organizational execution planning is done only superficially. Among others, this can be explained by always-limited budgets for work planning. As a result, real-time information about the construction progress and a reliable demand forecast is always difficult to obtain, which are prerequisites for an on-demand delivery of ETO-components. According to Ballard and Howell (1998), "for construction crews, the largest categories of reasons for failures are missing materials and failure to complete prerequisite work." Usually, to avoid a lack of material on-site, which would cause construction interruptions, costly intermediate storages are used extending so the delivery time. Well-known approaches in research, like the Last Planner System (LPS) or the Location Based Management System (LBMS), are very useful to increase collaboration on-site and to improve the reliability of construction schedules. However, they have a limited impact on synchronizing the supply chain between the job shop fabrication and the construction progress on-site.

The approach presented in the paper describes how off-site and on-site production planning can be synchronized by means of a decentralized and pull-based control loop. The approach integrates three basic Lean Management concepts: Build-to-Order (BTO), Just-in-Time (JIT) and Pitch-Set-Flow. A first IT-prototype, which integrates the thinking and principles of Industry 4.0, like "Real Time Capability", "Decentralization" and "Self-Control", was developed and tested in an Italian company, which develops and realizes unique façade geometries and building envelopes planned by renowned international architects.

STATE OF THE ART

The LPS was developed by Ballard (2000) to *"decentralize decisions and empowering crews to plan and schedule detailed tasks"*. As important contribution to the traditional project management system, the LPS adds a production control component where the so-called Percent Planned Complete (PPC) indicator is measured (Ballard 2000). The PPC is computed by dividing the completed by the planned work. Thus, a high PPC value indicates a reliable construction schedule (Lincoln and Syed 2011). In the LPS assignments should be detailed enough to recognize if they were completed at the end of the week, but they have not necessarily to be coupled to construction locations (Ballard and Howell 1998). According to Navon and Sacks (2007), one of the limitations of the LPS is a weak or missing real-time construction progress measurement on-site as a fundamental precondition for coordinating trades on-site and the supply chain. To facilitate construction progress measurement, Kenley and Seppänen (2010) propose the so-called Location Based Management System (LBMS), which brakes a project in small locations and uses them to plan and control workflow. However, the focus of the LBMS is to coordinate construction works on-site and not to support a Just-in-Sequence (JIS) and Just-in-Time (JIT) delivery.

Supply Chain Management (SCM) can be defined as the material flow coordination within multiple tiers of suppliers to the customer, aiming at low inventory levels, low unit cost and short delivery times. It evolved in the manufacturing industry, side by side with the JIT-methodology, as one of the fundamentals of the Toyota Production System (TPS) (Shingo 1988). Today, Enterprise Resource Planning (ERP) systems are used as IT-support for SCM. Although, ERP-systems contributed mainly to the productivity increase of the manufacturing industry, the production planning functionality is most of the time centralized and based on the Material Requirement Planning (MRP) methodology (Hopp and Spearman 2001). MRP is based on the erratic assumptions of 1) infinite capacity levels of production lines and 2) constant lead-times (Hopp and Spearman 2001). The first one creates problems if the capacity reaches its limit, because lead-times are extended (Hopp and Spearman 2001). The second one is problematic because by using fixed values, one tends to use pessimistic or long lead-times to cope with uncertainty, which induces high inventory levels (Hopp and Spearman 2001).

Pull control mechanisms (as part of the JIT approach), like Kanban or CONstant Work In Progress (CONWIP), trigger the production based on the real demand and not just its forecast (Takahashi and Hirotani 2005). Furthermore, in Pull systems, WIP levels are measured and production is released accordingly. This is different from conventional Push systems (like MRP), where capacity, which is needed to release production, has to be estimated. Kanban is part specific and it is impractical to be used in non-repetitive manufacturing like job shops, which are common in the ETO-environment (Hopp and Spearman 2001). Otherwise, in CONWIP part numbers are assigned to a CONWIP card, which is allocated to a production line where every card should contain the same amount of work. This allows using CONWIP pull control mechanisms in a wide variety of manufacturing environments. Such Pull control mechanisms are originally based on physical cards and have been mostly used to manage production within companies. By using an appropriate IT-support, the connection between demand and supply can be extended to be used within companies. Especially, in the construction industry, it could allow to synchronize demand and supply between the site and the supply chain. The emerging research area “Industry 4.0” in Europe and as “Industrial Internet” in US (Bungart 2014; Evans and Annunziata 2012), paves the way for an on-demand production and delivery in construction supply chains. The term Industry 4.0 represents the so-called “fourth industrial revolution”, which takes place in this era and proposes an IT-support for integrated manufacturing processes. Hermann et al. (2015) describe the major features of Industry 4.0 as embedded computers and networks (Cyber-Physical Systems (CPS)), which monitor and control physical processes connected over the Internet of Things (IoT). As a result, a gathering of steering information in real-time as well as a decentralized planning can be reached. Furthermore, by implementing frequent feedback loops within decentralized planning functionalities, a self-organization and self-control is pursued.

APPROACH DESCRIPTION

In Figure 1, the proposed approach is visualized schematically. The ETO market interaction strategy in construction consists mainly of three departments, which are connected in sequence (Dallasega et al. 2015b). The *Engineering* department focuses on the elaboration of shop floor drawings. Based on the shop floor drawings, the *Fabrication* department produces ETO-components. As a result, the *Installation* department assembles ETO-components into the building. Usually, coordination is based on a central *Master Schedule* resulting in a so-called Push system. Furthermore, these departments work in separated silos with big lot sizes. As a result, high and uncontrolled levels of WIP occur, extending the overall lead-time.

The approach we propose is based on a Pull mechanism from the construction site (Figure 1). Here, as soon as customer specifications are clear, the so-called Process Planning workshops take place, involving actors from design and execution (Dallasega et al. 2015c).

These Process Planning workshops are based on the Last Planner System (LPS), where the focus is given to the definition of the sequence of construction tasks preventing the so-called "chasing work" (Ballard and Arbulu 2004). During these workshops, based on the shop-floor drawings the necessary tasks on-site are identified. Furthermore, the sequence of work, which should flow from Engineering to the Installation on-site, is defined. As major difference to the traditional approach, where the amount of work released is based on the Master Schedule, in the proposed approach it is based on the levels of WIP between the Engineering, Fabrication and Installation departments.

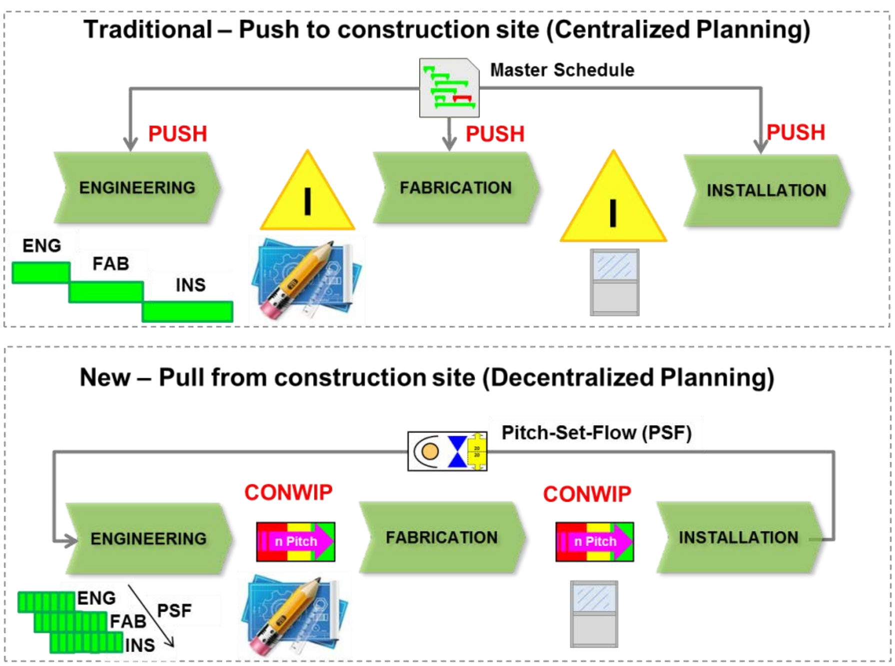

Figure 1: Pull from construction site in ETO

INCREASING THE DEMAND RELIABILITY ON-SITE

The fundamental principle consists of breaking down large job orders in approximately equal parts, to reach an optimal capacity saturation and minimal non-productive time throughout the supply chain and on-site. Here, the collaborative Process Planning workshops are organized, where actors from execution and design participate. Based on engineering drawings the installation process on-site is defined, in terms of tasks to be performed and dependences among them. For every task the so-called “Pitching” concept is applied, which is used for scheduling and monitoring the execution process. A “**Pitch**” defines the amount of **Construction Areas** (e.g., 2 rooms) which can be completed by a specific **Crew** (composed of a minimum number of workforce e.g. 4 workers) in a specific time **Interval** (e.g., 1 day or 1 week). The amount of “Pitches” is initially estimated by experts from execution, and then aligned to the customer demand by varying the number of crews. As a result, the customer demand is broken down into small lots with approximately equal size used to schedule and monitor the construction progress. Special emphasis is set on tracking physical parts of the building (Construction Areas). Furthermore, these workshops define the sequence of “Pitches” which should flow from Engineering to the Installation on-site. As a result, the so-called Pitch-Set-Flow (PSF) concept is applied, which defines the set of components, which should flow in one Pitch interval from fabrication to the site. This allows to parallelize the departments Engineering, Fabrication and Installation and so to drastically reduce the overall lead-time.
For a detailed explanation of the “Process Planning” and “Pitching” concepts, by means of practical case studies, please refer to Dallasega et al. (2013).

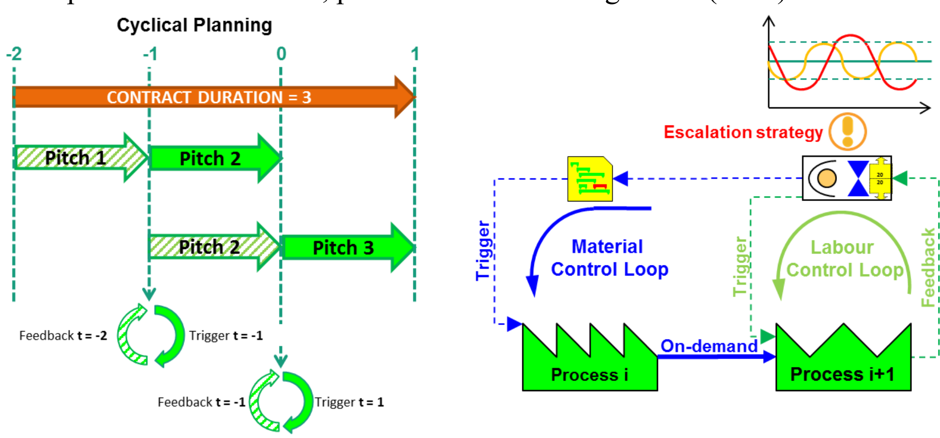

Figure 2: Increasing the demand reliability and self-regulation principle

To handle the high variance and the variability on-site, the so-called “Cyclical Planning” approach is used (Figure 2). It is based on the “Rolling Planning” approach, which is needed to handle the uncertainty of data in production planning, used in a wide variety of manufacturing industries (Stadtler et al. 2012). Here, when the first period of the planning horizon is finished a new planning period is added. When a plan has been generated and confirmed, the first planning period is called “*frozen period*” where no changes are allowed. This permits in the manufacturing environment to force that the planning is going to be implemented, avoiding a rescheduling of the following intervals.

As visualized in Figure 2, the scheduling of Pitch 2 (t=-1) should be based on the completion of Pitch 1, or in other words, according to the work performed in t=-2. Pitch 1, Pitch 2 and Pitch 3 should have approximately equal size and should fit within the contract duration. Furthermore, Figure 2 visualizes the self-regulation circuit by means of a customer-supplier relationship and two control loops. Considering the Labour Control Loop, the successor process i+1 (customer) triggers the work to be performed in the next time interval, according to the work completed in the previous time interval. Based on the scheduled and completed tasks (labour), the customer process (i+1) requests the needed material to the supplier process (i). The material control loop is based on the labour control loop, which means, if labour performance increases, the quantity of material requested increases. On the contrary, if labour performance decreases, less material is pulled from the supplier process (i). Of course, the demand increase and decrease should vary within a predefined corridor of flexibility (e.g. +/- 20% as visualized in Figure 2). If the demand variance exceeds the corridor of flexibility, an escalation strategy should be implemented by the responsible figures (e.g. the project manager).

Coupling of the Supply Chain to the construction progress

Based on a reliable information about the customer demand, the supply chain is synchronized to the construction site. The construction progress is tracked in real-time and accordingly ETO-components are released JIS and delivered JIT from first-tier and second-tier suppliers. Status information of the supply chain and of the construction progress are available in real-time. As a result, the availability of ETO-components is considered in the scheduling process. This is needed to prevent a lack of material on-site and consequent construction interruptions.

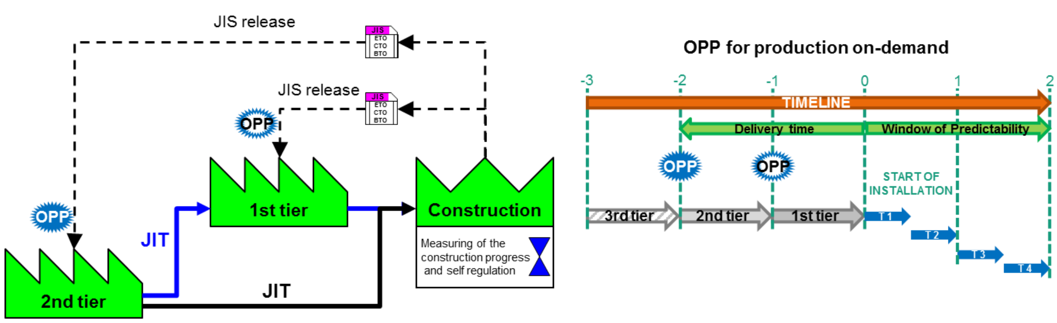

Figure 3: Synchronization of the supply chain to the construction progress

According to Ballard (1998), the delivery time should fit into the window of predictability and reliability on-site. This is especially challenging when considering ETO-components and multistage supply chains, both characterized by long lead-times. Figure 3 visualizes a two-tier supply chain, where the second-tier supplier delivers according to two alternatives: 1) ETO-components are delivered to the first-tier supplier for a last refining step and 2) ETO-components are delivered directly on-site for installation. Schweizer (2013) defines the Order Penetration Point (OPP) as the place in a manufacturing process where customer neutral production orders transition to customer related production orders. Considering Figure 3 (right), the window of predictability on-site consists of two time intervals (t=2). As a result, the OPP of first and second tier-suppliers should fit into two time intervals (e.g. 2 weeks). This allows triggering the supply chain based on the construction progress on-site, without intermediate storages.

PRACTICAL IMPLEMENTATION AND TESTING

The approach is implemented and tested in collaboration with the company Frener & Reifer GmbH (F&R). It is a medium sized company located in the north of Italy, acting as European leader in the delivery of high-class design facades. The implementation project consists of the new building Swiss Re Next at Mythenquai in Zurich (Switzerland), where F&R realizes the facades (Swiss Re Next 2016). The façade installation at Swiss Re Next started at the end of September 2015 and is planned to be finished at the end of April 2017.

The practical application of the pull-based control loop for on-demand delivery is shown in Figure 4. In this case, the window of predictability on-site consists of four calendar weeks (CWs). Since currently F&R works with a delivery time of more than four CWs, the fabrication process was mainly split in a prefabrication and an on-demand assembly and delivery to the site. A Lean Manufacturing (LM) supermarket is used to introduce an Assemble-to-Order (ATO) manufacturing system, suitable to follow the customer demand on-site. Furthermore, it is used to compensate the demand variability coming from site.

The Master Schedule links the processes upstream and downstream of the supermarket. It contains important milestones agreed with the customer and used to provide deadline constraints for the three departments. The Master Schedule was elaborated during the Process Planning workshops, where the responsible of the engineering department, the project manager and the installation supervisor participated. Based on the technology content, or in other words the façade type, the needed tasks for installation were identified in collaboration.

As visualized in Figure 4, the Labour Control Loop consists of scheduling (Trigger) and controlling (Feedback) the work processes within small time intervals. Based on the available capacity and on the scheduled tasks on-site, the material is requested from the supply chain. To guarantee that the right components are delivered in the right quantity, to the right location and at the right time, the final assembly is triggered according to the construction progress (Material Control Loop).

In the project, a weekly granularity for planning and control was used. The Cyclical Planning approach was used to schedule the working processes for the construction crews and to request the needed material. Every planning cycle consists of four CWs. At the beginning of CW41, the material needed for installation in CW44 is requested from the fabrication department of F&R. One week is needed for final assembly, one week to organize the transportation and logistics and one week before installation the requested material should arrive on-site. As soon as the material arrives on-site, the truck is unloaded and the material is disposed to the right Construction Area (within the levels of the building). At the same time, the delivery is controlled and checked in the IT-prototype. As soon as the scheduled week for installation is over, the construction progress is registered in the IT-prototype as a basis for the next planning cycle. The used IT-prototype was developed in Microsoft Excel. So far, a first web based application is going to be developed (Dallasega et al. 2015c). Furthermore, the company F&R is going to implement the IT-Prototype

(Microsoft Excel) in its ERP-system by extending a module needed for scheduling and monitoring the installation process and releasing the needed components on-site.

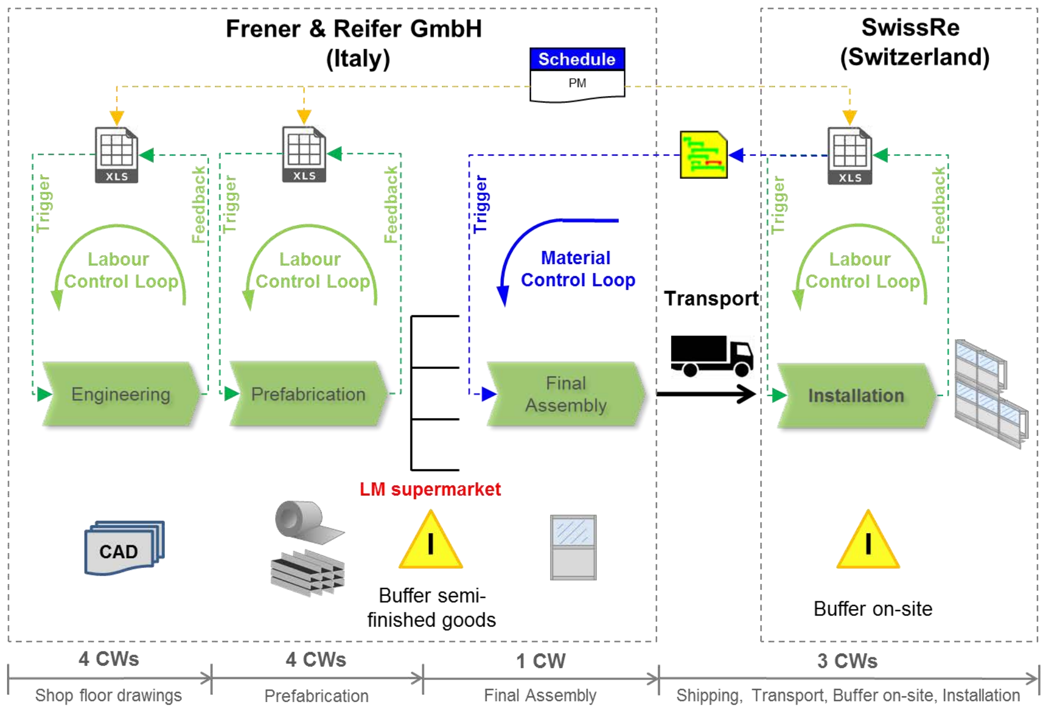

Figure 4: Testing of pull-based control loop for on-demand delivery within project SwissRe

As shown in Figure 4, the supermarket is placed between prefabrication and final assembly. As soon as the construction site is ready for installation, semi-finished components (stored in the supermarket) are assembled and delivered to the site for installation. The supermarket has a two-fold function: firstly, it allows minimizing the space needed for storing components and secondly, it permits to sequence production orders and the delivery to different construction sites.

IMPACT OF THE APPROACH

The first application of the approach was done at the Expansion Project Hospital of Bolzano. It showed that by spending **1 hour** for using the **methodology**, a working amount of **6 hours** could be **saved** (Dallasega 2016). As a result, a labour saving (on-site) of around 8% compared to the initial estimate could be reached (Dallasega 2016). Starting from September 2015, the methodology has been implemented and tested at the project Swiss Re Next in Zurich (Switzerland). According to the participating experts, the methodology allows to avoid traditionally problems like late or wrong material deliveries. Furthermore, thanks to the Labour Control Loop, problems can be identified early on and improvement actions can be taken in time, preventing so cost explosions. As a result, after seven months since the construction site started, the project is on budget according to the calculation department.

CONCLUSION AND OUTLOOK

To synchronize ETO-supply chains to the construction progress, the challenging part is to introduce a reliable demand forecast on-site. In this article, the "Pitching" concept was used to break down job orders in construction with approximately equal size, reaching low and controlled levels of WIP and at the same time short delivery times. As different from other industrial sectors, the construction industry is characterized by high variances especially on-site. To handle unpredictable events in an efficient way, the "Cyclical Planning" approach was introduced.

In future research, the approach will be extended to cover the entire building project. Specifically, the synchronization of Make-to-Order (MTO) supply chains within the phases of skeleton and interior construction will be considered.

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OFF-SITE PREFABRICATION: WHAT DOES IT REQUIRE FROM THE TRADE CONTRACTOR?

Baris Bekdik[1], Daniel Hall[2], and Sigmund Aslesen[3]

ABSTRACT

The purpose of the paper is to show what is required to industrialize a building process from the standpoint of the trade contractor. Rationalization of building processes has, over the years, caught the attention of numerous IGLC papers. Although significant contributions have been made to further understand and improve existing construction processes, relatively few contributions have focused on the opportunities for industrialization from the trade contractor's perspective. This paper uses an in-depth case study to address the deployment strategy for off-site fabrication techniques and processes used for modular plumbing fixture carriers deployed on two large-scale hospital projects in the United States. Findings include the organizational and technological arrangement for prefabrication. The paper applies value stream mapping to visualize the process and improve it. Because this work looks at only one case study, the conclusions are limited in generalizability to other prefabrication operations. However, it represents an important in-depth case from the trade contractors' perspective and will contribute to the growing body of research focused on industrialization and prefabrication in lean construction. .

KEYWORDS

Lean construction, modularity, prefabrication, standardization, value stream mapping (VSM).

INTRODUCTION

Industrialization includes the process by which a traditionally non-industrial sector of the economy becomes increasingly similar to the manufacturing industry. The process implies variations of greater use of prefabrication, preassembly, modularization and off-site fabrication techniques and processes (National Research Council 2009). By definition, the production performed outside of the construction area in a temporary or more permanent workshop off site, is named as prefabrication (Gibb 1999, Ballard and Arbulu 2004). Among the benefits attributed are improved production control due to reduced variance in the material and information flow (Lennartsson et al. 2009),

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decreased complexity of the on-site construction process (Larsson and Simonsson 2012), improved quality and productivity in construction (Viana et al. 2013), schedule savings and reduced on-site labor (Antillón et al.2014), just-in-time delivery, zero defects and customized products (Bildsten et al. 2010), and reduced lead times (Ballard and Arbulu 2004).

All the potential benefits considered, one might expect the construction industry to embrace industrialization. The majority of works on building sites are, however, still performed manually. "The primary categories of work involved in construction are the handling and transport of materials, the fabrication of elements or modules, fittings and connections, the positioning and fixing in the corresponding place, and the prior and subsequent processing steps using special tools" (Girmscheid 2005). These work steps are not very different from other areas of industrial production. Nevertheless, the challenges or constraints facing construction industrialization seem to be substantial and diverse, amongst others including the low degree of standardization in products and processes (Hermes 2015); the lack of design-production interface (Tillmann et al. 2015, Larsson and Simonsson 2012); the low IT integration in the industry (Blismas 2007); the multiple project environments creating a high level of uncertainty (Bertrand and Muntslag 1993); the market-driven, short term buyer-supplier relationships (Bildsten et al. 2010); the lack of trust between contractors and suppliers (Melo & Alves 2010); the reluctance among suppliers to adopt new standards (Lennartsson et al. 2009); the lack of holistic thinking in the product design (Björnfot and Stehn 2005); and the demand variability from the contractor, the late receipt of design information, the frequent design changes and frequent changes in installation timing and sequence (Ballard and Arbulu 2004).

Furthermore, there are some repeatedly mentioned ideas about realizing prefabrication in construction in the literature. One group claims that a high production volume is a prerequisite in order to apply prefabrication (Pan et al. 2007, Jaillon and Poon 2008 and Jonsson and Rudberg 2014). Some others add that large investments and sophisticated production is necessary for different trades to work on prefab modules. "A module is almost never the output of a single trade but must be seen as a product designed and manufactured by a number of different trade experts and most often installed at the site by the manufactures' own, specially trained crews" (Bertelsen 2005).

This paper takes the above mentioned challenges into consideration and it focuses on off-site prefabrication from the perspective of the single trade contractor. The case company is one of the largest mechanical, electrical, and plumbing (MEP) building system experts in US. The company has proven to be successful in its strategy to industrialize part products and provide services related to their installing. The paper's particular interest is on what is required for this strategy to become economically viable. In an attempt to answer this question, we emphasize the industrial fabrication including the use of standardized working methods and tools as well as new information technology; the logistical planning related to production facilities, storage of materials and the transportation and installation of modules on site, and; the use of contract models to support the industrialization.

CASE STUDY

The case company, Southland Industries is one of the largest mechanical, electrical, and plumbing (MEP) building system experts in US. The case company is currently engaged in delivering two large-scale new hospitals for Sutter Health located in San Francisco, California. St. Luke's Replacement Hospital is a 20,900 m2 (215,000 square foot), 120 bed project and Van Ness and Geary Hospital is a 68,750 m2 (740,000 square foot), 274-bed project (CPMC 2020). The case company has signed an Integrated Form of Agreement (IFOA) to deliver these two hospitals. This IFOA approach requires pain and gain sharing, where all team members share in the risk and reward for delivering the hospital on time and on budget.

To maximize production efficiency for the two hospitals, the two projects are leasing a large warehouse on Treasure Island in the San Francisco bay. A part of that warehouse is dedicated for the case company's prefabrication of modular plumbing fixture carriers. This is in addition to more typical prefabrication of the mechanical ductwork produced for other projects as well in the case company's main factory. At the time of the study, the case company had begun work on both the St. Luke's Replacement Hospital (STL) and the Van Ness and Geary Hospital (VNGC). Most of the work done so far is VNGC but work at STL is beginning now.

METHODOLOGY

Our case study proposes a map to visualize the flow of resource usage, including time, labor, and inventory through implementation of Value Stream Mapping (VSM) (Rother and Shook 1998). For this research, we conducted as a group and individually a number of visits to the final construction site and temporary workshop where the manufacturing takes place. Our observations are based on our participation in big room meetings, interviews with contractor and trade project managers, architects and owner representatives. Moreover, we have had the privilege to observe and take time records of the manufacturing work performed by the use of jig modules in the temporary workshop. The current and suggested future state Value Stream Maps will be shared in the analysis section and finally improvement suggestions at macro and micro level will be given in the discussion and conclusion section.

ANALYSIS

In analysis section we will present the value stream map (VSM) of operations for the case company, followed by a description of several of the areas. Furthermore, areas of improvement suggestions presented on the same figure 1 with circles on the VSM then are discussed in detail in the discussion section.

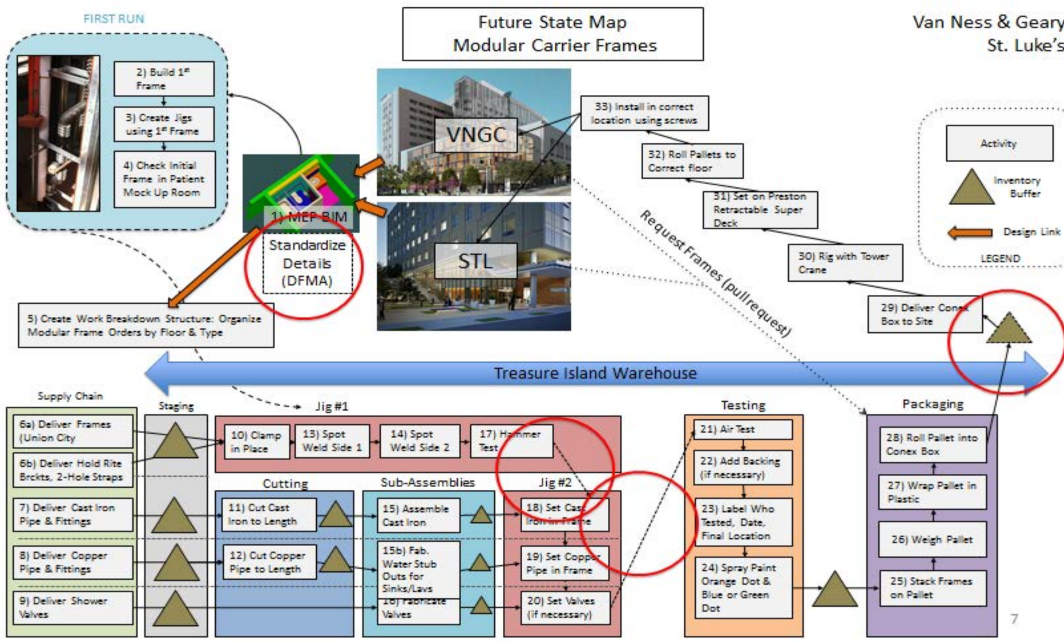

Figure 1 Value stream map of the modular frames

VALUE STREAM MAP (VSM)

First Run

The process begins with a fixture carrier design created using Building Information Modeling (BIM). As the creator of the modules states "it wouldn't really be possible without the BIM." BIM allows the practitioners to see the overall picture and therefore catch the similarities in design in different parts of the structure. Therefore, it becomes possible to identify each repeating module with number or repetitions and then create a jig in order to build it if it is feasible. From cut sheets that come from the BIM, a "first run" to create an initial set of jigs for a carrier frame is made. Then the first frame is built without a jig, and then that frame is used to create the initial set of jigs. Jigs are checked continuously for both accuracy to the BIM and easy to use for the workers. Altogether, twenty jigs have been made. Some of the jigs have adaptors so they can have additional configurations. It is difficult to estimate how long it takes the creator of the jigs to make one. However, after the experience gained during the process it takes now only couple of hours to build a jig.

In addition, there are many common elements between the two projects. Therefore an economy of scale is possible by using the same jigs with some little modifications in order to build for two projects. A few of the first VNGC carrier frames are mounted in the patient mock-up room to make sure that they fit. Birch and seven-layer plywood are used to make all parts of the jigs. This is easy to work with and reconfigure as necessary. There is no leveling or measuring required. Everything is set by stops and jigs, and locations can be calculated and fixed. This not only avoids the risk of making measurement mistakes, but also saves considerable time for the worker who does not have to bother with placement, leveling and tolerances during operation.

Supply Chain

The supplies for the modular carrier frames are delivered to the warehouse and brought in with a forklift. The frames for the carriers are made in the main factory and are delivered. Because the main factory has many competing project needs, occasionally those frames are not delivered before the previous set runs out, causing the team to work on something else for a short while. The cast iron pipe and copper pipe is delivered in long stock lengths and staged in large stock quantities in the warehouse.

Cutting & Sub-Assemblies

Separate cutting stations are set up to cut the cast iron and the copper pipe to length. Special consideration has been given to ensure cuts can be made using blocks and a stop, to reduce the need for workers to measure. Once pipe is cut to length, it is pre-assembled and readied for placement in Jig #2.

Jig #1 & Jig #2

At Jig #1, rhe strut is spot-welded to the metal frame for the fixture. The following work activities that occur on the current state map: 10) Clamp in Place; 13) Spot Weld Side ; 14) Spot Weld Side 2; and 17) Hammer Test. The purpose of the activity is to spot-weld square strut across the metal frame as shown in Figure 2 on the left hand side, which serves as strength for the frame and provides the attachment points for the cast iron and copper assemblies. Before the activity can take place, the frame material must be assembled and delivered by Southland’s sheet metal shop in Union City. Jig #2 is the location where the completed frame is set in place and the cast iron and copper pipe assemblies are installed in the correct location. Jig #2 also uses a wheel to rotate and flip the frame around, so that the worker is always able to perform the work most efficiently.

Figure 2 Welding jig on the left and stock of prefabricated modules on the right

Testing

An air test is completed on all finished assemblies, which are now considered rough-in modules. Once passed, a label is fixed to the module stating who did the testing, at what time the testing occurred, and where the final location (site, level and room) of the fixture is. A green paint dot is sprayed on the rough-in module to indicate that it has passed the test. The case company also uses different colored paints for a second dot, to distinguish between the two jobs. VNGC is painted with a blue dot and St

Luke's with a red dot. Each finished item has a code written in black permanent marker pen on the bottom of the frame. For example, we saw LV-1 for the lavatory frame type 1.

Packaging and Storage

The completed rough-in modules are stacked together on a pallet and weighed. The frames are grouped by their floor location. Each shipping container can hold with 7,25 tons (16,000 lbs.) and the case company is very careful not to go over this weight. Currently they are storing completed and wrapped pallets on the Treasure Island floor and then moving them into the completed Conex Box. It would be preferable not to move the pallets twice but because the fabrication is far ahead of installation, it is necessary at this point. Right now the first and second floors of VNGC are completely fabricated and in storage as some of the prefabricated modules can be seen in Figure 2 on the right hand side, while installation of these items is not until mid-2016 at the earliest. Temporary shop will accumulate a very large inventory buffer on site before it is time to begin delivering the rough-in modules.

Delivery

The delivery plan is the part of the current state map that has not occurred yet because the construction sites are not ready for the rough-in modules. The current plan is for each site (VNGC or STL) to call temporary shop when they are nearing the point when rough-in modules are required on a certain floor. At that point, Treasure Island will deliver the container to the site. The entire container will be rigged using a tower crane, and the pallets will be rolled onto the retractable Super Deck at the correct floor for their installation. However, one of our hosts mentioned that the site has changed delivery projections almost on a weekly basis. This current delivery process has not begun and is likely the most uncertain part of the process to date.

DISCUSSION

By employing lean construction concepts, the case company has set up a successful prefabrication operation for rough-in modular frames. The current state of operations represents a commitment to the lean construction philosophy. The decision to use prefabrication is a long-term philosophy, the use of the production line will greatly reduce (material and time) waste, and the tasks have been standardized and "mistake-proofed."

The work is exceeding expectations already. Although the delivery and installation of the rough-in modular carriers has not started yet, there is reason to believe the team will continue to successfully meet the new challenges as they arise for the overall benefit of the project. We tried to investigate the improvement possibilities by applying lean approach defending the optimization of value stream in a manufacturing process. The case we have chosen is a an example of a large scale hospital building construction in the context of California that can be taken as an example by worldwide construction professional building large scale facilities.

This case study is a clear example of what a single trade contractor can do to boost product modularity. The improvement suggestions studied for this case serve to the purpose to achieve standardized work for the future projects to come. As the off-site production observed is the very first attempt, neither we nor the host company had the previous project records to compare the work done. According to the company professionals, the man-hour estimates in the planning phase were made based on the similar type of work performed at site. They had foreseen six employees working for both St. Luke's Replacement and Van Ness and Geary Hospital projects but during the execution of the manufacturing the project team realized that three full time employees were sufficient to serve the project pace on site. Even this man-hour reduction alone proves the benefit of batching different construction project works together in a workshop. Moreover, the project team all agreed that hospital construction required far more sophisticated prefabrication operation than a typical project would normally do. Therefore, we believe that the current successful prefabrication operations can provide a standard to be improved for the future projects.

The improvement suggestions for the off-site manufacturing are parallel with the lean spirit of continuous improvement. Although, the suggestions are very much case specific and the starting point can generically be applied to other off-site manufacturing operations as well.

An overall analysis of the current value stream map shows three opportunities to improve. First, the case company could look to reduce inventory buffers and attempt to achieve more of a continuous flow. The current state map reveals that the process uses many inventory buffers (shown with a triangle). These inventory buffers act as a decoupling mechanism to separate tasks with different cycle times. Inventory is identified as one of the seven types of waste in a production system (Ohno 1988). While some decoupling buffers are necessary, future work could look to reduce inventory between tasks and achieve a more single-piece (e.g. continuous) flow (Viana et al. 2013). To exemplify, a typical inventory buffer between the production lines can be mentioned: When a batch of frames is done at Jig #1, they are stored out of the way in groups around ten to twenty as they await the availability of Jig #2. By setting activity at Jig #1 and Jig #2 to a similar takt time, frames could move directly from the Jig #1 station to the Jig #2 station (with a small inventory buffer of 1-3 frames in between). This would reduce the need for additional storage and the motion of carrying and stacking the frames after each batch.

Packages waiting in the inventory for the shipment to the site are again other great sources of the waste. It is very understandable that managers want to have a buffer between the site work and the workshop. However, missing communication and plan changes at the construction site cause the workshop to work with a greater contingency than required.

Second, the case company could use the success at workshop to cross-train others in the company. This includes management through the lean "go and see for yourself" philosophy and the workforce through the principle of creating challenging and meaningful work to develop the skills of all employees.

This would give management insights and vision should they want to replicate this operation for future projects. In addition, the workshop staff could seek opportunities to challenge their workforce through additional cross training of employees. The operations at the workshop are somewhat specialized at this point. By switching in additional employees or rotating the tasks for current workers, case company can continue to develop the skills of all employees. This would ensure that existing workers have challenging and meaningful work and that new workers have confidence in the tasks if the same prefabrication is attempted on future projects.

Moreover, such a close relation between site and workshop management will increase the efficiency in communication and help to solve the extra inventory buffer problem described above.

Third, case company has the opportunity through BIM to standardize the design of future plumbing carriers so that many of the same jigs can be reused. While this may not always be within trade contractor's control (for example, a project might employ a different MEP engineer who requires different details), it would be a great benefit to continue this prefabrication on future projects. Future BIM designs could use the existing jig setups. Furthermore, case company team have gained valuable insight into what type of fixture design is easy to assemble and which is more challenging. If this feedback can be communicated to the design team, future BIM designs could make assembly even more productive. This concept is referred to as design for manufacturing and assembly (DFMA) and could give case company the opportunity to leverage the gains at the workshop and increase productivity on the next project.

This will also allow for continuous improvement of the current process using DFMA principles. Furthermore, more reliable manufacturing and installation schedules will be planned based on the data from previously completed projects.

The three above mentioned improvements support each other. More efficient results can be achieved by the implementation of all of them simultaneously.

Finally, with the repetitive work and the production volume the productivity will increase and the improvements will become more visible. In order to make best use of the present modules created (jigs) for the manufacturing in the future, the design of the projects to come should be developed according to the design for manufacturing and assembly (DFMA) principles. The project team has already very valuable experience in different types of modules. Some modules are easier to adopt and to work with while some others are difficult and more time consuming. Why not to make the most favorite modules best practice for the next projects?

CONCLUSION

Our case study focusing on the prefabrication process of the mechanical works is a clear example of the achievements that can be made even as a single trade contractor in a large scale hospital construction. Moreover, contrary to the barriers mentioned in the literature the modules created during the prefabrication process do not require high volume production or high capital investments. Although, those modules are created to serve the current project design, they represent proven solution for the future projects to come.

Furthermore, an implementation of standard modules not only facilitates the manufacturing in a controlled off-site location and assembly on construction site but also help the design phase to be more consolidated. Moreover, the applied modules increase the cost and scheduling predictability both during the manufacturing and assembly.

Once the work is performed by implementation of standard modules reducing the product variety (Mohamad et al. 2013), the next level of improvements will be the main topic. We believe by standardization of the manufacturing operations a level of dexterity will be attained and improvements will require more radical changes such as involving other trades into the manufacturing operations.

The involvement of different trades in order to execute offsite production of modules has many product design and organizational challenges. Therefore, the early involvement of the pain and gain sharing philosophy of Integrated Form of Agreement (IFOA) will make the next level of modularization possible. Although, the observed projects are executed with IFOA, there is a missed opportunity to modularize the production units such as entire bathrooms or patient rooms requiring the cooperation of multi-trades. Observed off-site manufacturing case study can be baseline for future case studies in order to move from one-a-kind type of production to standard work. And then modules having multi-trade functions finally can be realized.

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A LITERATURE REVIEW ON 4D BIM FOR LOGISTICS OPERATIONS AND WORKSPACE MANAGEMENT

Cristina T. Pérez[1], Luara L. A. Fernandes[2], and Dayana B. Costa[3]

ABSTRACT

Planning the logistic operations and the construction site layout is extremely important to avoid waiting time, double handling, transportation wastes and workflow conflict. Therefore, workspace management can support the Lean thinking through minimization or even completely eliminating the transportation, inventory and motion tasks, which are all non-value adding activities. In fact, much has been written on ways to minimize site logistics waste but few studies have addressed the use of 4D BIM for logistic operations and transportation waste reduction on jobsites. This paper presents a literature review of mainstream studies of 4D BIM, focusing on logistic operations in order to identify study opportunities for waste minimization in workspaces and workflows. The methodology employed is based on a review of the literature published in the last 10 years, in which information was collected from the International Conference of Lean Construction (IGLC) papers and a set of mainstream computing in civil and building engineering journals. This paper aims to contribute by providing a state of art on 4D BIM for site layout planning and workspace management for this knowledge area.

KEYWORDS

Building Information Modeling (BIM), 4D modeling, logistics and workspace.

INTRODUCTION

Nowadays, the construction industry is growing in size and complexity. Some issues such as lack of workspace, concurrent and constrained areas and poor workspace planning cause significant loss of time and money in a construction project (Moon et al. 2014). These problems are closely related to the construction logistic operations planning.

Construction logistics include the planning, execution, steering, documentation and the monitoring of all projects related to the flows with regard to materials, people, space and information (Lange and Schiling 2015). The term flow has some important intuitive qualities, such as a chain of events (sequence), continuous movement, moving freely, and

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adding value (Pérez et al. 2014). In logistics, Jongeling and Olofsson (2007) define workflow as “the flow of resources through locations”. Bowersox and Closs (1996) define material flow as the movement and storage of materials and finished products, and information flow as the identification and specification of different requirements in a logistics system.

On the other hand, the increasing complexity of projects, has increased the developing and usage of Information and Communication Technology (ICT) approaches (Bryde et al. 2012), and following this trend, the expansion of BIM (Building Information Modelling) has been massive in the last decade. BIM can be defined as "a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all design team members to collaborate more accurately and efficiently than using traditional processes” (Lee 2008). Some new concepts and BIM applications have been developed for different purposes in the construction industry, such as 4D, 5D, 6D and 7D dimensions.

Specifically, the aim of 4D BIM models in production planning is to provide a virtual environment for simulating, viewing production processes and operations, and for identification of spatial conflicts that can occur in the three dimensions and across time (Tantisevi and Akinci 2007). Despite the fact that several studies can be found in the literature on 4D modelling application in construction, few of them are related to logistics operations and there is still a lack of a systematic body of knowledge concerning this area. Therefore, this paper presents a literature review of mainstream studies of 4D BIM, focusing on logistics operations, and workspace management published in the last 10 years aiming to explore how the construction management community has approached this virtual environment for waste minimization in workspaces and workflows. According to Pérez et al. (2014), the logistic management is focused on cost reduction, and one way to do that is through the flow management for waste minimization. Therefore, the study of logistics operations will allow to identify opportunities for waste minimization. This paper aims to contribute by providing a state of art on 4D BIM for logistics and workspace management.

RESEARCH METHOD

This study was developed based on a literature review of empirical and theoretical studies already published. Moreover, this study was performed aiming to identify study opportunities for waste minimization in workspaces and workflows through the use of 4D BIM tools.

RESEARCH SOURCES SELECTION

The first stage involved the selection of journals that had within their scope issues related to design, architecture, construction, technology, informatics, and management in order to identify the one most closely related to the field of this study, according to the Table 1.

The proceedings from the International Group of Lean Construction conference from 2005 to 2015 were included as a data source, due to the relationship between logistics and lean construction and its concepts of non-value adding processes and wastes. The understanding of benefits, changes in information and BIM tools themselves and lean construction principles should result in a conceptual understanding of the theory of production in construction (Sacks et al. 2010). Aiming to increase the sample size, oil, gas and rail sectors publications about the theme were searched.

Table 1: List of the selected journals

Journal	Institution
Journal of Architectural Engineering	ASCE
Journal of Construction Engineering and Management	ASCE
Journal of Computing in Civil Engineering	ASCE
Journal of Management in Engineering	ASCE
Advanced Engineering Informatics	ELSEVIER
Automation in Construction	ELSEVIER
International Journal of Design Computing	ELSEVIER
International Journal of Project Management	ELSEVIER
Construction Management and Economics	Taylor and Francis
Journal of Civil Engineering and Management	Taylor and Francis
Journal of Information Technology in Construction	ICRIBC*
Construction Innovation	Emerald Insight
Engineering, Construction and Architectural Management	Emerald Insight
Computer aided Civil and Infrastructure Engineering	Wiley Online Library
International Journal of Architectural Computing	SAGE Journals
Journal of Information Systems and Technology Management	TECSI – USP
Conference Proceedings of IGLC	IGLC
Institution of Civil Engineers	ICE

*International Council for Research and Innovation in Building and Construction

DATA ANALYSIS

A preliminary search of these journals and proceedings was performed to focus on BIM, 4D or/and logistics. Firstly, all articles published in the last ten years were analyzed and the papers that had those words in the title and/or the keywords were selected. Due to the number of papers identified and also because the majority of the articles were related to only one or two of the issues simultaneously, such as BIM and 4D, the data analysis was narrowed down focusing on the application of 4D BIM for logistics, using the three keywords and related keywords BIM, 4D and logistics. However, during this research, a lack of articles specifically about 4D BIM for logistic purposes was possible to identify. Only a few articles had the referred words in the tittle or in the keywords. Therefore, the research was expanded and other keywords related to planning and logistics were also used, such us: layout, transportation management, motion, location, supply chain management, workspace, workflow and space planning.

A total of 20 articles was chosen to be part of this literature review. The Automation in Construction Journal published 9 papers of this sample (47%), and the Journal of Information Technology in Construction published 4 papers (21%). The remaining journals and conference proceedings shared 32% of the articles, according to Figure 1. However, despite the identification of some papers in the oil, gas and rail sectors, only one of them (Li et al. 2013) used 4D BIM with logistics purposes. Figure 2 indicates that the evolution of the number of the articles in years was not significant.

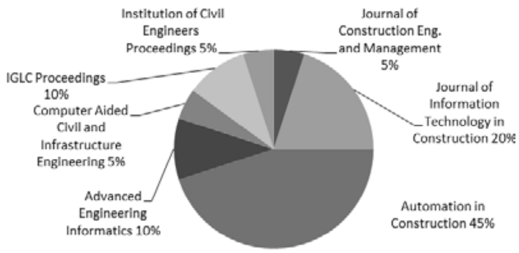

Figure 1: Number of articles founded per journal or proceedings

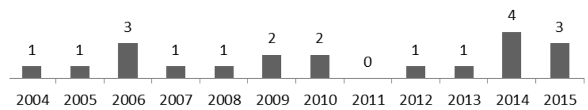

Figure 2: Number of articles by year

STUDIES RELATED TO 4D BIM FOR LOGISTICS PURPOSES

The 20 papers selected were classified according to their main features (see Figure 3). The first classification of the articles was related to the project stage, meaning Design stage (2 papers) and construction stage (18 papers). Then, the papers were classified in terms of spatial conflicts (workspace conflict process) and spatial time conflict (schedule conflict process).

Stage	Dimension	Contribution	Approach	Product	Unit of Analysis	Authors
Design (2)	Spatial-Time (2)	Proposal (1)	Rule-based heuristic strategies (1)	A system framework		Cheng & Kumar 2015
		Analysis (1)	-	Benefits and limitations	Site process	Bortolini et al. 2015
Construction (18)	Spatial-Time (16)	Proposal (11)	Algorithm (3)	Genetic Algorithm (GA)	Interior building space	Mallasi 2009
				Congestion penalty indicator	Oil refinery Reactor Column	Chua et al. 2010
				An optimized algorithm	Express railway project	Moon et al. 2014
			Artificial Intelligence (8)	4D integrated site planning system (4D-ISPS)	Building and jobsite	Ma et al. 2005
				Visual Planning tool	Jobsite	Dawood et al. 2005
				Software tool	Workspace	Riendau 2006
				Visual Planning tool	Jobsite	Dawood& Mallasi 2006
				A concept for visualizing workspace competition	Workspace	Mallasi 2006
				The intersection test	Workspace	Chavada 2012
				A bounding box model and an algorithm	cable-stayed bridge project	Moon et al. 2014 (P17)
				A holistic solution for workspace management	Workspace	Kassem et al. 2015
		Analysis (5)	-	The use a combined method to plan workflow	Workflow	Jongeling & Olofsson 2007
			-	3 types of analyses: (workflow + planning of temporary structures + productivity)	Workflow	Jongeling et al. 2008
			-	A tool to System evaluation, Usabil ity study, and Management plan	Workflow Construction project	Tsai et al. 2010
			-	A construction model	Site Layout	Li et al. 2013
			-	A 3 comparative analysis of layout(static + phased +dynamic site layout planning)	Site layout	Andayes & Sadeghpour 2014
	Spatial (2)	Proposal (2)	Rule-based heuristic strategies (1)	A 4D product and a process model	Crane location	Tantisevi & Akinci 2007
			Algorithm (1)	Geometrical approach	Crane location	Tantisevi & Akinci 2009

*Number in brackets indicates the number of papers in each section

Figure 3: Papers classification according to their features

At the Design stage both papers were related to spatial-time conflicts. For example, Cheng and Kumar (2015) established a rule-based heuristic strategy and Bortolini et al. (2015) analyzed the benefits and limitation of the use of 4D for logistics to improve the performance of the site assembly process. For the construction stage, the highest number of articles is related to the spatial-time conflict detection (16), space conflicts appear only in 2 articles. In terms of spatial-time conflicts Mallasi (2009), Chua et al. (2010) and Moon et al. (2014) proposed different algorithms. Artificial Intelligence is the approach used by some authors (Ma et al. 2005; Dawood et al. 2005; Riendau 2006; Dawood and Mallasi 2006; Mallasi 2006; Cahavada et al. 2012, Moon et al. 2014, Kassem et al. 2015) to identify schedule and workspace conflicts. In addition, in terms of spatial conflict detection Tantisevi and Akinci (2007; 2009) proposed a rule-based heuristic strategy and an algorithm respectively to model workspaces of mobile cranes.

DESIGN STAGE

Two articles (Cheng and Kumar 2015, Bortolini et al. 2015) were performed during the design stage and both of them deal with layout planning on an operational level.

Cheng and Kumar (2015) state that layout planning should be carried out not just on a strategic and tactical level, but also on an operational level in order to ensure a smooth workflow. Bortolini et al. (2015) agree about the necessity to model critical logistics operations with a fine level of detail. According to Bortolini et al. (2015) through 4D simulation, the times of each process involved could be analyzed in detail and thereby increases the assembly productivity, reducing inventories and work in progress and seeking a continuous flow of production. The simulation of the activities on an operational level means simulating both value-adding and non value-adding activities (Bortoloni et al. 2015).

However, according to Cheng and Kumar (2015), managing the layout planning on an operational level has certain limitations, such as: (1) the level of development of the BIM model should match the level of detail in the construction schedule, (2) the reporting of construction progress and amount of materials used would have to be performed frequently, (3) the presence of buffer zones is not taken into account, and (4) the supplier has to update the date when the material is ready to dispatch and dispatched.

CONSTRUCTION STAGE

Most previous studies on the use of 4D BIM model during the construction stage for logistics can be classified according to their focus on the conflict detention.

Spatial and time conflict detention

Most of the papers related to space-time confliction detection mentioned the Critical Path Method (CPM). In fact, most studies on 4D models are simply a translation of the output of a CPM network that contains only transformation activities. It implies that the so-called flow activities are being neglected once more (Bortolini et al. 2015)

A) Algorithm Proposal

Different authors (Mallasi 2009; Chua et al. 2010; Mon et al. 2014) analyzed the conflict and congestion at the workspace and schedule dimension, conceiving the idea of utilization. As a result, those authors proposed algorithms for quantifying space and time congestion at jobsite.

Chua et al. (2010) described the concept of utilization as a measure of how much a resource is put in use through the concept of space demand and supply. In this same vein, Mallasi (2009) compares the workspace with the approach of 'cutting 2D-shaped parts from 2D metal sheets with minimum wastage of material'. The material waste (area utilisation) is minimised by Genetic Algorithm (GA) searching for the optimum utilisation of sheet area. The case is similar to reducing the site space-usage occupied by the activities' execution workspaces'.

According to Chavada (2012) the workspace can be divided into the following categories: (a) main workspace (associated with value added activities); (b) support workspace (associated with non-value added activities); (c) object workspace (considered permanent space, once built by an activity and it covers all building objects); and (d) safety workspace (area that allows a tolerance between two workspaces to prevent safety hazards). The workspace categories proposed by Chavada (2012) were used as a basis for the identification of them in the three studies which proposed an algorithm approach (Table 2).

The classification of workspace from the studies indicates the construction process and the object that they will accommodate, but to identify the potential features needed for congestion minimizationthe workspace should also have in its project plan information related to the activities that will be accommodated.

Table 2: Workspace type classifications

Workspace	Mallasi (2009)	Chua et al. (2010)	Moon et al. (2014)
Main workspace	Process space	Process space	Installation space
Support workspace	Equipment path	Interdiction[1] Space	Transfer space
	Support space	Dead space	Loading space
	Path space	Resource handling space	
Object workspace	Product space	Product space	Prefabrication space
	Workspace		
	Equipment space		
	Storage path		
Safety workspace			Safety space

*Adapted from Chavada (2012)

B) Artificial Intelligence Proposal

Of the 19 papers studied, 7 used Artificial Intelligence (AI) to plan workspace, meaning that they investigated the generation, allocation, conflict detection and conflict resolution at workspaces with the use of an Industry Foundation Class (IFC) tool.

Ma et al. (2005) introduce a 4D Integrated Site Planning System (4D-ISPS) which integrates schedules, 3D models, resources and site spaces together to provide 4D graphical visualization capability for construction site planning. Riendau (2006) proposed a software tool which follows the various versions of a project, creating a new set of files that are interconnected and produce a 4D interface to navigate through these files. Dawood et al. (2005), Mallasi (2006) and Dawood and Mallasi (2006) introduced the

[1] Interdiction spaces are spaces where no product, process, or resource is allowed to occupy, and are typically specified for reasons of hazards or protection

Critical Space-Time Analysis (CSA), a concept to quantify the congestion degree between the overlapping workspaces, and to visualize workspace congestions in architectural projects. Moon et al. (2014) suggested an optimized algorithm based on a location-constraint GA that can minimize workspace interference. Kassem et al. (2015) present the results from the development and evaluation of a methodology and an Industry Foundation Class (IFC) compliant 4D tool for workspace management. Chavada (2012) presents a novel approach for the management of AEWs. by integrating the traditional planning process (CPM) and BIM data in a 4D/5D environment and providing real-time management and rehearsal of AEWs. Table 3 sums up the category of papers.

Table 3: Main focus of the papers which used AI to study workspace

Workspace aspect studied	Ma et al. (2005)	Riendau (2006)	Dawood et al. (2005)/ Dawood and Mallasi (2006)/ Mallasi (2006)	Chavada et al. (2012)	Moon et al. (2014)	Kassem et al. (2015)
Generation	X		X	X	X	X
Allocation		X	X	X	X	X
Conflict detection			X	X	X	X
Conflict resolution				X		X

Most of the studies presented in this section were focussed on workspace generation, allocation and conflict detection. However, the effort to resolve conflicts in order to optimise workspace utilization in the workflow is relative small.

C) Analysis

A set of papers among the reviewed papers performed an analysis of the use of 4D BIM (Jongeling and Olofsson 2007, Jongeling et al. 2008, Tsai et al. 2010, Li et al. 2013, Andayesh and Sadesghpour 2014). However, only Li et al. 2013 and only Andayesh and Sadesghpour (2014) focused their analysis on logistics purposes. Jongeling and Olofsson 2007, Jongeling et al. (2008) and Tsai et al. (2010) are more interested in understanding the workflow.

Jongeling and Olofsson (2007) present a method for the planning the workflow by combined use of location-based scheduling, such the LOB scheduling technique, and 4D CAD. The case study presented by Jongeling and Olofsson (2007) is limited to the planning for workflow and does not address the control of workflow. Jongeling et al. (2008) show how different types of 4D content can be extracted from 4D models to support 4D-content-based analyses and novel presentation of construction planning information. Tsai et al. (2010) presented a framework to assist the introduction of a 4D tool for consulting firms that have large organizational structures and well-established workflows.

Li et al. (2013) present a construction model, which was developed from design model and linked to the construction programme. The 4D model included temporary site components and the traffic access routes for vehicles and people. As the logistics plans need to be reviewed in a daily basis in order to reflect the changes on site, a computer program was developed.

Andayesh and Sadesghpour (2014) state that traditional approaches related to site layout planning have focused on static layout or dynamic in terms of change layout according to the construction. However, those authors argue that within the approaches that were previously grouped under the general term "dynamic layout planning", there are in fact two distinct approaches of phased and dynamic layout planning. The phased approach proposed by Andayesh and Sadesghpour (2014) offers an improvement over the static approach in terms of over-allocation of the space. However, since it does not reflect the changes within each phase, it still does not allow for the most efficient use of site space in the final layout.

Thus, the main contributions of the papers presented in this section are related to the study of the time and duration of construction objects (equipment, materials and workspaces) on the jobsite. Therefore, scheduling opportunities should be identified during workflow and layout planning in order to minimize the waste of time, waiting by crews, rework and disruptions.

Space conflict detention

Two papers (Tantisevi and Akinci 2007, 2009) used 4D BIM without considering the schedule in their analysis. Tantisevi and Akinci (2007) proposed an approach for generating workspaces that encapsulate spaces occupied by mobile cranes moving during an operation. Tantisevi and Akinci (2009) expand the representation of cranes implemented in Tantisevi and Akinci (2007) and other previous approaches to incorporate functional information, such as lifting. According to the authors, functional representation illustrates the design intent of cranes and describes how they should be expected to behave under different operating conditions. The output of the approach of Tantisevi and Akinci (2009) is a 4D model, which includes construction processes described in multiple levels of detail. The geometric transformations generated by this approach can be used to model workspaces of mobile cranes to identify spatial conflicts and determine conflict free locations for mobile cranes.

In these studies, crane operation was decomposed into small motions that are composed of a sequence of geometric transformations. Similarly, 3D model should be divided in multiple levels of detail in order to be used as the basis for the visualization, the modelling workspaces, identification of possible spatial conflicts.

CONCLUSIONS

Numerous studies related to BIM including 4D CAD have been performed, particularly in the area of work schedule, workspace interference and conflict detection. The literature review performed indicated that the number of papers focused on how 4D BIM has been used for logistics purposes in building environment is relatively limited because its application is fairly new. The fact of having enlarged the initial search with other words, such us: supply chain management, space planning, workspace and workflow deviated from the main objective of this literature review. Most of the papers found with the keywords were related with three main elements: generation and allocation of workspaces, detection of congestion and spatial-temporal conflicts, and the resolution of identified conflicts.

Some studies (Bortolini et al. 2015; Cheng and Kumar 2015) pointed out the benefits of using 4D BIM to help in daily operational decisions that do not adhere to the original layout plan. This is based on the idea that the lack of site layout planning at an operational level generates most of the daily layout problems at the jobsite. In fact, some papers have pointed to the need to perform further studies at the operative level approach in order to study the movement and workflows of workforce at jobsites. Despite 4D models have been used at oil and gas sector for several years, the main applications were related to the identification of conflicts among components.

However, planning of workflow with a 4D BIM model requires additional objects that are not included in most of today's 3D building models, because most 3D models are limited to building components (Jongeling and Olofsson 2007). Thus, space should be considered as a resource that is related to a location and a task in a project for the planning of workflow. The Line of Balance (LOB) technique is pointed out by some authors (Jongeling and Olofsson 2007, Bortolini et al. 2015) as a useful mechanism to achieve that, due to the fact that 4D BIM tools, combined with LOB, could facilitate logistics planning.

The main contribution of this paper is to highlight the main uses of 4D BIM by the construction management community in the last ten years for logistics purposes. Further studies focusing on workflows are necessary to reduce daily logistics problems at jobsites.

In addition, 4D building models need to be organized according to a location-based logic, avoiding workflow conflicts. For that, 3D CAD building components should be linked with the schedule of the tasks. Those linkages could potentially allow the detection of the congestion and the spatial–temporal conflicts between workspaces. However, there is no commercial software that offers this sort of function. Moreover, 4D models need to be updated frequently, since the amount of information used varies according to the requirements of each project, and once again, there is no commercial software for automatically updates. Moreover, this literature review allows the authors to understand the main uses of 4D BIM for layout management area and to identify study opportunities for conflicts minimization in workspaces and workflows from the introduction of traffic access routes for vehicles and pedestrian into the model.

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IMPACTS OF LEAN OFFICE APPLICATION IN THE SUPPLY SECTOR OF A CONSTRUCTION COMPANY

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ABSTRACT

Studies considering the impacts of implementing the Lean Office in a supply sector are of high importance for construction companies, because such companies depend on the consolidation of their businesses and efficient management strategies; they also depend on suppliers of materials and services external to their organization. Thus, the use of Lean Office as a management tool gives construction companies a competitive edge in the present market situation. The purpose of this research is to apply Lean Office tools in a construction company - supply sector, evaluating the impacts in the sector after this implementation. The method used in this work was the case study research. A small construction company contributed with information required by this study. Initially, a description of the business is done with the preliminary design of the supply sector; from this, the current state value stream map is prepared. Then, the value stream map is created for the future state, applying the improvements identified while studying the company. The results led to the identification of faults and opportunities for management improvements. Action plans (Kaizen plans) were prepared aiming for the improvement of the production processes. This research is restricted to a specific company in the industry. One of the researchers is part of the company's staff and had access to information needed for the study. This work aims to contribute spreading the use of lean tools to improve the management of companies, regardless of size. After applying the kaizen plans in the supply sector, new indicators, such as cycle times, lead time and added value, were checked and compared to the previous state of the company.

KEYWORDS

Lean construction, lean office, supply sector, Kaizen plans, Value Stream Map.

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INTRODUCTION

The market shows itself more and more competitive. Because of this fact, companies have been searching for efficient strategies for the improvement of their production processes (Alves 2007). One of the ways to improve the production system of a company is by means of the lean thinking.

Liker (2004) asserts that this mentality or system was highlighted in the 80's, because of its quality and efficiency, becoming a model of competitive production. This fact caught the attention of many researchers and companies, bringing prominence to the lean thinking and disseminating this philosophy to the administrative areas of offices (lean office) and constructions (lean construction) (Womack et al. 2007).

The lean office philosophy, addressed in this article, represents the use of lean concepts in office environments. According to Greef et al. (2012), this is different from the lean manufacturing, because the focus is not the productive planning; in the lean office the strategies are focused in the administrative processes.

Considering this difference, the resources (value) for the lean office are: the supplies or products that are necessary for the office activities and information, which can be in the digital, printed, electronic, oral or graphic form (Lago et al. 2008). In this sense, applying the lean office in the supplies sector is relevant, since this sector is responsible for the efforts that link corporations to their customers, distribution networks and suppliers aiming for advantages in the market, which is more and more competitive (Chen and Cox 2012).

According to Al Maian et al. (2015), the management of the supply chain in civil construction considers the complexity involved in the companies and presents unique challenges, creating a network of independent contractors, sub-contractors, and suppliers that often span the globe. For these authors, there is a continuous challenge in guaranteeing coordinated planning of the diversity of equipment, goods and materials that are necessary throughout the development of the company.

In this way, this article reports a case study, carried out with a construction company using the lean tool, of the value stream mapping for the supply sector of the company. It is intended to evaluate which are the cycle times and waiting times in the production processes that compose the sector; it is also intended to create an action plan with the purpose of reducing the lead time, by means of changes in deficient administrative routines, resulting in optimized efficiency for the sector.

LITERATURE REVIEW

LEAN OFFICE

The lean office corresponds to the use of the lean thinking modified for administrative environments or offices. For Chen and Cox (2012) can be more difficult to bring the concept of Lean into the office environment than a manufacturing area because of a lack of understanding, a lack of cooperation between departments, and a lack of directive from the top.

According to Monteiro et al. (2015), this philosophy primarily aims to reduce costs, eliminate reworking, minimize communication problems, eliminate unnecessary activities, increase productivity, improve the efficiency of the administrative functions and use the workspace in the best way in the office environment.

Tapping and Shuker (2003) describe the necessary steps for the implementation of the lean office, they include: (1) committing to the change: this represents communication and flexibility in the application of tools, with the acquisition of support from the high administration being essential for the change; (2) choosing the value stream: for the lean office, the flow of information in a given administrative sector is generally chosen; (3) learning about lean: the concepts and terms associated with the lean thinking must be well understood by every person involved in the process; (4) mapping the current state: the map of the current state exposes the units of the production process (processing time and transmission of information) by using a set of symbols and icons; (5) identifying actions for lean development: these are action plans created from the use of lean tools and from the elimination of unnecessary activities for the production process - this step aims to develop a plan of continuous improvement of the stream; (6) mapping the future state: three phases must be employed for the correct drawing of this map, they are: the phase of understanding the customer demand, the phase for implementing the continuous stream so that the value desired by the customer is established and the leveling phase (equally distributing the work); (7) creating Kaizen plans: this step does not require the creation of a new future state map, however, many modifications should be done on the map in order to obtain continuous improvement in the production processes (kaizen); (8) implementing of kaizen plans: to practice the action plans developed and to observe the results.

MANAGEMENT OF THE SUPPLIES SECTOR IN CIVIL CONSTRUCTION

The supplies sector is responsible for the management of materials and resources with time; it significantly influences the maintenance of the financial flux and in the satisfaction of the customers. However, for Vrijhoef and Koskela (1999), construction supply chains are still full of waste and problems caused by myopic control. The acquisition of materials in the civil construction is usually done with urgency; this can cause delays in the delivery of such materials and, consequently, delays in the chronogram for the delivery of the project.

In order to avoid this scenario, Khutale and Kulkarni (2013) points out some important factors regarding the acquisition of materials, they are: compliance with the quality and necessary parameters for the items guaranteed by the suppliers; maximum negotiation with the suppliers, in order to guarantee the best possible conditions for purchasing/employing; evaluation and maintenance of partnerships with the suppliers, in order to guarantee the continuous improvement of the process.

According to Al Maian et al. (2015), the managers are challenged to improve the Supplier Quality Management (SQM) in an environment with limited resources. Hence, the managers must identify efficient practices for the SQM and choose the one that can bring the most benefits and assure quality for the supplier and materials.

In order to improve the management of the chain, Wibowo and Sholeh (2015) suggest the definition of key indicators for the development, such as: Perfect order fulfillment, Order fulfillment lead time, Production flexibility, Supply chain management cost and Inventory days of supply. According to the authors, the contractors must have a strategic plan for the acquisitions, because it is complicated to substitute a supplier during the development of the project.

According to Safa et al. (2014), the procurement and management of construction materials involve challenges related to reducing inventory, speeding delivery, and increasing the control of materials, decreasing the overall project cost. The authors also state that a variety of project-specific criteria are involved in the supplier selection process, including price, lead time, cash rebate, and supplier performance.

METHOD

The method used in this work was the case study research. A small construction company was identified that contributed information needed to do the study. One of the researchers is part of the company's staff and had access to the various data needed for research. A construction company selected that did not have the lean philosophy in its administrative environment, or in its supplies sector. Initially, a description of the business is done, the preliminary design of the Supply sector and from this it is prepared to present value stream map. Then the value stream map is created in the future state, applying the improvements identified in the study in the company.

APPLIED STUDY

THE COMPANY

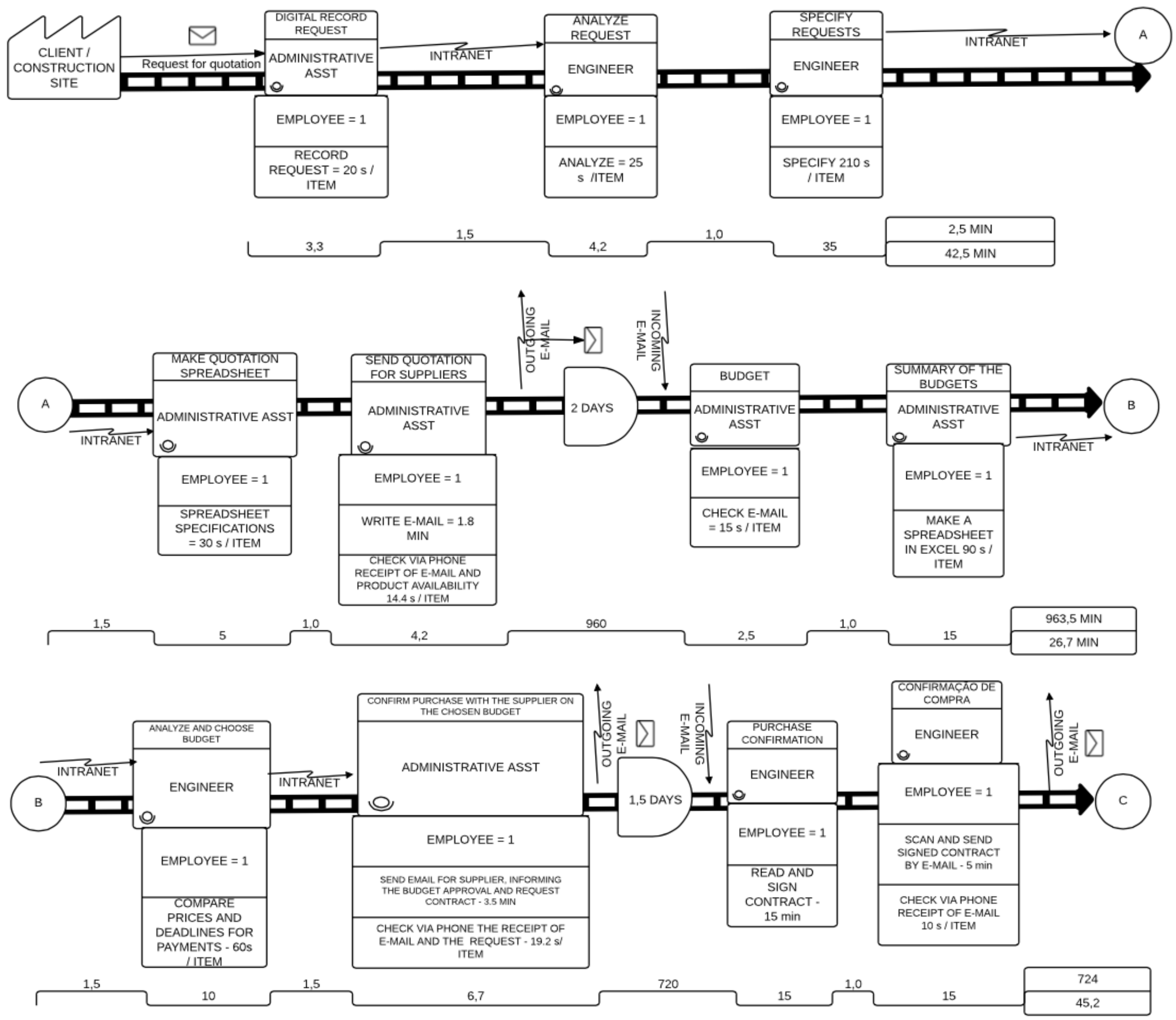
The studied corporation is a small construction company, localized in Tiete, São Paulo, Brazil. The company manages and carries out different projects for commercial, industrial and high standard residential enterprises. As the company is small, it does not have formal departmentalization. The organizational structure of the company consists of seven employees: three civil engineers, an architect, an administrative manager, a trainee (auxiliary civil engineering) and an administrative assistant. However, it is possible to observe certain collaboration among its employees. The supply sector is managed by a civil engineer, advised by administrative assistant.

CURRENT STATE VALUE STREAM MAPPING

According to Tapping and Shuker (2003), the principals concepts the Value Stream Mapping (VSM) are described as: *Cycle Time* (CT) – It is represented by the time that passes from the beginning to the end of an individual activity or process; *Total Cycle Time* (TCT) – It is understood as the summation of all cycle times of the individual activities or processes inserted in a stream value; *Waiting Time* (WT) – This concept is attributed to the time that a work unit will wait until the next process is ready; *Lead Time* (TLT) – Represents the summation of the total cycle time and the total waiting time; *Added Value* (AV) – It is obtained by the ratio between the total cycle time and the lead time. This concept is obtained as a percentage and can be described as: the percentage, inside the lead time (total time for processing an order), used in activities that add value.

Since the company did not have any indicators about how many requests were made per day, a quantitative analysis was carried out considering a month of service. For calculating these indicators the following were considered: the business hours practiced by the office, which are from Monday to Friday, from 8 a.m. to 5 p. m., with one hour for lunch, summing 8 hours of work daily, or 480 min; the average number of requests in a day. This resulted in 5 requests per day; the average number of items per request, which resulted in 10 items per request.

With these indicators established, it was possible to draw the current state value stream map (Figure 1), in which every process existing in the supplies sector and their respective times can be observed. After the determination of each time indicator, calculations were carried out in order to determine the TCT, the TLT and the AV. For elaborating the map, the construction company has also provided some relevant data such as the time for deliveries and for receiving feedback from the suppliers.



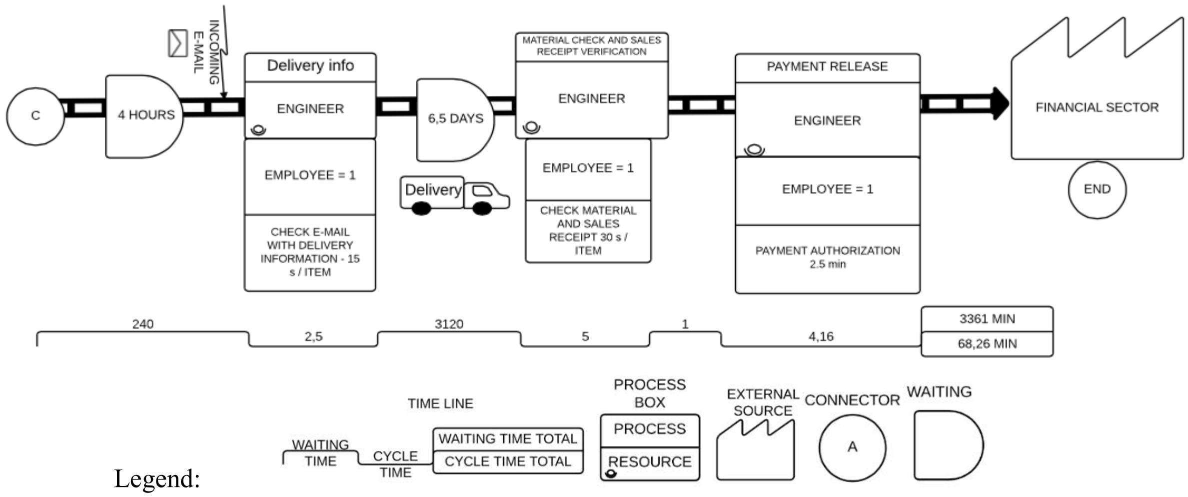


Figure 1: Current state value stream mapping.

In summary in Figure 1, the process develops as follows: the communication between the construction and the procurement department is done by telephone, technical visits and e-mails. On average, 10 requests are sent to the supply sector by telephone, e-mail or by purchase requisition spreadsheets. The information is received and digitized by the administrative assistant and it is sent, through intranet (internal network message), to the engineer in charge of the sector that verifies the request. The next procedure is the detailed specification of the product (model, code, color, quantity, unit etc.). Next, the administrative assistant creates requisition spreadsheets with quotation and prepares the e-mails for the previously established suppliers. With the quotations received, an e-mail is sent to the chosen supplier confirming the acquisition and contract (when necessary). After organizing the contract documentation, the company waits for the materials; it takes about 6.5 days for the products to arrive in the construction site. When the requested materials arrive in the construction site, the engineer in charge verifies the invoice and the integrity of the products. Having received the material in perfect conditions, the engineer authorizes the payment. This information is transmitted to the financial department via intranet.

Looking at Figure 1, the following results were obtained from the current state VSM for the supply sector: total cycle time of 116 minutes, lead time of 10.8 days and added value of 2.24 %, that is, only 2.24 % of the activities add value to the production process of the sector. The remaining represent waiting activities, which can be divided in the times for receiving feedback from the suppliers and for delivering the materials.

PROPOSAL OF AN ACTION PLAN

This plan intends to verify each bottleneck present in the current state VSM and to verify the best options for changing that can be applied in order to reduce the waiting times, that is, the lead time.

Considering the results obtained from the current state VSM, six action plans (Kaizen plans) were created and deployed, which intend to optimize the supply sector. They are:

- Elimination of incorrect steps of the production process. Processes that do not add any kind of value to the supply chain;
- Change of collaborator in specific processes. It was observed that, in some processes, the collaborator responsible for that step should be different. This decision was made intending to reduce the number of steps related to the transmission of information, reducing in this way the waiting time between processes;
- Addition of one collaborator to a specific process. In steps having high cycle times, a new collaborator (Trainee) was added in an attempt to reduce the cycle time;
- Automation of confirmations for email messages, that is, when the email is received by the suppliers, a message confirming the delivery is automatically sent to the construction company;
- Implementation of partnerships with suppliers. The partnership aims to reduce the waiting times for receiving email answers with contracts and budgets;
- As implied by the current value stream map, the delivery of the material in the building site is the activity demanding more waiting time; 6.5 days, which corresponds to 60.3 % of the total waiting time. This happens because the company considers an average of the times for delivering materials without making a difference between them. In this way, this plan suggests that the materials should be separated in 4 groups, these are: routine materials, representing 66 % of the total required materials and taking 1 day, on average, to be delivered; leverage materials, representing 21 % of the total with an estimated delivery time of 3 days; strategic materials, representing 8 % of the total and having an average delivery time of 15 days; bottlenecking materials, representing only 5 % of the total and having a delivery time of 30 days.

FUTURE STATE VALUE STREAM MAPPING

Primarily, the takt time was calculated for drawing the future state value stream map. For calculating this parameter, it is necessary to establish a standardized unit of measurement. This unit was defined from the daily demand of requests. The calculation of the takt time per unit of requests was carried out as follows:

$$\text{Takt time (requests)} = \frac{\text{Total available operational time}}{\text{Daily demand (requests)}} = \frac{400}{5} = 96 \text{ minutes/request}$$

When we compare the calculated value of the takt time (requests) with the cycle time of the process (T_{cycle} = 116 min), a difference of 20 minutes is observed; that is, the daily demand is higher than what the process can produce, generating delays in the supply chain. Considering this discrepancy, it is necessary that the cycle time of the processes are reviewed, so that their sum is less than or equal to the takt time of the requests. In Figure 2, the future state value stream map can be observed.

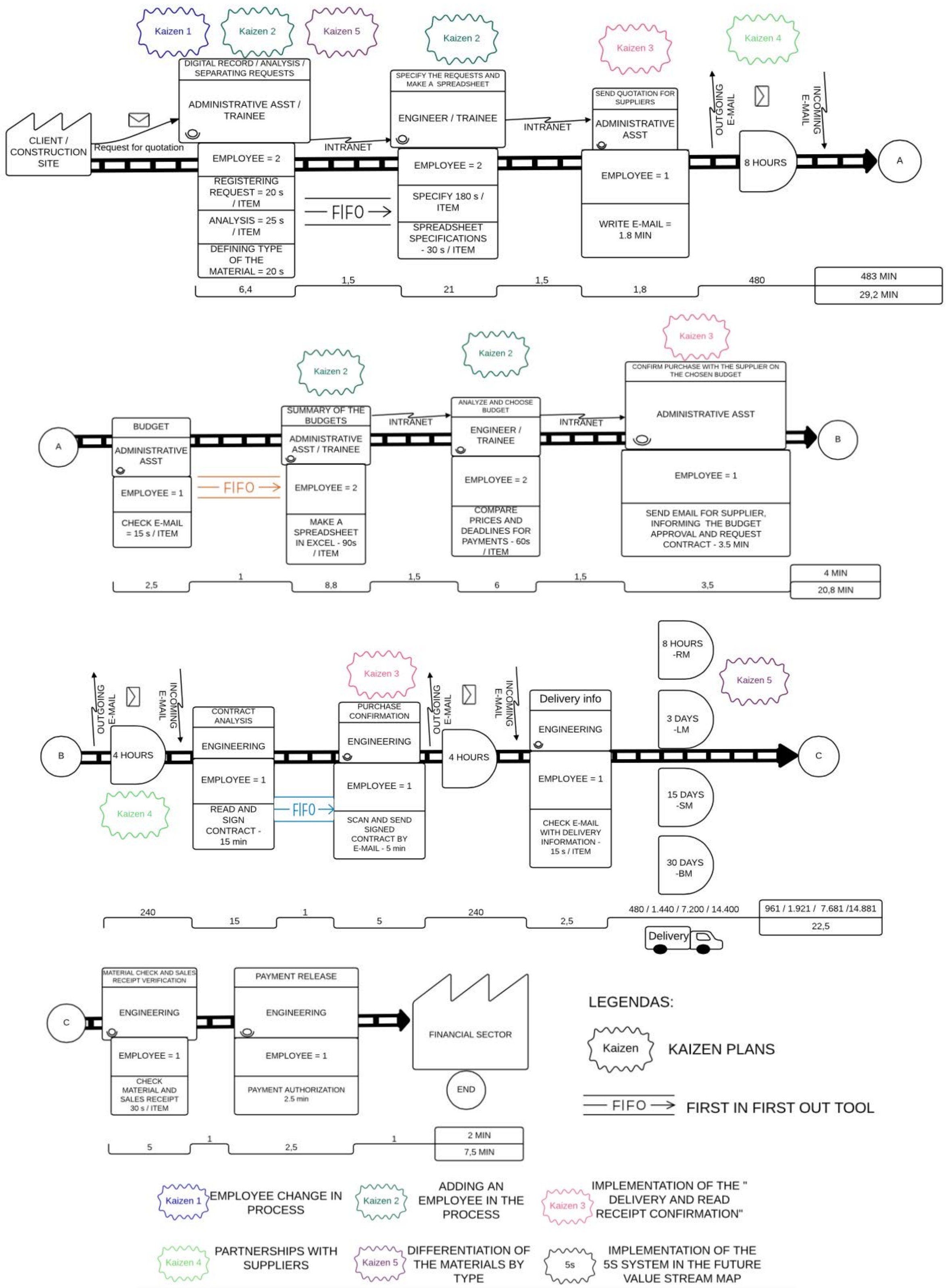


Figure 2: Future state value stream mapping.

After this calculation, it was established which are the lean tools to be used in the stream; they are: (1) the "5s process" (sometimes referred to as the Visual Work Place) is about "a place for everything and everything in its place" (Salem et al. 2005) - in this case, aims to reorganize the administrative processes in a simple way; (2) the "first in first out" tool, which establishes order for the logical information processing (Greef et al. 2012), in the case of this construction company, ordination for the requests.

With all of the indicators calculated and with the changes made to the current state map, measurements of the new processing times were carried out and the future state map was drawn. In Figure 2, the future state value stream map can be observed.

The results from the future state value stream map are as follows: the total cycle time was 80 minutes; the lead time and added value were separated for the different material categories. The results for the takt time and added value were, respectively: routine materials – 1,530 min, 5.2 %; leverage materials – 2,490 min, 3.3 %; strategic materials – 8,250 min, 1.0 %; bottlenecking materials – 15,450 min, 0.5 %.

CONCLUSION

Considering the cycle time, there was an improvement of 31 % or 36 minutes when comparing with the same index in the current state map. This result is satisfactory, considering that the takt time for the production process of a request is 96 minutes, that is, higher than the cycle time in the future state. In this way, it can be implied that there will not be any delays in the supply chain related to processes carried out by the office.

The separation of the materials in four distinct groups enabled four different indicators in the future state map, for the waiting time, lead time and added value. For comparison of these indicators with the ones obtained from the current state value stream map, the materials that are requested more frequently were considered, that is, the routine and leverage materials, which represent, together, 87 % of the requests. For the strategic and bottlenecking materials there was no improvement due to the deficiency in the waiting time indicator used by the company.

The lead time in the future state map for routine materials was 1530 minutes. When this value is compared with the same indicator in the current state map, an improvement of about 70.3 % was observed in the performance. For leverage materials this optimization was of 51.8 %. Regarding the indicator for the added value for routine and leverage materials, the improvements were, respectively, of 3 and 1.1 %. The reasons by which the evolution in these parameters was not great were: reduction of the cycle time in the future state map; the waiting times for the delivery of civil construction materials are generally high (8 hours minimum).

By the end of the case study, it was verified that the results from the application of the lean office in the supply sector was favorable, since there was reduction in the cycle and waiting times. This optimization was possible due to: commitment and understanding of the collaborators regarding the lean philosophy; development of a strategic plan applied to the current state stream value map; correct use of lean tools. Finally, it is important to always review and improve the VSM, in order to guarantee the fullest operation of the lean philosophy in the administrative sector of the construction company.

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SECTION 9: TEACHING LEAN CONSTRUCTION

Neeraj, A., Rybkowski, Z., Fernandez-Solis, J.L., Hill, R., Tsao, C., Seed, B. and Heinemeier, D.(2016). "Framework Linking Lean Simulation Principles to their Application on Construction Projects." In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.9 pp. 3–12. Available at: <www.iglc.net>.

FRAMEWORK LINKING LEAN SIMULATIONS TO THEIR APPLICATIONS ON CONSTRUCTION PROJECTS

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ABSTRACT

The QUESTION this paper seeks to address is: Can the principles illustrated by Lean simulations be systematically linked to applications of those principles on actual projects? The PURPOSE of this research has been to ease the transition between theory and practice by aggregating published case studies as well as lean simulations and making links between them.

The RESEARCH METHOD adopted for this study included: (1) prepare a systematic literature review sourced from LCI and IGLC databases; (2) collaborate with the Lean Construction Institute to construct an inventory of existing lean simulations and the principles they illustrate; (3) analyze published case studies and simulations for the lean principles they embody; and (4) develop a matrix to establish logic connections between simulations and case studies from actual projects. FINDINGS were assembled onto a Simulation/Case-study matrix. This research involved locating, translating, and organizing 23 years of published, organically developed, construction case studies from IGLC and LCI databases. Therefore one LIMITATION of this this research is that it included only those simulations and case studies that have been published.

One IMPLICATION and VALUE of this research is that it offers a framework to assist lean educators and facilitators when teaching Lean Construction. This matrix can also serve as a "seed" for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

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KEYWORDS

Lean simulations, case studies, Lean Construction teaching, Simulation/Case-Study matrix, Lean principles

INTRODUCTION

Simulations and lean project case studies have appeared in academic publications for over two decades. Yet novices to Lean Construction (LC) have expressed frustration over an inability to make mental connections between the principles illustrated by simulations and potential applications of those principles on actual construction projects. Structured literature reviews indicate that implementation of lean principles on a construction site are often incomplete or incorrect because the workers do not have a comprehensive understanding of lean construction principles and are therefore hesitant to apply lean methods and tools (Heyl 2015).

Although several books such as *Toyota Production System: Beyond Large-Scale Production* (Ohno 1988), *The Toyota Way* (Liker 2005), *Factory Physics* (Hopp and Spearman 2008), and *Modern Construction: Lean Project Delivery and Integrated Practices* (Forbes and Ahmed 2011) have been published, a single comprehensive source does not exist that conveys a definitive interpretation of how to implement lean principles on a construction site (Tsao et al. 2012).

A typical course on Lean Construction requires accumulation of diverse publications that can facilitate a broad understanding of its application to construction contracts, design and office activities, field operations and supply chain relationships of capital projects (Tsao et al. 2012). There is a gradual shift from traditional course delivery methods that primarily emphasize textbooks as lean educators are evaluating other interactive approaches that encourage analytical thinking and conversation between students and educators (Tsao et al. 2013). A simulation can offer a better learning environment to demonstrate the impact of decisions on a process because it can be easier to understand the functionality of an actual system under real time conditions (Caňizares and Faur 1997; Walters et al.1997).

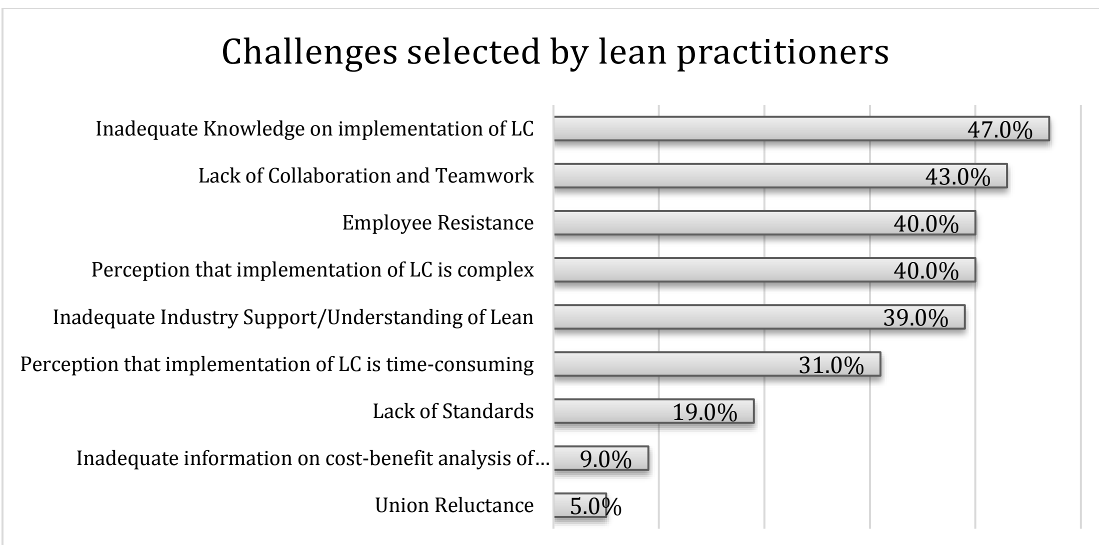
Izquierdo et al. (2011) recommended that the development of case studies is an ideal approach to impart knowledge about Lean Construction (LC) after analyzing feedback from a Basic Management Functions Workshop (BMFW). This workshop was developed to train construction industry employees in the application of LC principles in order to maximize value and minimize waste for customers.

NEED FOR A "SIMULATION-CASE STUDY" FRAMEWORK

Successful implementation of Lean Construction (LC) requires a determined approach and committed project participants (Heyl 2015; Hirota and Formoso 1998). Figure 1 shows that 47% of lean practitioners selected "inadequate knowledge on implementation of lean construction" among project stakeholders as a major challenge (McGraw Hill Construction 2013).

Benefits achieved through Lean can be difficult to grasp when that knowledge is transmitted only through textbooks (Rybkowski et al. 2008). Although simulations are often played at lean construction workshops and there are numerous published case study articles describing productivity gains gleaned from lean methods implemented on construction sites, novices still express frustration about their inability to connect principles illustrated by lean simulations to their actual applications in construction. Clarifying lessons illustrated by the lean simulations is an important first step to supporting the research question: Can the principles illustrated by Lean simulations be systematically linked to applications of those principles on actual construction projects?

The effectiveness of a simulation as an appropriate teaching methodology depends on the applicability of its associated learning outcomes to a real-time scenario (Ashwin and Pitts 2007; Rolfe 1991). Teaching the complex concepts of Lean philosophy to students and employees who have no experience with Lean can be challenging. When teaching students using lean simulations, it is imperative to develop a creative context so that they can observe and understand the importance and inner workings of Lean philosophy. However, when teaching employees/practitioners, it is also important to translate Lean thinking into an applied context using case study analysis so the lessons become relevant to those working in the construction industry.



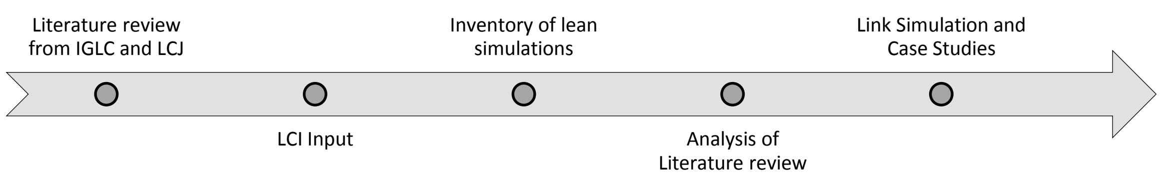
- Figure 1*:* Major challenges encountered in the application of a Lean approach to construction sites (according to lean practitioners).
- Adapted from (McGraw Hill Construction 2013, page 39)

The objective of this research is to offer a framework to assist lean educators and facilitators when teaching Lean Construction. This matrix can also serve as a “seed” for various international communities to extend and share how specific lean principles can be incorporated into their own cultural traditions within project delivery processes.

RESEARCH METHOD

The Lean Construction Institute conducted a study with the Knowledge Transfer Laboratory Team from May 18-21, 2015 in Dallas, TX to identify frequently used lean simulations. Thirty-three lean simulations were identified during the study and were published in August of the same year on the Lean Construction Institute website as a matrix entitled "LCI Simulation Matrix." The simulations identified in the "LCI Simulation Matrix" illustrate fundamental aspects of lean processes that are applicable to the construction industry. "Simulation/Case-study matrix" provides an elaborate model approach that can be implemented on any construction project.

The method adopted for this study was a structured literature review. Various lean construction case studies were reviewed to identify how lean principles are being adapted to the construction delivery process. Although the authors acknowledge there is not yet a clear consensus with respect to lean principles, this research references the 14 principles of Liker's *The Toyota Way* (2005) because the book offers a recognizable and relatively comprehensive framework for lean. Figure 2 illustrates the method adopted for this research. A systematic literature review sourced from IGLC and LCI database was conducted using keywords such as "Lean Simulations," "Case Study," Lean Principles," "Teaching Lean" and "Application/Adaption to construction site." The names of authors who regularly write about simulations and lean case studies were also searched. Construction project case studies were selected based on their relevance to the 14 principles illustrated by Liker (2005) in *The Toyota Way.*



- Figure 2*:* Research methodology adopted to identify the link between lean simulation principles and their application to the construction industry

LIMITATIONS

This research involved locating, translating, and organizing 23 years of organically developed construction case studies from IGLC and LCI Databases. However this research is limited to only those simulations and case studies that have been published.

DELIMITATIONS

The scope of this study was limited to simulations in lean that are being applied to the construction industry as well as to case studies from the construction industry. The research does not include simulations or case studies from any other industry.

RESULTS

Research by Neeraj (2016) focused on seven lean concepts to establish links between lean principles and their application on construction projects. These concepts provided a means to categorize specific simulations, and included:

1. Pull Planning, Small Batch Sizes and Multi-skilling
2. Supply chain problems in construction
3. Collaboration and Communication
4. Continuous Improvement
5. 5S
6. Last Planner System
7. Target Value Design

This paper builds on work by Neeraj (2016). Table 1 illustrates a link between lean simulations that represent collaboration and communication and their application to construction projects. Similarly Table 2 illustrates applications of the Last Planner System principles and Table 3 illustrates applications of Target Value Design principles to construction projects. While many simulations and case studies illustrate more than one principle, the tables are intended to help highlight generally dominating principles.

CONCLUSION

This research explored 8 of the 33 simulations currently listed in the "LCI Simulation Matrix" published by the Lean Construction Institute. The paper provides a framework to link lean principles to their application on construction projects as represented in published case studies. The case studies document impacts on the success of a project where time, cost and quality have been improved.

This research represents an important first step in systematically connecting principles of Lean game simulations to their practical applications on building projects. The objective of this research is to assist lean educators to make memorable links between the lean principles illustrated by simulations and their actual applications, thereby also benefiting practicing stakeholders. The intent is that future researchers will expand on this framework, facilitating among construction stakeholders a better understanding of lean principles and their potential applications to actual projects.

Table 1: Collaboration and Communication

Lean Simulation	Lean principles illustrated in ***The Toyota Way*** (Liker 2005)	Lean Construction Tools	Case Studies that implement these lean principles
1. Magic Stick Simulation (provided by Alan P. Mossman) **2.** Silent Squares Simulation (Building Dynamics Group, Ohio State University Extension) **3.** Maroon – White Simulation (Smith and Rybkowski 2013) **4.** Win as much as you can Simulation (Gellerman 2003)	• Principle #13 – *"Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly."* *Simulations 3 and 4 illustrate Principle #1 as well as Principle #13*: • Principle #1 – *"Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals."*	• Big Room meetings • A3s	• Alarcón et al. 2011* • Chin et al. 2004 • Elsborg et al. 2004 • Fundli and Drevland 2014 • Kulkarni et al. 2012* • Riley and Horman 2001* • Tribelsky and Sacks 2010

*Case Study providing exceptional understanding of the learning objectives

Table 2: Last Planner System

Lean Simulation	Lean principles illustrated in ***The Toyota Way*** (Liker 2005)	Lean Construction Tools	Case Studies that implement these lean principles
5. Colored Blocks Simulation (DPR Construction) **6.** Parade of trades Simulation (Tommelein et al. 1998) **7.** Villego Simulation (http://www.villego.com)	• Principle #3 – *"Use 'pull' systems to avoid overproduction."* • Principle #4 – "*Level out the workload (work like the tortoise, not the hare)."* • Principle #11 – *"Respect your extended network of partners and suppliers by challenging them and helping them improve."* • Principle #14 *"Become a learning organization through relentless reflection and continuous improvement."*	• Pull Planning • Percent Planned Complete for reduced Variability and workload levelling (Heijunka) • Root Cause Analysis (5 Whys) and Go to the Gemba for learning • Kaizen (Continuous improvement) • Last Planner System (LPS) of Production Control	• Ahiakwo et al. 2013* • Al Sehaimi et al. 2009* • Bortolazza et al. 2005 • Fiallo and Revelo 2002 • Formoso and Moura 2009 • Junior et al. 1998* • Kalsaas et al. 2009 • Kim and Jang 2005 • Porwal et al. 2012* • Soares et.al. 2002 • Tommelein and Beeche 2001 • Valente et al. 2013

*Case Study providing exceptional understanding of the learning objectives

Table 3: Target Value Design

Lean Simulation	Lean principles illustrated in ***The Toyota Way*** (Liker 2005)	Lean Construction Tools	Case Studies that implement these lean principles
8. Target Value Design Simulation (Munankami 2012)	• Principle #3 – *"Use 'pull' systems to avoid overproduction."* • Principle #13 – *"Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly."*	• Target Value Design	• Ballard et al. 2015 • Do et al. 2014* • Kim and Lee 2010 • Melo et al. 2014* • Oliva and Granja 2013 • Rybkowski 2009*

*Case study providing exceptional understanding of the learning objectives

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TEACHING LEAN CONSTRUCTION: A SURVEY OF LEAN SKILLS AND QUALIFICATIONS EXPECTED BY CONTRACTORS AND SPECIALTY CONTRACTORS IN 2016

Thaís da C. L. Alves[1], Marcelo M. Azambuja[2], and Bander Arnous[3]

ABSTRACT

Early studies conducted by researchers and Lean practitioners have reported strategies, methods, and content used to teach Lean Construction. However, none of the publications address the demands from the construction industry. What skills and qualifications are necessary to qualify for a job at companies that implement or are in the process of adopting Lean practices? What topics should be emphasized in the classroom? This study intends to answer these questions. Our main goal is to identify the set of Lean skills and qualifications that are considered important by construction companies. The researchers conducted a survey of job descriptions on the websites of general contractors and subcontractors listed as members of the Lean Construction Institute (LCI). Recent graduates from construction programs usually pursue jobs as project engineers, assistant project managers, project managers, schedulers, and superintendents. For this reason, only descriptions associated with these roles were collected and analyzed. The findings of this research identify major lean competencies required by the construction industry and provide guidelines for development or improvement of lean construction courses offered at universities.

KEYWORDS

Teaching, Lean Construction, Lean skills and qualifications, survey, curriculum

INTRODUCTION

The Lean Construction Institute (LCI) has the goal of "*operat(ing) as a catalyst to transform the industry through Lean project delivery using an operating system centered on a common language, fundamental principles, and basic practices*." In order to

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accomplish this goal, LCI states its vision as: "*Transform the Design and Construction Industry supply chain to provide value and enable other industries through Lean and integrated approaches*" (LCI 2016a). There are many ways in which both statements can be implemented as concrete actions to change the industry, one project at a time, using Lean and integrated approaches. One such way is through the hiring of professionals capable of actually implementing Lean in construction projects based on their experience in previous projects, their continuing education efforts, and/or their involvement with LCI communities of practice (CoPs). Another way is through the teaching of Lean in universities that educate professionals that will join the industry (see Tsao et al. 2012, 2013 for some examples). The study presented in this paper aimed at verifying if LCI member companies are requesting, in at least some of their job openings, skills and knowledge related to Lean Construction. Our initial purpose was to use these findings to provide guidelines for development or improvement of Lean Construction courses offered at universities. However, as the study developed, we noticed a trend that we did not expect at first in terms of what LCI member companies are looking for in terms of Lean-related skills. Therefore, the discussion presented in this paper might be just the beginning of a conversation in terms of how LCI-member companies and academics can help shape up the future of the construction industry one job posting at a time. The study used the published list of LCI corporate member companies as the point of departure for the sample analyzed.

LITERATURE REVIEW

The interest in learning and teaching Lean has been growing amongst universities in the United States and abroad as they respond to an interest of academics, and a growing demand from the industry, and offer courses on Lean-related topics both at the undergraduate and graduate levels. Faculty in these universities tend to use interactive methods in order to encourage critical thinking and discussion about how Lean concepts are used. Tsao et al. (2012, p.1) suggested that an effective approach to teaching Lean Construction should combine: "*readings, lectures, discussions, simulation exercises, team projects and assignments, field trips, and guest speakers to mix theory with action.*" Similarly, Tsao et al. (2013) analyzed the approaches used by seven faculty in seven institutions and verified that the instructors took a very dynamic approach to teaching Lean Construction including similar readings across their curricula and using a variety of methods to convey the message, especially using simulations to engage students and make them experience the benefits of Lean in practice. The use of multiple methods to teach Lean is also appreciated by the students, as documented in student evaluations discussed by Pellicer and Ponz-Tienda (2014) and Nofera et al. (2015).

In a similar fashion, the literature at large on the use of simulations to teach Lean presents multiple instances in which academics have developed and used simulations to convey important Lean tenets, systems, and specific tools. The literature on simulations also documents the diversity in terms of where and how Lean is being taught.

Some of the first documented efforts by construction researchers to teach Lean using dynamic methods can be illustrated by the work developed by Iris Tommelein at

University of California, Berkeley, and documented in the Parade Game simulation (Tommelein et al. 1998) to illustrate the effect of variability in production systems, and Rafael Sacks' LEAPCON simulation to mimic the influence of change orders and pull systems (Esquenazi and Sacks 2006). Later, the Villego simulation was also developed to illustrate use of the Last Planner System^{TM} (LPS) (Warcup and Reeve 2014).

Along the same lines, a group of faculty at Central Washington University (Martin et al. 2014) developed a simulation to teach integrated project delivery (IPD). Graham et al. (2012) integrated the use of Building Information Modeling (BIM) and IPD in an architecture course in Rhode Island (RI). During their course, the instructors conducted the students through an exercise in integrating BIM and IPD from the conceptual stages of a project including working with consultants. Students also had to consider a mandate by the owner to reduce project costs by 20% during the detailed design phase, which pushed them to really understand what the owner valued before making decisions to cut costs.

On the assessment side, in Texas, Rybkowski et al. (2012) developed a method to evaluate how much participants were confident in what they had learned in a workshop they developed to teach Lean-related concepts. The workshop involved multiple simulations and group discussions over three days for a group of practitioners who felt more confident regarding their understanding of Lean after taking this workshop.

Pellicer and Ponz-Tienda (2014) discussed their approach to teaching Lean at the Universitat Politècnica de València in Spain using a multi-faceted approach including lectures, exercises, simulations and a project-based approach to develop the course. Later in the course, they focused on advanced scheduling techniques and LPS, having the students to work on a project with a number of boundaries that had to be solved using Lean tenets. Likewise, Hyatt (2011) developed a course to integrate Lean, BIM, and green principles at Fresno State University in California. He consistently used the LPS throughout the course to teach Lean principles, and found out in the end that students wanted to know more about Lean Construction.

The efforts described take care of some of the challenges identified by Alves et al. (2012) in terms of bridging the gap between Lean Construction practice, research, and implementation. The three main challenges facing Lean Construction academics and practitioners as identified by Alves et al. (2012) were: the different meanings given to Lean, its tools, and principles; the need to have academics and practitioners working collaboratively to better understand and implement major concepts and systems and not only tools, and; the constant need to engage people in meaningful learning experiences when Lean is being taught and disseminated. The work presented in this literature review highlights the efforts developed by academics to support the dissemination of theoretical aspects of Lean, grounded in activities that engage participants and contribute to higher order learning. These activities contribute to higher order learning because students do not only memorize concepts, in fact they see these concepts applied in practice while developing a common understanding of Lean terminology.

However, it is not clear yet if the efforts of academics and the graduates, who have been exposed to these activities and courses, are becoming part of the industry and performing activities that require mastery or even basic knowledge about Lean. To the authors' knowledge, no study has shed light on this question: is the industry requiring/demanding graduates that are well-versed in Lean Construction concepts, principles, and tools? This paper starts this conversation by looking at LCI corporate members and what they ask in their job descriptions available online.

RESEARCH METHODOLOGY

The data collection stage started by choosing the sample from the Lean Construction Institute (LCI) corporate members list posted at LCI's website (LCI 2016b). The authors first working hypothesis was that: *H1: LCI member companies seek to hire candidates that have knowledge and skills related to Lean Construction principles and tools, and these companies have requirements related to that in their job postings.*

It was decided that the search for job postings would cover a third of the LCI corporate members, and that the sample was going to be randomly selected. The sample was created after including the first member on the LCI list and adding every third member to the list of companies to be studied. In the end, 35 members were identified during the first round of data collection.

In parallel with the definition of the companies to be investigated, it was decided that the study would be focused on five job categories, namely: Project Manager, Assistant Project Manager, Project Engineer, Scheduler, and Superintendent. This is a limitation of this study, which identified these job categories based on the authors' knowledge about job positions usually sought by students graduating from construction engineering and management (CEM) programs. It is important to note that during the search, job titles were limited to the specific category, so any generalization or specification has been excluded. For example, neither a project coordinator nor a senior project manager is considered a project manager, for the purpose of the data collection. However, a construction project engineer is still considered a project engineer, due to the fact that the subjects of this paper are construction related. This is another limitation of this paper as one might say that data from openings for 'senior project manager' could potentially contain more Lean-related content when compared to the more entry-level positions analyzed. However, the analysis presented herein aims to inform about a potential gap in terms of what is being taught in universities and the positions most CEM graduates apply for upon graduation.

Furthermore, from each company only one job offer was included for each individual job category. This job was prioritized based on location, and the state of California was chosen as the main location. The reason for this choice was that it is commonly believed that California is one of the leading states in Lean Construction implementation in projects of different types and sizes. The authors' second working hypothesis was that job openings in California would tend to have requests for knowledge related to Lean implementation or mastery of its tools and techniques. The authors considered that the Project Production Systems Laboratory (P2SL), a leader in Lean Construction research, is located in Berkeley, CA and works closely with the local Northern California LCI Community of Practice (CoP). Additionally, there are two other LCI CoPs in the state, Los Angeles and San Diego. Thus, this second working hypothesis assumed that: *H2 –*

job openings in California have a higher chance of requesting candidates with specific Lean-related skills and/or background. If no jobs were available in California, then jobs located at the company headquarters geographic area were investigated. After that, the position was randomly chosen from those available. Finally, while this paper only considers "full-time" job postings on the firm's official website, it is important to note that there might be other job offers posted elsewhere.

INITIAL ANALYSIS OF THE SAMPLE

Only 20 of the 35 LCI member companies analyzed had job offers that matched the job categories defined for the search. This required the addition of other members not initially considered in the first sampling effort. Additional companies were randomly chosen from the LCI members list and added into the sample to make the number of companies with valid entries to at least match the original sample of 35 companies.

The final sample covered 52 firms, 38 of which had some sort of job description that could be used in the analysis. The sample included 98 job descriptions, coming from these companies, and this was the number of entries analyzed. Moreover, the final sample included: 33 Project Managers, 8 Assistant Project Managers, 29 Project Engineers, 18 Superintendents, and 10 Schedulers. Data were collected during one month between February and March, 2016.

RESULTS AND DISCUSSION

The authors searched the final sample of 98 job descriptions to find Lean specific terminology. Only 8 companies included Lean terminology and/or related Lean practices in their job descriptions. Lean practices or tools were not well covered despite the fact that LCI Corporate member companies formed our sample. All other job descriptions focused their content on traditional project management skills and tools that are usually taught in CEM programs (e.g. Critical Path Method and knowledge of software such as Primavera and MS Project).

Nine job descriptions (9.2% of our sample) expected job candidates to have some Lean skills or qualifications. The positions were as follows: three project managers, two project engineers, two schedulers, one assistant project manager, and one superintendent. These jobs were located in: California (3), Minnesota (1), New York (1), Ohio (1), Washington (1), Wisconsin (1), and one not specified (company located in California).

A comprehensive analysis of these jobs indicates that companies expect people to know what Lean is in broad terms, but no specific skills or qualifications were listed except for two positions. Below is a list of broad statements with specific Lean-related terminology found in our sample:

"Collaborate with project teams to implement continuous improvement and lean strategies throughout the project delivery process".

"Mastery of Lean scheduling tools and techniques".

"Able to motivate and lead teams through Lean planning exercises".

"Schedule in Design/Build or IPD environment".

"4-D: Integrating schedule with BIM models".

"Provide intentional leadership for project team in areas of LEAN construction, project site safety and career development".

"Apply and implement Company's Lean project delivery system".

"Effective LEAN planning & scheduling".

"Ability to implement leading-edge technologies such as BIM and LEAN to benefit the project"

Only two jobs out of the 98 analyzed (from two companies out of 52 analyzed) presented detailed descriptions related to Lean skills/qualifications and responsibilities. They are as follows:

"Develop and maintain 3-week look ahead schedule using Lean tools. Coordinate and assist with scheduling of assigned subcontractors and self –performed work using Last Planner (Weekly Work Plan, Constraint Log and Plan Percent Complete) and Pull Planning (Collaboration+Communication+Commitment)".

"Help the Lean Production Leader to provide control, metrics and reporting for: Team Leaders, Supervisors, Trade Partners, Customers and other team members; help develop team members to be Last Planner System experts; motivate and drive the team to a zero-waste culture through detailed standard process and job instruction creation. Plan, develop, coordinate, and manage preconstruction and construction project activities in support of the project team while encouraging a collaborative environment and an integrated project culture."

"Develop scope of work for preconstruction services; Facilitate Lean training and integration of Trade contractor team members; Assist with all tasks that support the development of reliable estimating in the Target Value Design process including, qualifications, scope evaluation for the selection of trade partners; constructability reviews".

"Be or possess the ability to become knowledgeable in Lean principles and processes and support the implementation of these principles and processes on the project. Plan and lead pull planning sessions in support of the last Planner process. Become knowledgeable of the Standard Process and its' practice. Understand, lead and facilitate Last Planner processes in order to integrate Lean production principles and processes into the construction project. Be able to lead a Task Force effectively to maintain project milestones and resolve constraints. Understand the process of working in a VDC model and has some experience working hands on in a VDC model".

"Must be able to identify a breakdown and pull the Andon cord if required".

Analysis of this limited data set suggests that knowledge of the Last Planner System™, and one of its components, the Pull Planning technique, are the common abilities demanded by companies at the moment. The scheduling process seems to be the focus of attention, even though there were a couple of references to preconstruction services and the Lean Project Delivery System^{TM}, which is a trademarked term by the LCI. Another observation that can be drawn from these job descriptions is that companies are looking at ways to integrate Lean and BIM. One of the most generic descriptions about this included language such as "*ability to implement leading-edge technologies such as BIM and LEAN to benefit the project*."

Two companies listed that candidates should be able to train, motivate, and lead teams through Lean planning exercises. There is no comment on what these exercises are, but this is the type of skill that only professionals or college students who were exposed to Lean training offered by industry organizations (e.g. LCI, AGC) or undergraduate/graduate courses would be able to have. Given that 4-8 years of experience was necessary for these positions, this requirement certainly limits the access of entry level or less experienced college students to jobs requiring Lean-related background and skills.

Twenty-one positions expected candidates to have experience using Primavera and MS Project, even though there are several commercial software packages available to support Lean construction implementation. Regarding Lean tools and software, only one job mentions knowledge of "Our Plan".

The authors also searched the sample for the following terms: collaboration, collaborative scheduling, commitment, ethics, and trust. Our results were:

"Collaboration" – 8 jobs, 5 companies

"Collaborative Scheduling" - No jobs

"Commitment" – 15 jobs, 11 companies

"Ethics" – 4 jobs, 2 companies

"Trust" – 8 jobs, 7 companies

Even though collaboration, trust, and commitment are words often mentioned when relational contracts and Lean implementation are discussed (Lichtig 2005, Darrington et al. 2009), they did not appear frequently on the data set analyzed. The authors speculate that some of these terms might be considered as implicit aspects related to the job of forming teams and building projects. However, if some of these terms are indicated in the job descriptions, they can actually take a more prominent role in terms of what candidates should be expected to deliver when hired and also become a trait that will be evaluated in candidates' job performance analyses.

CONCLUSIONS

This study intended to identify skills and knowledge demanded by LCI corporate members. The original idea was to find out what the industry needs were in order to inform and guide academics in the process of developing or improving their Lean construction courses. Our findings indicate that there is a lack of "pull" from the market regarding Lean skills and knowledge, especially for entry-level professionals. This conclusion was somewhat unexpected, as the sample provided no content or feedback that can be used by academics in their course preparation. The sample suggests that knowledge of the Last Planner System^{TM} is a must have attribute. However, why do we need to develop an entire course on Lean Construction including simulations and multiple forms of teaching if all students need to know is to how to schedule a project following the Last Planner System™ directives? Perhaps future research should try and discover the reasons why LCI firms are not explicitly listing Lean skills in their job postings. Are they training their own experienced employees and/or new hires? Until there is a clear demand from the marketplace, also materialized in these job postings, construction schools might not have much incentive to introduce Lean Construction courses in their undergraduate curriculum. Also, students are usually motivated to learn skills that are valued by companies, and faculty are typically hearing the demands from advisory board member companies to improve course offerings. It is our opinion that if this situation remains the same, Lean might not advance as a discipline in CEM programs in the near future.

The authors tested two working hypotheses in this study:

H1: LCI member companies seek to hire candidates that have knowledge and skills related to Lean Construction principles and tools, and these companies have requirements related to that in their job postings. This hypothesis was not confirmed. Only 9.2 % of all job descriptions demanded Lean skills and two companies provided detailed descriptions including Lean skills and practices.

H2 – job openings in California have a higher chance of requesting candidates with specific Lean-related skills and/or background. This hypothesis was not confirmed either. Only three jobs in the entire sample required Lean skills in California.

This study proposed more questions than answers to the issues related to Lean teaching and how that relates to skills valued by the market. This topic deserves further investigation and attention from the LCI whose goal is to serve as the catalyst to transform the construction industry.

The study has limitations in that the sample was defined based on the assumption that jobs in California would have more Lean related requirements, given that the Lean Construction movement started more strongly in California before spreading out in the United States and abroad. Additionally, the sample was based on job postings of LCI corporate members during one month in 2016. Additional research can be done using data from other members from the LCI (e.g., owners, sponsors, law firms, associations).

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UNDERSTANDING INSPECTION CHALLENGES IN THE EPC INDUSTRY: A SIMULATION APPROACH

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ABSTRACT

How can the inspection task and its challenges be mimicked in a simulation? The purpose of the research was to use a simulation to highlight challenges and trade-offs faced by inspectors in the Engineering Procure Construct (EPC) industry. A literature review was conducted and results were shared and discussed with a group of subject matter experts (SMEs) who are part of Construction Industry Institute Research Team 308. A simulation was identified and modified to address important concepts related to the inspection process in the EPC industry. The simulation is more generic in nature to allow a broad-based audience to use it. Versions of the simulation were tested with students in a classroom setting and SMEs, their feedback was collected, and a final version of the simulation defined. Participants found the discussion about variables considered to be useful and the simulation to be a good representation of what happens in practice. Lean researchers often view inspection as a contributory or wasteful activity. However, inspection should be designed and managed like any other activity.

KEYWORDS

Inspection, Simulation, Nonconformances

INTRODUCTION

In the Lean literature, inspection is viewed as a wasteful activity that should be eliminated or reduced if processes delivering products and services are capable and reliable. However, the reality of the construction industry is that products are manufactured around the globe in environments that differ sharply from one company or country to another, and that might severely impact how products are delivered.

This paper addresses the challenges related to the inspection process through a simulation exercise that aims to abstract a product that needs to be inspected given certain

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constraints. The idea and the need to develop this simulation were born from discussions of the Construction Industry Institute (CII) Research Team 308 (RT308). The team had been investigating ways to assure products delivered to the Engineering Procure and Construct (EPC) industry are free of defects, and working to precisely define how inspection and fabrication capabilities of suppliers can be defined (Walsh et al. 2015). The team's goal was to provide EPC contractors with more information on how to define their own inspection efforts for products with different levels of criticality (and risk) in a project (Neuman et al. 2015, AlMaian et al. 2015). However, as the project progressed, it became clear that a number of factors to define such numbers were missing from the industry, and are not collected by EPC contractors on a regular basis. EPC contractors each have their own ways to define how capable suppliers are, how critical/risky materials are for their projects, and, based on that, gauge how many inspection hours should be assigned to purchase orders. But the industry has no standard way to assign inspection hours and procedures examined by RT308 show that they vary widely between companies.

Despite this scenario, the team decided to develop or adapt some sort of exercise that would capture the challenges of the inspection task, more specifically, and could serve as a basis for discussion on what additional factors need to be taken into account when the inspection effort is defined. Several Lean concepts and principles were considered including, but not limited to, those related to visual management and how they support cycle time reduction during inspections through the elimination of non value-adding activities, and the understanding of what clients (inspectors) value.

This paper describes the process RT308 went through until a simulation was found and adapted to mimic the inspection process in a way that was valuable to the CII membership and beyond. The authors aim to contribute to the discussion that inspection is needed in many cases in our industry and, like other activities, should be properly designed using Lean principles employed to design processes and systems.

RESEARCH METHOD AND TIMELINE

The research method is described in its five phases alongside relevant references used to develop the simulation activity. The literature review and other references are included throughout the narrative to reflect the process the team underwent to develop and test the inspection simulation. The discussion on how the simulation evolved mimics the goals of design science research, where developing, testing, and evaluating an artefact to emulate the inspection process is part of the research process.

PHASE 1 – UNDERSTANDING THE DEFINITION OF THE INSPECTION EFFORT

RT308 had been investigating the problem of non-conformances and the inspection role in improving quality in the products sourced to EPC projects for close to 3 years (Neuman et al. 2015). The previous investigation indicated that the definition of criticality levels of a purchase order (PO), in and by itself or in relation to the project, was a factor to define the inspection levels assigned to POs. Additionally, supplier-specific characteristics were also used to define the effort.

Early in 2015, the team took on a new challenge, which was related to defining fabrication capabilities of suppliers (P_{fab}) and the inspection capability to assure products would be delivered free of defects (P_{insp}) to EPC firms. The work started to be crafted after RT308 presented the results of its original work during CII's 2014 conference, and was approached by practitioners interested in knowing more about how to define these variables. After a review of procedures on how EPC organizations define the criticality levels of the products they acquire and the inspection effort necessary to assure quality products, it became clear that there was no standard procedure available in the industry to define P_{fab} and P_{insp}. The principal investigators (PIs) could identify commonalities regarding the main process and areas surveyed by EPC contractors to evaluate and select suppliers, but not to define the inspection effort assigned to different purchase orders (Alves et al. 2016). Additionally, SMEs indicated that the way data is currently collected at suppliers' facilities and sites might result in non-conformances being under-reported.

Given this scenario, the team discussed the possibility of developing an experiment that could be used to collect data about the inspection capability of inspectors given different scenarios. The team had a lengthy discussion on potential ways to design an educational exercise to illustrate how these factors play a role in the definition of P_{insp}. The goal of the experiment would be to measure data on P_{insp} and the simulation could be used later in CII training events and courses. The PIs were tasked with reviewing the literature on the work of inspectors, as well as on design of live simulations (which are conducted with people as subjects being observed during the simulation). The team identified potential considerations for the simulation:

- Goal: get data about P_{insp} by running this exercise in an environment that can give us powerful insights with minimal risks and high availability. (Versus being in an actual shop and being able to see all that we believe is important to define P_{insp}).
- Sampling: What kind of products/elements will be used in the inspection process? Potentially sampling elements based on different types of inspection required (visual, measurement, procedural, matching).
- Randomness: time and frequency of visits (that defines what will be inspected at the time of the visit – whatever is available at the time of the visit.)
- Other issues: Number of shifts, productivity of the supplier, experience of the inspector (e.g., someone who has been through the simulation before versus a newcomer), information provided to the inspector
- Human and organizational factors: who will participate in the simulation? What matters and needs to be inspected? What are the most critical attributes that need to be inspected? Example: you have 10,000 items that need to be inspected (potentially). You pick the ones you think are most critical but one that might not be critical turns out to impact construction installation.

PHASE 2 – UNDERSTANDING INSPECTION PERFORMANCE

The literature on the inspection activity was reviewed to identify potential ways to address the development of an experiment to collect data on inspection capability (P_{insp}). According to Drury (1992), in his comprehensive paper on inspection performance, the inspection activity is complex and prone to error, making it difficult to design the inspection effort to match a desired level of performance. This also makes the inspection process a prime candidate for study under Lean. Specific functions of inspection in manufacturing include (Drury 1992, p.2282): ensure that a faulty part does not reach the customer, help in defining the state of the manufacturing process, work as a point to capture data about the product and its related manufacturing process. These functions portray the inspection effort as an activity that is aimed to assure customers get the value they expect from products, and also to support continuous improvement through making the manufacturing process transparent by providing data collected during the process.

One way to improve the performance of the inspection activity is by improving the inspector's ability to inspect a product per unit of time, i.e., improving conspicuity (Drury 1992, p.2289). Conspicuity can be improved by making the inspection process to rely on a more visual system that aids inspectors in detecting nonconformances. Visual systems and visual management are topics that have gained increased attention from the Lean Construction literature (Viana et al. 2014, Tezel et al. 2015). Galsworth (2005, p.10) defines a visual workplace as "*a self-ordering, self-explaining, self-regulating, and self-improving environment – where what is supposed to happen does happen, on time, every time, day or night – because of visual solutions.*" A similar approach can be used in designing the inspection task to take advantage of visual aids, color-coding, instructions and procedures, list of potential defects, an uncluttered work area where inspection is performed, gauges, and *poka-yokes* (fool-proof devices), to name a few. Visual systems should help "*improve the discriminability between imperfection and a standard*" (Drury 1992, 2291) to help the inspectors in making the right decisions.

During the inspection activity, at least four major characteristics that influence the performance of the inspector have to be taken into account (Drury 1992):

- Accuracy – the inspector should make the correct decision on the majority of the components/characteristics inspected.
- Speed – inspection should be timely in capturing non-conformances and avoiding them to continue to exist or propagate throughout a process. Additionally, there is always a trade-off involving how fast an inspector works versus how many nonconformances can be caught.
- Flexibility – the inspection effort must be able to deal with multiple types of potential nonconformances and give them proper disposition.
- Stability – devices being used during the inspection activity should remain stable and not need constant recalibration. In a similar fashion, inspectors should face, to the extent possible, stable conditions to develop their task.

These characteristics turned out to be extremely relevant during the discussions about the design of an experiment or a simulation that could be replicated for educational purposes. Should the team decide to develop an experiment, a set of products and equipment would have to be maintained in pristine conditions so that the experiment could be replicated multiple times in a controlled environment under similar conditions. This would require a laboratory type of setting where volunteers would participate in the experiment and data would be collected about that. Alternatively, a simulation activity could be developed and widely replicated for educational purposes but it would be more difficult to come up with precise numbers about the inspection capability of a group of inspectors.

Task Analysis of Inspection and its Outcomes

The inspection task can be divided into four major steps: present the items for inspection, search the item to locate nonconformances, decide on the appropriate categorization for the non-conformance, and take action to accept or reject the item (Drury 1978). Furthermore, Wang and Drury (1989, p.181-190) have identified the following subtasks that are part of the inspection task, and related them to the major type of skill necessary to perform each subtask: orient the item (manual), search the item (perceptual), detect a flaw (perceptual), recognize/classify item (perceptual), decide status of item (perceptual), dispatch item (manual), and record of information about item (manual and perceptual). Based on their research, and given that most of the tasks related to the inspection task are perceptual and subject to human error, research on inspection has consistently found large differences among inspectors.

Finally, the inspection task is not complete without the final disposition of the item and its categorization into one of the four states indicated in Table 1. An item can be correctly accepted or rejected (true-positive and true-negative) or incorrectly accepted or rejected (false-positive or false-negative). At the end of this phase, the challenges related to the inspection task and important issues to be addressed in an experiment or simulation become more defined. The issues discussed in this section formed the basis of the simulation activity adopted by the team.

Table 1 – Inspection Decisions and outcomes (Adapted from Drury 1992, p.2286)

Inspection Decision	True State of Item	
	Conforming	Nonconforming
Accept	Correct accept (True-Positive)	Miss (False-Positive)
Reject	False alarm (False-Negative)	Hit (True-Negative)

PHASE 3 – EXAMPLES OF EXISTING INSPECTION EXPERIMENTS AND FACTORS/METRICS MODELED

During this phase, RT308 searched the literature for examples of experiments and simulations involving the inspection task, or examples that could be adapted to support the goals of the team to mimic the inspection task. The literature revealed not only what types of experiments and/or simulations could be developed but also which characteristics of the inspection task were often mimicked and had their results quantified.

The ability of inspectors to correctly categorize an item is impacted by many factors which include, but are not limited to: the training they receive (Drury 1992); physical, personnel and organizational factors (Drury 1992); their skills in terms of attention, perception, detection, recognition, memory, judgement (Drury 1978, Wand and Drury 1989); and the payoffs related to the task (Chi and Drury 1998).

Wang and Drury (1989) used different tests used to evaluate inspectors' performance (circuit pattern inspection, computer-generated symbols, and color video comparator) by comparing the following performance measures: search time (time to locate a fault), ending time (time to define that an item had no fault, and the item was good), search error rate (probability of failing to identify a fault), decision error rate (probability of locating a fault, but categorizing it incorrectly), and overall error rate (resulting probability of making the wrong decision). Their study indicates potential metrics that could be used in the design of an experiment or simulation.

Chi and Drury (1998) conducted a controlled experiment to observe the performance of ten subjects who examined computer-generated integrated circuit boards chips, under varying conditions. The variables that made up the scenarios included: defect rates, values of accepting/rejecting good/faulty items, cost of accepting/rejecting good/faulty items, time to make a decision, and the probabilities of accepting/rejecting a good item. Those authors asked the inspectors about the criteria they had used to make a decision about the items. What they discovered was that inspectors would change their inspection criteria based on different payoff conditions.

In another experiment, Drury and Sinclair (1983) investigated indicators related to hit rate (percentage of faulty items rejects) and false-alarm rate (percentage of good items rejected) of inspection of cylinders performed by experienced inspectors and a prototype of an inspection device. They found out that inspectors performed better than the machine because they could differentiate small flaws that would not render items unacceptable. One interesting insight from this paper was the importance of keeping items in pristine condition throughout the experiment. Additionally, factors affecting the inspection task to assure reliable results would need to be tightly controlled, e.g., using the same defect types and their severity, assuring randomness of the factors involved during the test (Drury 1992). Assuring that the defects and their frequency remains the same would be necessary to avoid having inspectors find new nonconformances along the way because of the way items were handled through the experiment. This challenge turned to be a big red flag for RT308 in that if the team adopted this option the approach would be limited to a controlled environment and/or items versus being widely available to CII members.

In a large experiment conducted at Microsoft by Carver et al. (2008), 70 subjects were requested to inspect a document (loan arranger), find, categorize, and record six different defect types (omission, ambiguous information, inconsistent information, incorrect fact, extraneous, miscellaneous) to evaluate the relationship between inspectors' background and the effectiveness of their decision. Carver et al. (2008) defined effectiveness as the dependent variable, and educational background, educational degree, industrial experience, requirements experience, and inspection experience as the independent variables. They found that level of education, prior industry experience, and other job-related experiences did not impact the effectiveness of the inspector. However, subjects who had experience in writing requirements performed statistically better (found more defects) than the other participants. This experiment highlights the importance of having an artefact that will not be changed throughout the experiment, is easy to replicate, and contains a specific list of known nonconformances beforehand.

Fen and Drury (2010) recruited ten male engineering graduate students, and paid them to participate in training and practice sessions using images in a computer display. Subjects were asked at the end of the experiment to report their search and decision-making strategies. They found that subjects would stop the search after some time searching, and varied their decision criteria depending on the pay structure.

The main lesson learned from the literature review was that the design of an experiment would work to be tested in a controlled environment but its educational impact in the EPC industry would be limited due to the challenges related to its replication in training sessions. Additionally, it would be hard to keep the artefacts reviewed always in the same conditions that they had in the beginning of the experiment. That said, the authors started the discussion about developing a new simulation or searching for examples that could be adapted to mimic inspection in the EPC industry.

PHASE 4 – ADAPTING AN EXISTING SIMULATION

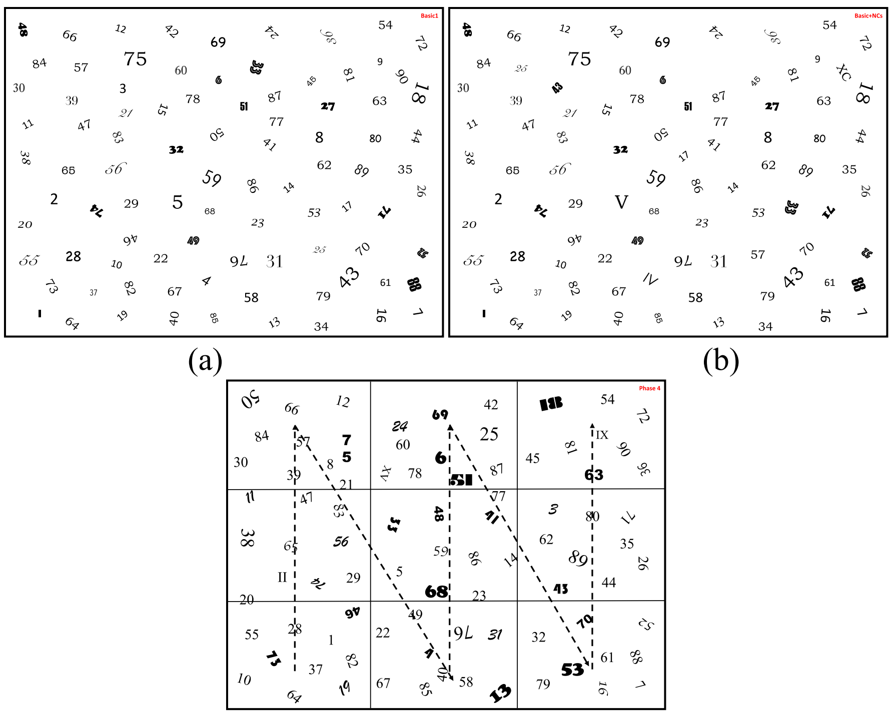
The outcomes of each phase were presented to the team during six months of literature search and discussion. At every step, the SMEs would provide comments that steered the PIs towards the most appropriate solution to this task. At this phase, the team was convinced that developing a simulation would be more beneficial, as it would serve as an educational tool about the inspection process, even if precise numbers to estimate P_{fab} and P_{insp} would not result from the simulation. Around the five-month mark, while searching for existing simulation activities, the PIs came across the 5S numbers game (Superteams 2015). The 5S game was a simple paper and pen version of an existing simulation that was considered a viable alternative to accomplish the goal of educating the industry about the challenges of the inspection effort. The next step in adapting this simulation to mimic the inspection task was to include technical terminology familiar to the EPC industry to make the simulation more appealing and educational to those involved.

The 5S game in its original format addresses the fact that organized and neat environment is conducive to higher productivity, and that a cluttered and disorganized environment slows people down and results in lower productivity levels. This illustrates Lean principles clearly. Participants are given 30 seconds and asked to search for numbers 1 through 50 in a letter-size paper showing the numbers in a disorganized format (different font types and sizes, numbers oriented in different directions, and numbers 1 through 90 printed on the paper). At the end of each 30-second period, participants are asked to indicate the highest number they found in sequence. During the different rounds of the simulation, participants discuss the challenges of each phase, and use one of the 5Ss to improve the organization of the numbers printed, which result in higher productivity at every round.

The team conducted the original version of the 5S game in a face-to-face meeting and discussed how it could potentially be adapted to reflect the challenges of the inspection process. One of the main points team members pointed out was that the 5S game process seemed very similar to an inspection task, however, it did not address the fact nonconformances might be found along the way. After multiple rounds of discussion and interactions some rules where defined for the first version of the inspection simulation.

Including Nonconformances and Defining the Rules

The first version of the inspection simulation used two basic sheets represented in Figure 1. Figure 1(a) shows the sheet used in Round 1 of the simulation where Arabic numerals (1-90) are dispersed throughout the page, and participants were given 30 seconds to find the numbers, and report at the end of the period the highest number found and the challenges they faced. Participants were instructed to strike through the numbers they found in sequence, that is number 4 could not be struck through unless numbers 1 through 3 had been found in order, and circle any number that was considered a non-conformance.



(a) (b)

(c)

Figure 1: Letter size sheets with: (a) Only Arabic numerals printed; (b) Arabic and Roman numerals printed, missing numbers; (c) Sequence of numbers shown

In Round 2, participants were given the same instructions, but this time some numbers were missing and Roman numerals were introduced in substitution for some of the numbers (e.g., the number 5 was written as V), both instances should be considered as nonconformances. The sheet shown in Figure 1(b) was used. However, during the original version of Round 2, participants were not instructed about the missing numbers and the Roman numerals, they were just told that there could be nonconformances on the sheet they were given for Round 2 introducing some complexity to the task. During Round 3, participants underwent a discussion about potential nonconformances and what they would look like; this tried to mimic a pre-inspection meeting between the inspection team, the customer, and the supplier. The sheet on Figure 1(b) was once again used. Finally, during Round 4, participants were told that the numbers were organized on a grid format as shown in Figure 1(c), and that the numbers were organized in sequence following the order shown by the arrows on Figure 1(c), e.g., number 1 should be on the lower left section, number 2 should be in the section right above it and so on. Numbers missing from the correct quadrant or misplaced were also to be considered as nonconformances. At the end of each of the four rounds participants were asked: 1. Which was the highest number you could "strike through?"; 2. Was there enough time to "inspect" numbers 1 through 50?; 3. Did you find any non-conformances? How many?; 4. What challenges have you found while trying to find the numbers?; 5. How do these challenges impact inspection?

PHASE 5 – TESTING THE SIMULATION

RT308 members tested initial versions of the inspection simulation in different settings over a period of three months. During the testing phase, team members conducted the simulation with students and practitioners and collected their feedback about the simulation to fine-tune how the sheets should look like, and what kind of instructions should be available to the facilitator. The feedback was analyzed by the team and incorporated as the team saw fit. The feedback about the simulation per se was mostly positive and it showed that the level of complexity involved in the process was adequate to achieve the team's goals. Some of the comments were related to: time pressures (keep looking for a number or assume it is missing and it is a non-conformance), vague instructions regarding what they should be looking for and learning about nonconformances on the go (if a number appears twice or in a different area of the grid, how should I categorize it?), searching/inspecting multiple attributes in a disorganized environment is very time consuming, understanding how the system (numbers) is organized results in an improvement in productivity. The current version of the inspection simulation also requests participants to collect data about variables related to the inspection decision and the state of the item, as shown in Table 1, to start building a database of numbers that might reveal relationships between speed and accuracy, and how that varies across different rounds. The facilitator of the simulation is now given instructions about the types and numbers of nonconformaces in each phase and share that with participants, who collected data throughout the simulation. Then, participants can compare what they got in terms true positives/negatives, and false positives/negatives, and benchmark their results against those kept by the facilitator and other participants.

CONCLUSIONS

The paper described the journey of a team to develop a simulation activity that could mimic characteristics of the inspection process outlined in the literature and suggested by a group of subject matter experts. The final version of the simulation captures important challenges (and complexity) related to the inspection activity such as: the trade-off between accuracy and speed, flexibility to deal with different scenarios and items to inspect, the existence of false positives and false negatives, and the importance of an organized environment and clear set of instructions to successfully complete the inspection task. Feedback collected from participants during the development and trial stages overwhelmingly suggest that this simulation is a good instrument to educate people about the challenges associated with the inspection task and many indicated that it made them better understand and gain an appreciation for inspectors tasks.

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SECTION 10: SUSTAINABILITY AND LEAN

Fuenzalida, C. Fischer, B., Arroyo, P., and Salvarierra, J. L., (2016). "Evaluating Environmental Impacts of Construction Operation Before and After the Implementation of Lean Tools." In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.10 pp. 3–12. Available at: <www.iglc.net>.

EVALUATING ENVIRONMENTAL IMPACTS OF CONSTRUCTION OPERATION BEFORE AND AFTER THE IMPLEMENTATION OF LEAN TOOLS

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ABSTRACT

Construction industry has a fundamental role in the impact caused to the environment, both during construction and operation. In this research three Lean tools - Ishikawa Diagram, 5 whys, and A3 reports- were carry out at construction site during wall and floor ceramic installation. The aim was to investigate whether the application of Lean tools improved productivity in the activity execution, and measure the environmental benefits obtained. The research methodology included analysing video recordings of the activity execution, working groups with workers and management, and training for using Lean tools. From this, it was show that the principal perceived waste was rework and its cause was lack of control. Furthermore, it was prove that these Lean tools' implementation reduces carbon dioxide emissions, for installing walls and floor ceramic, considering a reduction in the use of materials needed for the evaluated activity. In conclusion, Lean tools' implementation allows reducing environmental impact by concentrating reduction efforts on the most important activity wastes.

KEYWORDS

Lean construction, productivity, environmental impacts, wastes.

INTRODUCTION

Construction industry has high environmental impact because of construction itself and the building's later use and occupation throughout its lifetime. Lean Construction (LC), or construction without wastes, is an approach for construction management and

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production based on the production system used by Toyota. LC's goal is making processes more effective and designing production systems minimizing resources' loss to attack the stagnation problem and low productivity.

Lean in construction industry promotes continuous improvement throughout wastes reduction and value increase for the client. Considering wastes, everything that corresponds to time wasted, unnecessary work, wasted resources, and other activities that do not add value to final product.

Construction area has a great amount of activities that do not add value in its processes and that leads to low productivity. Thus, introducing new production techniques that aim for continuous improvement can be important in construction productivity and quality. Some Lean tools are the Ishikawa Diagram, the 5 why's analysis and the A3 report.

The Ishikawa diagram is a representation of a cause-effect analysis that carried out for any type of result. This diagram allows sort and classify all different causes for a certain effect. Ishikawa is for recognize the important causes generating an effect to influence over them and change the effect it is causing.

The 5 why's analysis is carried out to identify the root cause that generated the effect. It works by asking once why the effect happened, and to the response of that question, ask again, why it happened. Same proceeding is repeated until asking five times why it happened and by the end of the process, the answer is the root cause. Root cause must be modified in the case of wanting to alter the effect produced. For instance, in the case the effect is a problem that we do not want to keep repeating, to eliminate it we must act upon the root cause instead of generating short-term solutions.

The A3 report is a way of representing an action course, in which goals, methodology, agents involved and others are included. It is done in an A3 sheet to have a plan' summary set to carry out and to make periodical updates according to progress made and results.

This study presents an explanation to methodology and results of an investigation carried out in the context of the collaborative group GEPUC "Constructing Excellence". The principal goal is to apply Lean tools in construction site and measure the change in environmental impact that these tools allow because of a change in resources usage. Environmental impact will be measured in equivalent carbon dioxide' kilograms (kg of CO_2-eq). It is important to notice that emissions quantified correspond only to materials used. A more detailed analysis could incorporate the emission due to labour working hours. Specific goals are i) teach investigation participants' LC concepts, ii) identify frequent wastes and their cause, iii) qualify participants in three Lean tools application, iv) Create an audio-visual record of a critical work' execution and v) determine carbon dioxide emissions produced by using materials.

RESEARCH METHODOLOGY

The research consisted in the intervention of a particular site built by a construction company. In this site, we selected the installation of tiles to analyse. The people involved were seven; there was the project manager and other participants. Phases that makes up the investigation are present in Figure 1.

Figure 1: Phases of the investigation

VISIT 1 TO THE PROJECT

First, visit 1 to the site chosen by the company was carry out. In this session, participants were introduce to the concepts of value and waste, and a workshop took place to identify wastes existing in the site. The workshop consisted on four polls. The first one required participants to identify main wastes at the worksite. In the second one, the partakers should figure the causes of these wastes. The third poll was looking for the participants to match each type of waste to its main cause. The last poll consisted in identifying the five most common wastes and assigning them a relevance level according to individual perceptions. These four polls were carried out for a particular set of traditional construction wastes and another set of wastes strictly linked to environmental impacts.

After the workshop, there was a training in the three Lean tools implementation and a work in execution' recording took place (1 h) were it was possible to identify wastes and their causes.

After visit 1, the information was analysed through videos recorded and the polls' results. Besides, companies were asked to send information about the chosen work' yield and output so with this information, an analysis of most frequent losses and causes started.

ROUNDTABLE

Second, a roundtable was carry out were the project managers of each site participated (see Figure 2). In this meeting, visit 1' results were exposed and the A3 report elaboration was set in motion as to summarize the action course to apply Lean tools on the actual site.

Figure 2: Project Managers at the roundtable

VISIT 2 TO THE PROJECT

Third, there was a visit 2 at the site of each company. In this instance, a recording of chosen work took place for about 1 hour to identify improvements applied. Besides, a second poll was carry out to each person involved, this tried to clarify the participants' perception on the improvement obtained and raise awareness that the workshop brought the workers. At this, we asked managers to give new productivity measurements achieved after applying the action course with the investigation's Lean tools.

QUANTIFICATION OF IMPACT

In this phase, the recollected information through a second poll and recording was analysed. Then it was carried out the environmental impact' quantification provoked at the first recorded performance in comparison to the final achieved. We used this information to quantify the mass of CO_2-eq. emitted in each scenario.

CLOSURE REUNION

In the closure reunion was an exposition of obtained results to project managers and each company's important executives. In this instance, a conversation rose about the good praxis of each company to set an example for each other.

RESULTS AND DISCUSSION

First phase results about polls and waste detection workshop we will present. Then, second phase results about environmental impact quantification during work execution will be shown. Finally, there is going to be an interpretation of both sets of results.

PHASE 1 RESULTS

In the first poll carried out in the workshop that was registered through filming, it was decided that the most frequent wastes are work remade, error done throughout work and delay of activities.

Second poll' results are illustrating each cause of waste and the percentage of the team mentioned it as frequent (Figure 3). The results showed that no one named "excess of bureaucracy" as waste, while 86% of the team mentioned a lack of control and workforce as frequent wastes.

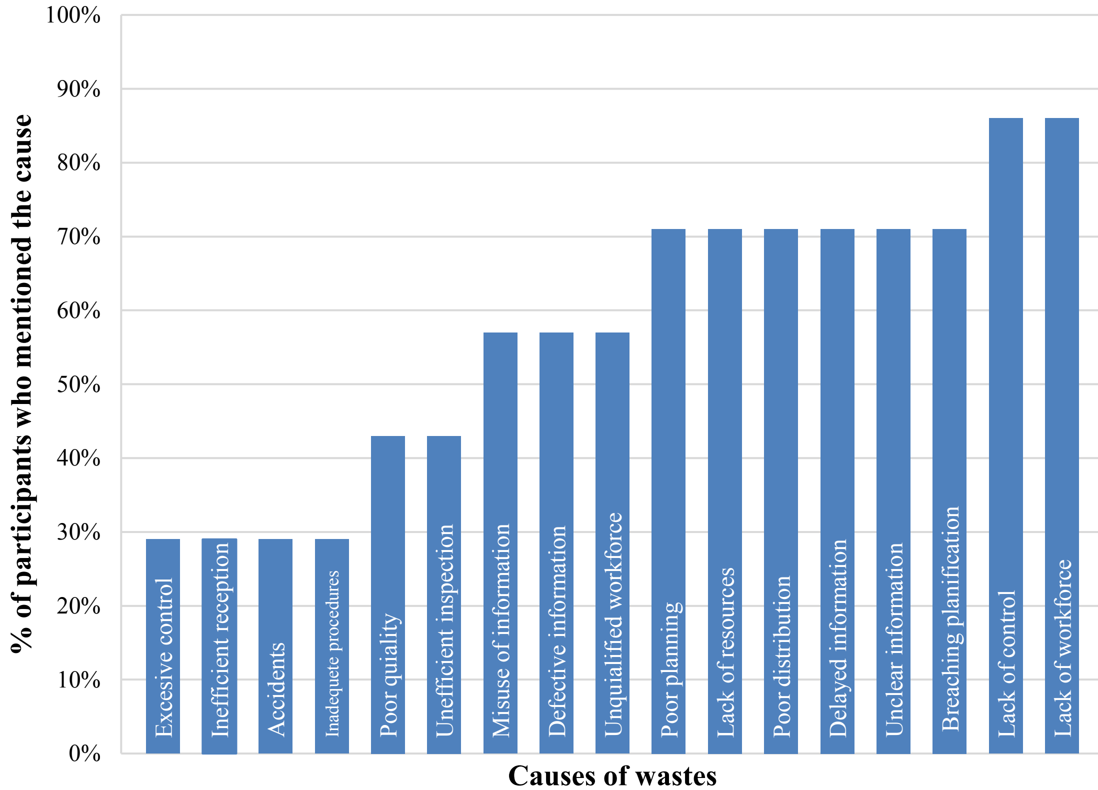

Figure 3: Frequent causes of waste identified by participants

In the third poll, the more frequent relations between wastes and its causes are work remade because due to lack of control, delay in activities by bad planning, work remade because unclear information, and work not done because a lack of workforce. About waste linked to environmental and social impact, the most frequent waste was loss of materials because lack of control.

Finally, final poll results' sets that the most important traditional type of waste for the participants' majority is work remade (see Figure 4). This waste was classified as important by the seven participants and got a score of 3,85 in average (where 0 is non-important and 5 is very important). The results on environmental and social wastes showed that the most important and frequently named by participants is material loss that is throwing away not used materials. This waste is identified as important by all of the participants with an average score of 3,14 out of 5 (see Figure 5).

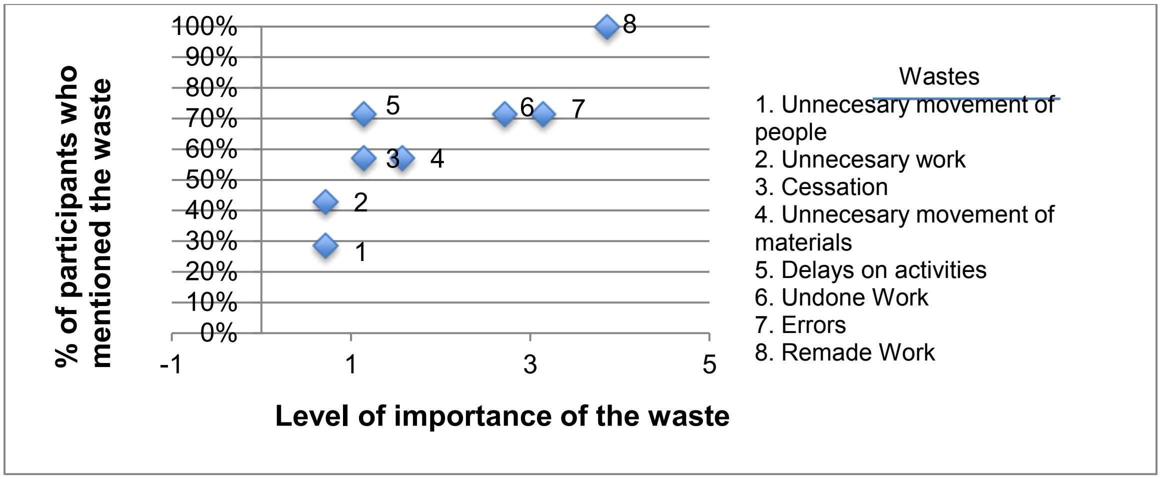

Figure 4: Level of wastes importance

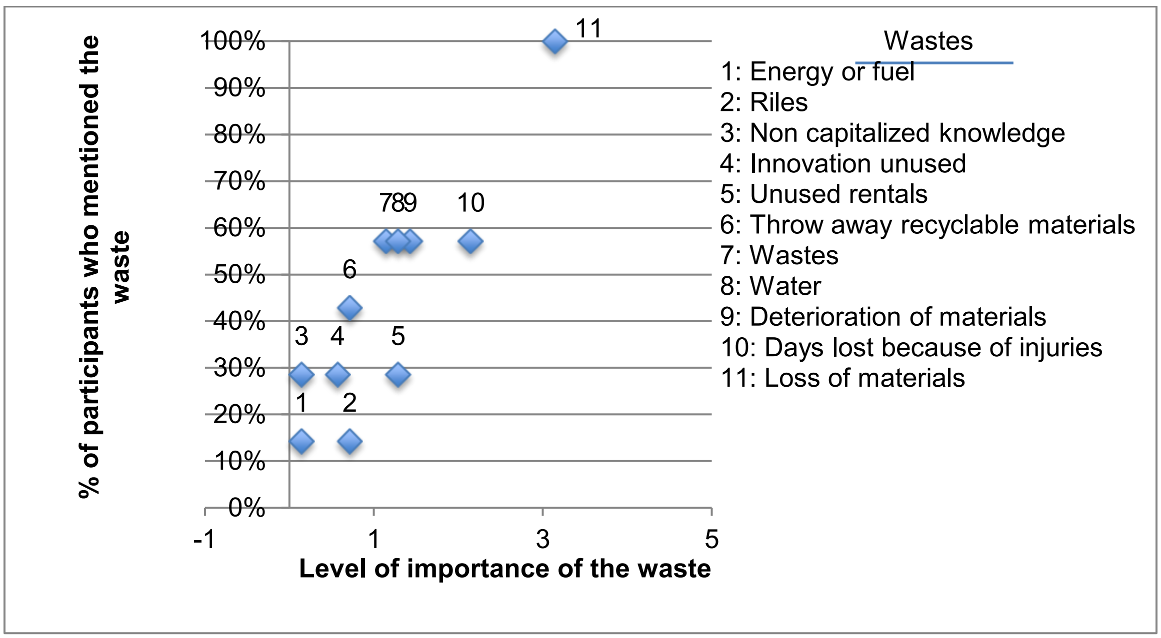

Figure 5: Level of environmental and social wastes importance

After analyse results in phase 1 we established that in construction sector exists many losses recognizable by those involved in the work. These losses have their causes that are because the job runs bad in suboptimal conditions. To avoid occurrence has to be a work execution' good planning to predict and control losses. Other lean tools and methods such as Last Planner System could help to reduce these wastes. However, that is out of the scope of this research.

PHASE 2 RESULTS

In phase 2 includes the environmental impact analysis generated by the installation of ceramics on walls and floors. We quantified this impact calculating the carbon dioxide emissions by the type and amount of material used in this work.

We present results and interpretation for first, ceramics used in walls; second, for the adhesive used in walls; and third, for ceramic and adhesive for the floor.

In table 1, we present the emissions of ceramics for walls. To understand the results, the calculation to obtain the first week' real emissions are shown in the study. The amount of ceramics used were 416 m^2, this is multiplied by emissions to produce 1 m^2 of ceramic walls that are 15.9 kg /m^2 [6]. This result in 6,614.4 kg of CO_2 -eq emitted for producing ceramics. To calculate the ideal emissions it is necessary to consider the geometric area covered with ceramic. Emissions without intervention were calculated taking into account that during the five weeks performance was the same that in the first one. Finally, for emissions with best performance we considered that work done during 5 weeks with the best-reached performance. For example, to calculate emissions without intervention we took week 1 performance, equal to 0.904. Thus, we divided the geometric area (376.15) by 0.904, obtaining 416.1 m^2 of ceramic. Then, multiplied this area by 15.9 kg/m^2 getting 6,615 kg of CO_2 -eq emitted.

Table 1: Summary of emissions per week for ceramics of walls

Emissions for ceramics of walls (kg CO_2-eq.)				
	Real emissions during the work	**Ideal Emissions (with optimal performance)**	**Emission without intervention (considering performance of week 1)**	**Emissions with best performance reached**
Week 1	6,614.40	5,980.79	6,615.91	6,004.80
Week 2	1,894.64	1,733.26	1,917.32	1,740.22
Week 3	3,192.08	3,178.09	3,515.59	3,190.86
Week 4	2,690.28	2,517.61	2,784.96	2,527.72
Week 5	520.88	477.80	528.53	479.71
Total	14,912.29	13,887.54	15,362.32	13,943.31

The gap between real and ideal emissions is 1,024 kg CO_2-eq that is a magnitude measure of the improvement generated if losses reduce to zero. The gap between real emissions and emissions without intervention is 450 kg CO_2-eq. we attribute this to Lean tools' implementation contemplated in this investigation. Although, it cannot be certain because may be other uncontrolled external factors, such as personnel change, that could influenced outcome. Anyway, after lean tools' were implemented an increase in performance was evident, being the best performance in the third week. If this performance were every week performance, they would have stopped issuing 969 kg of CO_2-eq. This results' interpretation is replicable for cases of adhesive and ceramic used.

In table 2, we present the emissions for the adhesive used for the installation of ceramics in walls. The optimal performance for adhesive recommended by the producer is 1.6 kg /m^2 per millimetre of thickness. The average thick used in walls is about 3 mm, thus the optimal performance is 4,8 kg /m^2.

Table 2: Summary of emissions per week for adhesive used in walls

Emissions for adhesive of walls (kg CO_2-eq.)

	Real emissions during the work	Ideal Emissions (with optimal performance)	Emissions with best performance reached	Emission without intervention (considering performance of week 1)
Week 1	447.10	283.24	343.66	447.10
Week 2	193.49	94.18	114.28	148.67
Week 3	229.51	172.70	209.54	272.61
Week 4	220.51	136.81	165.99	215.95
Week 5	31.50	25.96	31.50	40.98
Total	1,122.11	712.89	864.97	1,125.32

Table 3 shows the emissions by the ceramics used for the floor. In week 5 the work was finished, thus no materials used.

Table 3: Summary of emissions per week for ceramics of walls

Emissions for ceramics of walls (kg CO_2-eq.)

	Real emissions during the work	Ideal Emissions (with optimal performance)	Emission without intervention (considering performance of week 1)	Emissions with best performance reached
Week 1	5,810.17	5,293.73	5,810.90	5,390.76
Week 2	2,188.95	2,089.38	2,293.50	2,127.68
Week 3	1,433.58	1,407.24	1,544.72	1,433.03
Week 4	875.71	881.18	967.26	897.33
Week 5	0.00	0.00	0.00	0.00
Total	10,308.41	9,671.52	10,616.38	9,848.80

In table 4, we present the emissions for adhesive used in ceramics for floor. In this case, we considered 5 mm thickness of adhesive; thus, the optimal performance recommended by the producer is 8 kg/m^2.

Table 4: Summary of emissions per week for adhesive used in floors.

Emissions for adhesive of walls (kg CO_2-eq.)				
	Real emissions during the work	**Ideal Emissions (with optimal performance)**	**Emissions with best performance reached**	**Emission without intervention (considering performance of week 1)**
Week 1	1,271.70	574.62	1,192.98	1,271.70
Week 2	571.50	275.27	571.50	609.21
Week 3	405.01	185.40	384.91	410.31
Week 4	310.50	116.09	241.02	256.93
Week 5	0.00	0.00	0.00	0.00
Total	2,558.71	1,151.38	2,390.41	2,548.15

Analysing the results we can establish that emitted emissions may reduce to reach the ideal point. This would mean that processes are performing in the best way possible and that work is without losses or inefficiencies. However, all processes have necessary activities that do not add value for the client, thus present losses cannot reduce in 100%. Yet, the results show that emissions can reduce significantly with a good Lean tools' implementation. Importantly, these tools must be correctly implemented and with great monitoring, to promote a culture of continuous improvement throughout the project. Lean tools are not self-supported without a transverse effort of the organizations' culture and philosophy. This means those involved in the work, executive positions to operational, must be present in the intervention and improvement process, so they can improve and increase activities productivity through implemented mechanisms.

CONCLUSIONS

This research showed that exists a potential in Lean tools' implementation that can benefit productivity and reduce CO_2 emissions. Because of this, we recommend to enterprises to spend time and resources in these initiatives to create a culture where loss reduction and value creation is constant. People involved in this research are able to see this type of tools' usability, so it is possible create organizations where continuous improvement is part of their daily processes. This adds to the benefit that such actions can generate in the ecosystem through a resources reduction needed for each project.

To get improvements we recommend to companies conduct internal workshops based on concepts of loss and value, identifying the most common losses and their sources. Then, from the findings, implement corrective measures to eliminate all or part of frequent losses. It is necessary to communicate the corrective measures carried out to everyone involved at the work to create an awareness of continuous improvement. In addition, encouraging other projects to apply what they learned to generate knowledge. Continuous improvements are necessary to promote mechanisms for periodic quantification of loss reduction, and to encourage it with incentives to the most productive groups to align the objectives of all parties involved.

This study has identified that Lean and its associated tools remain superficially used by companies. Key concepts, value and losses, are not part of a common language that account more efficient and friendly environmental organizations. We proposed that future research must focus on the generation of common language on each organization, creating a culture inspired by change and continuous improvement. This research can also be expanded by studying other lean tools and methods and by including environmental impacts related with labour and equipments.

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RETHINKING WASTE DEFINITION TO ACCOUNT FOR ENVIRONMENTAL AND SOCIAL IMPACTS

Paz Arroyo[1] and Vicente Gonzalez[2]

ABSTRACT

Onho´s types of waste have been used in lean construction as guidelines. However, we argue that the lean construction community should question and rethink the definition of waste, and update the types of wastes in order to account not only for the production/economic impacts from design and construction, but also their environmental and social impacts. This paper provides insights about this issue and a literature review pertaining types of environmental and social waste derived from the construction industry.

We think that the transformation and value flow also needs to account not only for the products derived from the design and manufacturing process, but also needs to account for the inputs, such as energy and water as well as the by-products, such as air emissions, contamination of water, and soil. Finally, we think that more research is needed in this area, in order to extend the positive impacts of applying combined lean and sustainable principles in construction.

KEYWORDS

Waste, sustainability, lean.

INTRODUCTION

This paper deals with understanding waste as a broader concept that should consider sustainability. Onho´s types of waste have been used in lean construction as guidelines. However, we argue that the lean construction community should question and rethink the definition of waste, and update the types of waste in order to account not only for the production/economic impacts from design and construction, but also their environmental

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and social impacts. This paper provides insights about this issue and a literature review pertaining types of environmental and social waste derived from the construction industry.

CURRENT WASTE DEFINITIONS

Waste in construction has received much attention by industry and academia (Rahman et al., 2012; Viana et al., 2012). Project managers have been often inclined to conceptualize "waste" as physical construction waste (Wong et al., 2012). From a lean construction standpoint, waste represents resources or activities that are time and cost consuming, but creates no value (Koskela, 1992). Thus, it is about the elimination of all non-value-added steps in a process. The elimination of waste through the application of lean principles has well-known and positive impacts on cost savings and productivity in projects (Fliedner, 2008).

The lean concept incorporates the flow and value angles to production. A smooth process flow can increase value to the customer by minimizing waste. Inefficiencies in the flow of work (Koskela, 1992) may result in production waste (Ohno, 1998).

Ohno (1998) defines the following types of waste for production: Overproduction, Rework, Material Movement, Processing, Inventory, Waiting and Motion. In addition, Liker and Meyer (2006) add a new type of waste: Unused employee creativity: Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to employees. From a construction standpoint, production waste such as waiting times may happen due to the delay of a previous activity, inefficient space allocation, low productivity of a crew, deficient or insufficient equipment, delay in information flow, unavailability of material and external situations such as heavy downpour. Relatively, shortage of material may cause waiting, overproduction of other activities and defective output if less favored material were used to replace the current unavailable material. It has been claimed that each of the mismanaged flows may affect different types of production waste and it varies across different projects (Belayutham and Gonzalez, 2013). According to Viana et al. (2012)'s review on construction waste, all those wastes can be characterised into the traditional production waste.

However, the type of waste, including its impacts, that has not been considered in the common production waste definition is the environmental waste (Belayutham and Gonzalez, 2013). Environmental waste could be defined as the excessive use of resources that results in affluence released into the air, water or land that may endanger people and also the environment (US EPA 2007). From a lean standpoint, environmental waste does not add value instead increases cost through the excessive consumption of resources. This concept is similar to lean whereby lean waste also does not add value to the customer; in turn it elevates cost and time to the end user. In theory, production waste may cause environmental waste. However, the difficulty in relating both lean and environment is due to the fact that environmental waste is not the focus of improvement in traditional lean management (Belayutham and Gonzalez, 2013).

On the other hand, most management approaches in construction are technically-oriented methodologies focused on project and contract management, neglecting central social aspects related to peoples' behaviour both in individual and collective domains (Pavez and Alarcón, 2007). Lean thinking has been applied systematically to construction over 20 years (Alarcón et al. 2008), but implementation has largely focused on technical aspects rather than on the human and social aspects of projects (Pavez and Alarcón, 2007). Notwithstanding research of various social matters within the lean construction community, little research has been undertaken to understand the interactions between lean thinking and the social behaviour in a construction organization (González et al. 2015). Therefore, it can be argued that the classical definition of production waste from a lean standpoint also neglects the social dimension.

RESEARCH QUESTIONS AND METHODOLOGY

This research answers the following questions:

- What types of waste have been considered in previous studies dealing with sustainability and lean?
- What other types of wastes maybe incorporated to lean construction philosophy to account for social and environmental wastes?
- Are we reducing environmental and social wastes when removing Onhos´ wastes?

In order to answer the first question we have done a literature review using lean construction research in order to understand previous work trying to link sustainability and lean construction. To answer the second question we searched for literature outside of lean construction network in order to look for advice to incorporate other types of wastes related to sustainability in design and construction practice. Finally, to answer the third question we look at two previous case studies where researchers or practitioners have been focused on removing Onhos's wastes and we analysed whether or not other environmental and social wastes identified in this study have also been removed.

PREVIOUS WORK

Table 1 shows a literature review undertaken over recently published lean construction papers from the IGLC and journals matching with the terms "construction process", "waste generation" and "lean". This literature review does not aim to be exhaustive, but a sample of the trends in the investigation of waste from a lean construction perspective. Also, this provides insight on to what extent the lean thinking and the concept of waste is extensive to the environmental and social domains. It is observed that the majority of lean construction research deals with production waste in the first place, some on the linkages between production and environmental waste, and none on the impacts on the social dimension.

Table 1: Waste in lean construction research.

Authors	Title	Type of waste
Nikakhtar, A., A. Hosseini, K. Wong, and A. Zavichi (2015).	Application of lean construction principles to reduce construction process waste using computer simulation: a case study	Production waste
Mao, X., & Zhang, X. (2008).	Construction process reengineering by integrating lean principles and computer simulation techniques.	Production waste
Hosseini, A., Nikakhtar, A. and Ghoddousi, P. (2012).	Flow production of construction processes through implementing lean construction principles and simulation	Production waste
Nordin, N., Md Deros, B., A bdul Wahab, D. and Ab Ra hman, M.N. (2012).	A framework for organizational change management in lean manufacturing implementation	Production and environmental waste
Bertelsen, S., and L. Koskela.(2004).	Construction Beyond Lean: A New Understanding of Construction Management	Production waste
Alazmi. S., Belayutham. S., Rahman,A., and Vicente. G. (2013).	Integration of Production and Environmental Waste: A Theoretical Exploration	Production and environmental waste
Belayutham, S., González, V. A. and Yiu, T. W. (2015).	Clean-Lean Administrative Processes: A Case Study on Sediment Pollution During Construction.	Production and environmental waste
Sacks, R., Koskela, L., Dave, B., and Owen, R. (2010).	Interaction of Lean and Building Information Modelling in Construction	Production waste
Golzarpoor, H. and González, V. (2013).	A Green-Lean Simulation Model for Assessing Environmental and Production Performance in Construction	Production and environmental waste
Banawi, A. (2013).	IMPROVING CONSTRUCTION PROCESSES BY INTEGRATING LEAN, GREEN, AND SIX-SIGMA	Production and environmental waste
Hosseini, S.A.A, Nikakhtar, A, Wong, K.Y, & Zavichi, A. 2012.	Implementing Lean Construction Theory to Construction Processes' Waste Management	Production and environmental waste
Rosenbaum, S., Toledo, M., and González, V. (2014).	Improving environmental and production performance in construction projects using Value-Stream Mapping: Case Study	Production and environmental waste
Ghosh, S. , Bhattacharjee, S. , Pishdad-Bozorgi, P. & Ganapathy, R. (2014).	'A Case Study to Examine Environmental Benefits of Lean Construction	Production and environmental waste (CO_2 emissions)
Saurin, T.A. , Formoso, C.T. & Guimaraes, L.B.D.M. (2001),	Integrating Safety Into Production Planning and Control Process: An Exploratory Study	Production and Social waste
Saurin, T.A. , Formoso, C.T. , Guimaraes, L.B. & Soares, A.C. (2002),	"Safety and Production - An Integrated Planning and Control Model"	Production and Social waste

ENVIRONMENTAL AND SOCIAL WASTES

Literature from other fields have accounted for environmental and social impacts on construction industry, especially literature related to life cycle assessment (LCA) and social impact assessment (SIA).

LCA accounts for environmental aspects of construction (ISO 14040). "LCA is a method that attempts to systematically quantify the environmental effects of the various stages of a product's or a process' entire life cycle: materials extraction, manufacturing / production, use / operation, and ultimate disposal or end-of-life" (Pacca and Horvath 2001). Some of the impacts can also be stated as wastes, since they are the byproduct of fabricating building materials, transporting them or assembly them on site, and these impacts do not provide value for the customers. For example, building users, do not value the CO_2 emissions that resulted from manufacturing concrete. In summary, some wastes that are needed in order to account for environmental impacts of construction industry are:

Table 2: Environmental wastes from the literature.

Waste	Description
Air emissions	Accounts for all gases that are emitted to the air and can affect the environment or human health (EPA 2015). For example, global warming (CO_2, CH_4, N_2O, NO_2, CFC-11, CFC-12), stratospheric ozone depletion (CFC-11, CFC-12, CFC-113), photochemical ozone formation (VOC and NO_x), acidification (NO_x and SO_2).
Solid Waste	Accounts for materials are unwanted or unusable. For example, municipal waste (household waste, commercial waste, and demolition waste) and hazardous waste includes industrial waste (EPA 1998).
Waste water	Accounts for any water that has been adversely affected in quality by anthropogenic influence. Wastewater can originate from a combination of domestic, industrial, commercial or agricultural activities, surface runoff or stormwater, and from sewer inflow or infiltration (Tilley et al. 2014).
Noise disturbance	Accounts for any sound or vibration which: may disturb or annoy reasonable persons of normal sensitivities or; causes, or tends to cause, an adverse effect on the public health and welfare or; endangers or injures people or; endangers or injures personal or real property. This can also be defined as noise nuisance (Hogan and Latshaw 1973).
Over Illuminating	Accounts for the presence of lighting intensity higher than that which is appropriate for a specific activity (Simpson, 1990).
Excess of soil use	Accounts for the use of soil for the built environment, which prevents the use of that soul for animal's habitat (RCCAO 2012).

SIA accounts for the consideration of social aspects in corporate and public work. "SIA is the process of identifying the future consequences of a current or proposed action which are related to individuals, organizations and social macro-systems" (Becker 2001). Geibler et al. (2006) provides a comprehensive list showing the experience from the biotechnology industry. Some of the environmental waste may have social impacts too, such as air emissions and water scarcity but here we have listed the wastes directly related to social needs. We have identified wastes that can be easily found in the construction industry, such as:

Table 3: Social wastes from the literature.

Waste	Description
Lack of health	Accounts for wastes due to professional diseases, associated with performing a job. For example: risk for manipulating toxic substances (Geibler et al. 2006).
Lack of safety	Accounts for wastes produced by accidents and incidents that may happen in a job (Geibler et al. 2006).
Suboptimal working conditions	Accounts for wastes produced by not providing adequate tools, materials, spaces, ergonometric, and knowledge to perform a job (Geibler et al. 2006).
Lost of employment	Accounts waste of for not creating jobs, creating jobs that do not have continuity, or creating jobs in an area that may needed it less than other area (Geibler et al. 2006).
Lack of education and trainee	This refers to the waste that arises when people have a lack of training or education to perform their task, but also refers to the lack of professional growth (Geibler et al. 2006).
Knowledge not capitalized	Accounts for the lost of knowledge or know how of a company, maybe do to poor information systems, high personnel rotation, poor quality of personal knowledge exchange, poor review of personal knowledge exchange, low employee involvement in decision making (Geibler et al. 2006).
Unused innovation	Accounts for wasting employee creativity (Liker and Meyer, 2006). This may lead to losing improvement ideas and disappointment of employees.
Underestimating social acceptance	Accounts for wastes due to lack of client and stakeholder involvement, and lack of contribution to societal benefits (Geibler et al. 2006).
-Lack of societal dialogue	Accounts for wastes generated due to lack of dialogue with stakeholders involved in a project, such as lack of reporting activities, lack of communication with local community, lack of stakeholder involvement in decision making, and lack of engagement in political dialogue (Geibler et al. 2006).

Sustainability, in the beginning, considered people at the core of the concept according to the Brundtland Commission. Over time, however, it has been overlooked to pay more attention to the environmental and economic aspects of sustainability. In fact, social sustainability is often conceived as the mere indirect effect of the economic and environmental dimensions of sustainability. However, social sustainability is more than the improvement of some social variables such as improving the workplace climate or decreasing the environmental noise in a neighbour resulting from some industrial activity. It involves the overall social wellbeing (Brain, 2016)

These wastes presented in the literature are only a short list of what may be environmental and social wastes in construction. Some of them have been already introduced in previous studies in the IGLC, especially environmental wastes such as air emissions and solid wastes, and social wastes related to safety in construction. However, most of them are not traditionally included in the lean construction literature. In addition, lean research is often focused on the construction phase and do not considers all project´s lifecycle stages to quantify social and environmental wastes, while a significant amount of wastes are produced in the materials extraction, manufacturing, and operation stages of a construction project.

ANALYSIS OF TWO CASE STUDIES

In this section we provide a brief discussion of previous case studies that have attempted to measure the environmental or social benefits of applying lean construction principles and/or tools to eliminate waste. We have analysed two case studies, previously developed by the authors, where Onhos's wastes have been removed and we analysed wether or not other social and environmental wastes were removed. The studies analysed are presented as follows:

- Golzarpoor and Gonzalez (2013) developed a green-lean simulation model for assessing environmental and production waste in construction. In this research, the reduction of several lean production wastes were studied such as transportation and inventory (batch size) by simulating an earthmoving operation. While the reduction of waste in most cases decreased environmental waste such emissions, there were some cases in which the only variable affected was production by reducing costs and time, with no significant improvements on the generation of emission, and accordingly consumption of energy. It seems to be that there is a necessary trade-off between production and environmental performance in construction (Gonzalez and Echaveguren, 2012), which is not explicitly considered in lean-based management approaches used in this sector negatively affecting environment.
- Fuenzalida et al. (2016) applied lean tools to reduce Onhos's wastes in a construction project, specifically analysing the ceramic installation trade. In this study it is found that the reduction of Onhos's wastes also lead to a reduction of material waste that can be translated into less CO_2 emissions due to less material wasted. However, this study does not consider all environmental wastes as other ceramic material could be used to minimize CO_2 emissions during fabrication, or other air emissions. In addition, this study does not report on reduction of social wastes such as improving suboptimal working conditions.

In light of the previous examples, we argue that we are not necessarily reducing environmental or social wastes when reducing Onho´s types of waste. For example, when constructing a building we can do it very efficiently using continuous workflow and using innovative human action. However, we may not take care of the operation of the building and how air emissions will undertake in the next 50 or 100 years after construction is done. Also, when reduction of batch size strategies (e.g. JIT) is introduced some negative environmental externalities may emerge as a result of increased transportation, and accordingly, more energy and emissions could be generated. No mention to the social impacts is made, which is the corollary of systematically neglecting this aspect in the waste reduction research within the lean construction community.

CONCLUSIONS

In this research we have been able to summarized what types of waste have been considered in previous studies dealing with sustainability and lean (Table 1), and we have found mainly that several studies have measured environmental wastes such as: air emissions, and solid wastes. Other studies have considered social wastes mainly focusing on safety. Through the literature review we have provided a list of other wastes (Table 2 and 3) that maybe incorporated to lean construction philosophy to account a broader definition of wastes considering environmental, social, and economic needs. Finally, when analysing the two case studies we argue that environmental and social wastes may or may not be removed when removing Onhos´ wastes. Therefore, as a community we required more research and understanding of a broader list of waste to eliminate and to account for this wastes in all project´s lifecycle stages.

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LEAN AND SUSTAINABILITY: THREE PILLAR THINKING IN THE PRODUCTION PROCESS

Cathrine Andrea Johnsen[1] and Frode Drevland[2]

ABSTRACT

The concepts of Lean Construction and Sustainable Development share certain fundamental objectives, such as reducing waste and increasing value. The aim of this research is to investigate the extent to which the use of lean construction principles can assure increased sustainability in construction projects. This paper will explore the commonalities of these concepts and determine indicators that can be used to express the impact of lean on all three pillars of sustainability: economy, society and environment.

This work is executed as an explorative sample study of what are considered two of the leading companies in using lean construction approaches in the Norwegian construction industry. Semi-structured in-depth interviews of six key contributors were conducted. The work is limited to the production phase of a project, and focuses on sustainability in the process rather than of the product.

The main finding is that lean construction can have a positive impact on selected indicators for sustainability. This impact is primarily related to reduced stress, less sick leave, increased productivity, more efficient use of resources and improved quality. Lean construction observably has an evident impact on all three pillars of sustainability, and it should be focused on equating the social, economic and environmental aspects of future work.

KEYWORDS

Lean Construction, Lean and Green, Sustainability, Sustainable Development, Production Process

INTRODUCTION

Anthropogenic climate changes and global warming has become extremely important topics during the last decades. The concept of Sustainable Development has occurred as an initiative to improve social, economic and environmental conditions. The Brundtland commission was the first to define Sustainable Development in 1987, defining it as

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"*development that meets the needs and aspirations of the present without compromising the ability of future generations to meet their own needs*" (Kates et al. 2005).

The building sector uses 40 % of the global energy and contributes to approximately 30 % of the global annual green house gas emissions (United Nations Environment Programme 2009), and therefore has great responsibility and capacity to improve. Because of this, sustainability has become an important term in the construction industry, often referred to as sustainable construction or green building. In parallel the construction industry has experienced a relative decline in productivity compared to other industries (Langlo et al. 2013). The construction industry is in need of better resource efficiency, better productivity, less waste and increased value. Lean Construction can be the means to this end. This paper aims at investigating to what extent lean construction can contribute to better sustainability of construction projects.

This topic has been explored already by different authors such as Bae and Kim (2008), Huovila and Koskela (1998) and Lapinski et al. (2006). Previous literature describes the fundamental similarities between the two concepts. The most obvious connections are related to reducing waste and increasing value. Large parts of the literature explores primarily the environmental aspects of sustainability, such as Carneiro et al. (2012) and Valente et al. (2013). In this paper we have chosen to have a broad perspective looking at all three pillars of sustainability. The goal has been to identify actual connections between lean construction and sustainability. To facilitate this, we have formulated a set of indicators for each of the sustainability aspects. Hence, the research questions that this paper is based on are:

1. Which indicators can be used to show the connection between lean and sustainability?
2. To what extent does lean impact the given indicators?

THEORETICAL FRAMEWORK

Sustainability is a broad term used in many different settings, and has to be used at an appropriate level of abstraction. In social economics one distinguishes between macro and micro economy, where macro economy is giving an overview of the society's economy, while micro economy deals with the economy of individuals or companies (Andresen and Stoltz 2015). If we consider sustainability in the same way, stopping global warming and eliminating poverty can be considered macro level sustainability, while micro level sustainability in this work will be local sustainability in construction projects. Thus, in this work we have chosen to narrow it down to sustainability of the construction project. Improvements in micro level sustainability will contribute positively to the macro level sustainability.

Considering all the phases of a project would be outside the scope of this research, so we have limited the research to the production process of a construction project. Laedre et al. (2015) describes three different levels of sustainability in a project: strategic, tactical and operational. In this work we have concentrated on the operational level, which is the level most compatible with lean construction.

To ensure better sustainability in the construction industry there exists several tools and methods. One of them is BREEAM, which globally is one of the most used environmental certification systems. Green Building or Sustainable Construction does often have an extra cost of design and planning compared to traditional buildings (Lapinski et al. 2006). In addition, a lot of green projects are loaded with rework, delays, changes and overproduction due to bad selection of delivery methods. Waste in the process can limit both the building's and the project's sustainability (Klotz et al. 2007). By identifying waste, sustainable results can be improved through using delivery methods better suited to maximize value, such as Lean Construction. This implies the importance of sustainability in the production process, not just of the building itself.

As already mentioned, others have done research on this subject previously. Huovila and Koskela (1998) investigated this topic early in the lean construction history and explored the fundamental connections. They consider eliminating waste and adding value to the customer as the two most important contributions from lean to sustainability. Eliminating waste and adding value will contribute to sustainability by minimizing resource depletion and pollution.

Campos et al. (2012) investigated the relationship between lean construction and the sustainable maturity of construction companies. They found that principles such as focus on high quality, reduction of waste, flow of information between workers and project managers and continuous improvement are shared between the two concepts. Another interesting point of note was that the two concepts have mutual influence on each other: lean makes projects more sustainable and sustainability is making projects leaner.

Bae and Kim (2008) had a more practical approach, comparing lean methods to sustainability criteria based on a LEED checklist. They summarized the possible impacts from lean on each pillar of sustainability

- Economic impact: possible up front cost reduction, resource savings, operating cost reduction and high performance capability
- Social impact: workplace safety, occupant health, community well-being, loyalty among stakeholders and external image improvement
- Environmental impact: reduced resource depletion, pollution prevention by eliminating waste, and resource preservation

In Horman et al. (2006) they have used a set of social, economic and environmental indicators to compare site-built versus prefabricated buildings. Examples on indicators used are quality, material waste and working conditions. They also use indicators considering other aspects of the life cycle of a building, for example material choices, maintenance costs and deconstruction. The literature review found other authors presenting sustainability indicators for the construction industry, such as Cox et al. (2003), Toor and Ogunlana (2010), Ugwu and Haupt (2007).

METHODOLOGY

The purpose of this work was to find out to what extent Lean Construction can contribute to increased sustainability in construction projects. To do so it was necessary to investigate in what ways Lean Construction impacts the sustainability of construction projects. A literature review revealed that the concepts share several fundamental principles, but in our opinion a broader and more tangible evaluation would be preferable. To give a complete evaluation of Lean Construction's impact on sustainability, suitable indicators were developed for each of the three pillars of sustainability: social, economic and environmental. Indicators from the literature inspired the indicators chosen in this work, but in the end it was the authors who developed the set of indicators they found most appropriate for this research. There were found to be a lack of social indicators on the micro level of a project, and this area needed further research. The final indicators are presented in Table 1.

Subsequently the indicators were used as a foundation for qualitative data collecting. In-depth interviews were conducted with six key contributors from two of the leading companies using lean construction methods in the Norwegian construction industry. They are among the largest companies concerning turnover and employees, and they both carry out various types of construction and development. As the interviews were semi-structured they took the form of conversations or discussions, including some fixed questions. Following is a selection of questions from the interviews:

- How do you work with lean in your company?
- How do you work with lean in this project?
- What are the actions taken for sustainability in this project?
- How is lean influencing the following indicators for sustainability?
- Have you previously considered the connection between lean and sustainability?

To get valid answers from the interviews, skilled people had to be prioritized. It was a necessity that the informants had knowledge about both lean construction and sustainability. The key contributors interviewed were working as project manager, site manager, design manager, lean coordinator, BREEAM coordinator and H&S/quality/BREEAM coordinator. Most of the informants had corresponding answers, which indicates good reliability of the information.

The information collected from the interviews were processed and evaluated. The recordings of the interviews were listened to several times, and rough transcriptions were made. The authors evaluated the materials looking for similarities and differences. To be able to present the results graphically the qualitative data was quantified through creation of a frequency table with an ordinal scale. The scale ranged from -2, very negative impact, to +2, very positive impact. All the responses on all the indicators were rated. If an informant did not consider one of the indicators, or if the indicator were considered as not being affected by Lean it was rated 0. These numbers were the foundation for a radar chart inspired by a Sustainability Impact Assessment. As there where no negative impacts the chart has a scale from 0 to +2.

RESULTS

The selected indicators were inspired by the literature review. In the end, we composed a new set of indicators better adapted for this research. It was important to have various indicators for all three pillars of sustainability, to obtain a broad point of view. In addition, as this work is limited to the production process, the indicators had to be relevant to the production process and not the product or the whole life cycle as many of the indicators in the existing literature. The indicators chosen for this research are presented in Table 1 below, while more detailed descriptions of indicators and replies from the interviews are left out due to space issues. How the indicators originated are presented with the results, also due to space limitations.

Table 1: Indicators for sustainability

Social indicators	Economical indicators	Environmental indicators
Sick leave	Number of errors	Material waste
Number of accidents	Productivity	Use of resources
Equality	Profitability	Air pollution
Social dumping	Cost	Transport on site
Stress	Time	Energy use
Overtime	Quality	CO_2 emissions
	Changes	Construction noise

The informants gave different thoughts on how lean construction is influencing the sustainability of projects, through impacting the presented indicators for sustainability. A summary of the interviews is presented in Table 2, 3 and 4 below, one table for each pillar of sustainability. Thus, only the most prominent examples of lean principles or methods, which can impact sustainability, are presented.

Table 2: Social indicators

Indicator	Source/inspiration	Lean impact
Sick leave	Cox et al. (2003)	• Inspiration and motivation to get to work • Responsibility by involvement • Commitment to the group/project • Workers feel important
Number of accidents	Toor and Ogunlana (2010), Chen et al. (2010)	• Less mess • Good routines • Good planning and preparations • Less moving of materials • Daily huddle meetings
Equality	Dhondts and Houtman (1997)	• Having their own workers • Same rules for all actors in the project
Social dumping	Dhondts and Houtman (1997)	• Communication and culture • Continuous improvement between projects
Stress	Dhondts and Houtman (1997)	• Involvement of workers • Visualization and 3D models • Better plans
Overtime	Dhondts and Houtman (1997)	• Predictability • Better planning

On the subject of impact on social indicators involvement, found in Table 2, commitment, good planning and having their own workers stands out as the most influencing factors.

Because of involvement the workers will feel inspired, responsible and motivated about their work. Having their own workers will help the companies achieve a good culture and facilitate continuous improvement and learning. Better planning and visualization gives better predictability and better understanding among the workers.

The economic impacts from lean construction on sustainability, found in Table 3, are mainly related to better planning and involvement. Involvement leads to better planning, gives the workers ownership to the plans and motivates them to minimize use of resources and focus on quality and productivity. This can lead to less errors and changes, which directly leads to lower costs, shorter lead time and higher profitability.

Table 3: Economic indicators

Indicator	Source/inspiration	Lean impact
Number of errors	Toor and Ogunlana (2010), Chen et al. (2010)	• Visualization • Involvement of workers in the planning • Good dialogue • Commitment to other team members
Productivity	Cox et al. (2003)	• Involvement • Ownership to the work • Monday meetings and visual planning • Monitoring of progress • Common and clear goals
Profitability	Cox et al. (2003)	• Right information at the right time • Better planning • Ownership • Having theirs own workers
Cost	Toor and Ogunlana (2010), Chen et al. (2010)	• Less errors gives a cheaper project • Less sick leave is cheaper • Own workers are cheaper in the long run
Time	Horman et al. (2006), Chen et al. (2010)	• Learning and continuous improvement • Visual plans showing progress • Takt-time makes project duration predictable
Quality	Horman et al. (2006)	• Continuous improvements • Ownership • Involvement
Changes	Horman et al. (2006)	• Involvement • Collocation • Lean design phase

The impacts on environmental indicators are shown in Table 4. They are on one hand related to the choice of materials and production methods and on the other hand related to good routines, less mess and ownership. Ownership makes the workers recycle the waste and minimize the use of resources. Choosing prefabricated elements is also affecting construction waste and use of resources. Better resource efficiency is leading to less CO_2-emissions and energy use. Improved planning is influencing the local air pollution, construction noise and transport on site.

Table 4: Environmental indicators

Indicator	Source/inspiration	Lean impact
Material waste	Horman et al. (2006), Chen et al. (2010)	• Prefabrication • Recycling of waste • Ownership and responsibility
Use of resources	Ugwu and Haupt (2007), Chen et al. (2010)	• Prefabrication • Ownership • Better planning and avoiding mistakes
Air pollution	Chen et al. (2010)	• Less mess gives less pollution • Better planning and better methods
Transport on site	Horman et al. (2006)	• Well planned logistics, JIT • Involvement of workers • Continuous improvement and optimization during the project
Energy use	Chen et al. (2010)	• Involvement • Ownership and good routines
CO_2 emissions	Chen et al. (2010)	• Choice of materials • Better resource efficiency • Better planning
Construction noise	Bae and Kim (2008)	• People report unnecessary noise

To better illustrate the impacts from lean construction on sustainability, the impact on the indicators are gathered in Figure 1. This figure is inspired by a SIA, showing impacts within all three pillars of sustainability.

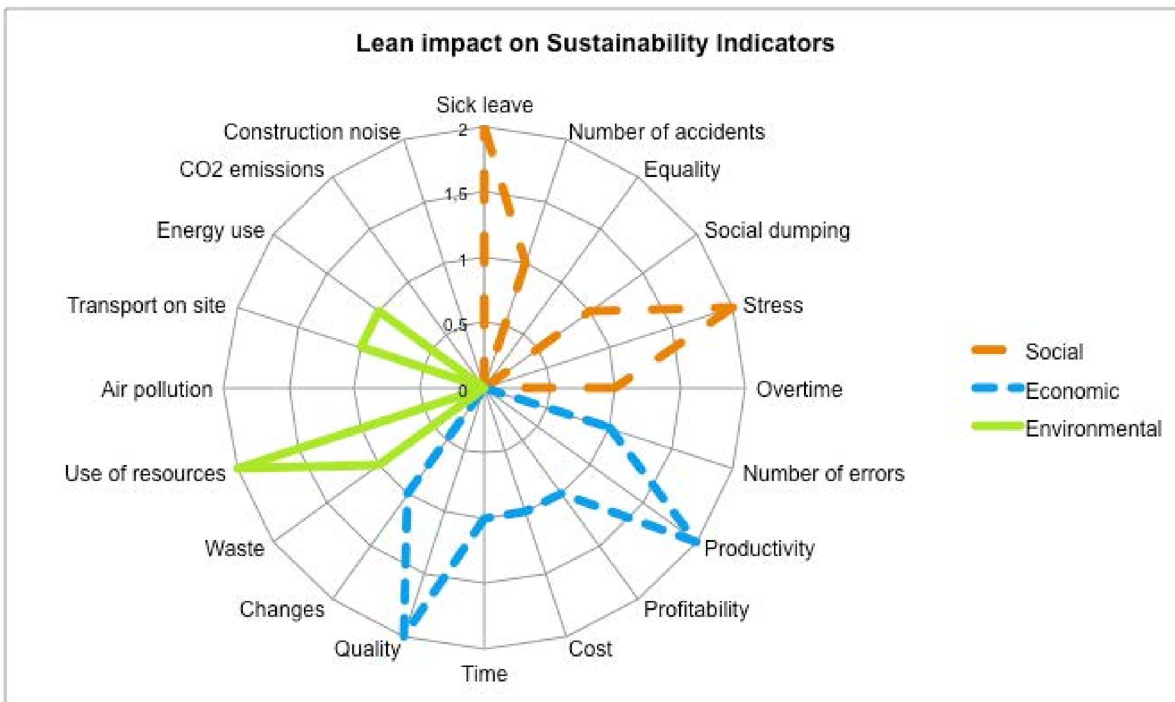

Figure 1: Illustration of lean impacts

As the diagram in Figure 1 shows, the biggest impacts from lean construction on sustainability are found on sick leave, stress, productivity, quality and use of resources. This research shows that lean construction has the least impact on equality, air pollution, CO_2-emissions and construction noise.

DISCUSSION

The selected indicators had a broad approach including indicators for all three pillars of sustainability. This was essential to successfully resolve the questions posed in this research. Some of the indicators need additional specification if they are to be used for quantitative research, even though they were found to be appropriate for this qualitative approach. This study was explorative and the purpose of the indicators were namely to indicate lean construction's impact on sustainability. The indicators were well suited for the research, with a focus on the production process, i.e. the construction process. This does not mean they cannot be used in other settings, as the indicators are considered as quite general. Most of the indicators found in the literature review were concerning the whole life cycle of a building, or the building itself. The indicators from the literature review have been used for a general evaluation of sustainability, while the indicators from Horman et al. (2006) had been used specifically to compare lean and sustainability. Still these indicators had a too wide perspective and too much focus on the product.

When it comes to the results of the interviews it is possible to conclude that lean construction has a positive impact on the three pillars of sustainability. This work did not identify any negative impacts from lean construction on sustainability. The findings are mostly supporting the literature. One exception is that Bae and Kim (2008) indicated that Just-in-Time might lead to increased emissions due to increased traffic, which was denied by several of the informants. They claimed Just-in-Time was beneficial for the sustainability in spite of more frequent traffic, as the logistics would be better organized. Another distinction from Bae and Kim (2008) was that they compared lean methods and tools with sustainability, while the interviews in this research revealed that many of the impacts are caused by values and principles, such as ownership and responsibility.

A challenge with the work was the ambiguity, the fact that none of the impacts on sustainability are solely caused by lean construction. Examples of other factors that could influence the indicators for sustainability are the companies' business strategy and daily practice. In companies using lean construction the values of lean will be implemented in their practice, but some of the values might have been implemented without lean as well. In one way these values will be lean no matter if the company defines them as lean or not.

Several of the informants mentioned that lean and BREEAM are well compatible. A question to consider is whether BREEAM might have a negative impact on lean construction. This could be caused by increased waste due to extra documentation, which will increase the duration of the process, and reduce the productivity. Campos et al. (2012) found that BREEAM made projects leaner, which is contradictory with the previous statement. BREEAM can contribute to making projects leaner by focusing on minimizing use of resources and reducing material waste. Some of the informants said that many of the BREEAM criteria were already obtained thanks to lean practices. Most of the environmental indicators in this research are coinciding with BREEAM criteria. This suggests that BREEAM is primarily evaluating environmental performance, not complete sustainability.

CONCLUSION

The intent of this research was to investigate to what extent lean can assure more sustainable construction projects, by defining indicators of sustainability and finding how lean affects them. The indicators chosen in this research were suited to show the connection between lean and sustainability in construction projects.

The interviews confirmed what the literature says, that lean construction and sustainability are connected. The most frequently mentioned impacts were related to reduced stress, less sick leave, increased productivity, more efficient use of resources and improved quality. Increased ownership, responsibility, involvement, visualization and improved planning were causing these impacts. Lean Construction observably has an evident impact on all three pillars of sustainability, and it should be focused on equating the social, economic and environmental aspects on future work on sustainability in the construction industry.

Although there was a high degree of agreement between the informants, more interviews would have been beneficial for the reliability of the findings. There were some challenges with the execution of the interviews, as the topic was quite unknown. It required the interviewer to present some background information, which might have influenced the informants. The interviews were semi-structured, however a more structured approach could have insured the informants would consider all the indicators. As an example, the social sustainability indicator equality was not discussed as much as the other indicators. Yet the findings from this work are considered both valid and reliable, and give a good indication as to what extent lean construction has an impact on sustainability.

As this work is entirely qualitative, conducting a more quantitative approach is recommended. For future work one can consider executing more interviews, doing a survey and perhaps modify the indicators. Another option could be to search for quantitative data on the given indicators through a case study, to see if they can confirm what is found in this work.

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A CRITICAL REVIEW OF THE FACTORS AFFECTING THE SUCCESS OF USING LEAN TO ACHIEVE GREEN BENEFITS

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ABSTRACT

Due to the rising recognition of sustainable development, various industrial sectors, including the building and construction sector, are facing increasing pressures to improve their environmental performance. The lean concept has proven to be effective in reducing waste streams and increase productivity. Many studies have therefore been conducted to link waste reduction and environmental performance improvement. A comprehensive literature review is conducted to investigate the development of integrating lean to achieve green benefits. The comprehensive literature review covers all journal articles in Scopus that have "green" and "lean" in their titles. It appears that majority of the studies within the area of lean and green focus on the conceptual framework. Very limited studies focus on the implementation of lean and green to address specific problems and provide measurable benefits. It should be noted that whether or not measurable benefits can be achieved affects the degree of implementation of lean and green at the industry level. As such, it is proposed that future studies on lean and green should be conducted and measurable benefits should be clearly articulated.

KEYWORDS

Lean, green, conceptual development, measurable benefits.

INTRODUCTION

The concept of sustainable development was firstly defined in the Brundtland Report as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (WCED, 1987, p.43). The report highlited the importance of meeting human's economic and social needs with the consideration of the natural environment. Since its inception, sustainable development has gradually been recognized as another fundamental pillar for construction projects, along with time, cost and quality. While construction and building activities are essential to satisfy the demands from increasing populations and developing economics, these activities harness

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nature, consume energy and resources and pose significant stress on the environment (Wu et al., 2016). Worrell et al. (2001) found that the cement sector accounts for almost 5% of global man-made carbon emissions. Transportation of raw materials is also energy intensive for countries which rely heavily on import of materials. As such, the construction industry is reported to have a significant impact on the environment. For example, Bribián et al. (2011) found that building represents 24% of global extraction. Yohanis and Norton (2002) found that the initial embodied energy from building materials in a single-storey office can account up to 67% of its operating energy over a 25 year cycle. Rodríguez et al. (2015) found that the European Union produces approximately 530 million tonnes of construction and demolition waste per year, which is 25% to 30% of the total solid waste generated.

Originating from the Toyota Production System, the core of the lean production philosophy is the observation that there are two aspects in all production systems: conversions and flows (Koskela, 1992). Conversion activities refer to those which actually add value to the product or process. Flow activities refer to non-value adding activities, which consume time, costs and resources but do not add value to the product or process. The concept was found to be effective in improving environmental performance. For example, the lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila and Koskela, 1998). EPA (2003) found that lean produced an operational and cultural environment that was highly conducive to waste minimization and pollution prevention, and that lean provided an excellent platform for environmental management tools such as life cycle assessment and design for environment. However, there are a few studies which found that the use of lean does not necessarily bring about green benefits. For example, Helper et al. (1997) found that there was no appreciable relationship between lean and green in the manufacturing industry.

In order to facilitate future research on the relationship between lean and environment, this paper presents the preliminary findings from a comprehensive literature review on previous studies around lean and green. However, different from previous studies on examining the relationship between lean and green, this paper has a special focus on the articles discussing why lean cannot always bring green benefits. In addition, this paper aims to find out whether measurable benefits can be achieved by integrating lean and green, as such benefits are the core KPI which most practitioners will examine. Considering this, the main research questions of the paper are:

1. Can lean be used to achieve green benefits?
2. Are there measurable benefits when integrating lean and green?
3. What are the factors that may affect the success of using lean to achieve green benefits?

RESEARCH METHOD

In order to address the research question effectively, a comprehensive literature review should be conducted. The comprehensive literature review covers all articles focusing on green and lean in the Scopus database. "Lean" and "Green" were used as the two keywords. Only journal articles (including magazines) were selected from the database. A total of 97 documents were identified.

A few key factors of these articles were recorded after the review. These factors include publication year, industry sectors, research method, lean technologies applied and green benefits recorded. This paper only presents some preliminary findings from the analysis focusing on the three research questions proposed earlier.

LEAN AND GREEN

CAN LEAN BE USED TO ACHIEVE GREEN?

Majority of the studies have reported that lean can be used to achieve green benefits. The integration of lean and green seems to be around their focus on waste reduction (Garza-Reyes, 2015). It seems that waste reduction is the key term when it comes to the integration of lean and green. For example, Mollenkopf et al. (2010) argued that the green-lean system searchers for opportunities to reduce the production of undesired products. By reducing the environmental impacts along with the undesired products, the environmental impact from their conception, supply chain to operations will be reduced. The discussion of the reasons leading to the integration of lean and green can be divided into several categories, including conceptual investigation (which discusses the theoretical development of lean and green), theoretical integration (which discusses the feasibility and benefits by integrating lean and green, and possibly other techniques), practical investigation (which investigates the potential of using lean and green to address specific industry problems) and empirical implementation (which investigates the implementation and quantifies the results of the implementation).

In the category of conceptual investigation, Duarte and Curz-Machado (2015) used the balanced score card to investigate the lean and green supply chain linkages and found that employee training and education (one essential lean element) can help achieve waste reduction, including scrap, waste water, solid waste, hazardous waste and energy waste, thus supporting the theoretical linkage of lean and green. Dües et al. (2013) investigated the theoretical background of lean and green and identified possible areas where the use of lean can achieve green benefits. For example, both lean and green have common attributes, including waste reduction, waste reduction technique, people and organisation, lead time reduction, supply chain relationship, service level and tools/practices. As such when the implementation of lean is centred on these common attributes, a favourable result can be expected. However, extreme care should be executed. There is a large difference when defining waste in lean and green. The waste concept in lean includes the production of goods not yet ordered, waiting time, rectification of mistakes, and excess processing, movement, transport and stock (Disney et al., 1997). These waste types are not necessarily environment-related waste.

In the category of theoretical integration and practical investigation, the integration of lean and green is discussed within specific industry sectors due to varied industry characteristics. For example, Dües et al. (2013), Wiengarten et al. (2013) and Duarte and Cruz-Machado (2015) discussed the integration of lean and green in supply chain management. It is found that environmental investment does not significantly improve operational supply chain performance. However, based on the complementarity theory, it is found that the impact of lean practices on operational supply chain management can be significantly improved with investment in environmental practices, indicating that there is a synergy between lean and green in operational supply chain management. Similarly, Galeazzo et al. (2014) and Sobral et al. (2013) found that the integration of lean and green can help achieve better environmental performance in manufacturing. However, the significance of the achievement is dependent on a few factors, such as the time of the implementation. There are a few isolated studies which discusses the use of lean and green in other sectors, such as automobile (see Kurdve et al., 2014) and product development (see Johansson and Sundin, 2014). However, majority of the studies are focused on supply chain improvement (e.g. see Cabral et al., 2012; Kainuma and Tawara, 2006; and Duarte and Cruz-Machado, 2014). These studies supported the argument that lean and green can be usefully integrated to achieve environmental benefits.

ARE THERE MEASURABLE BENEFITS?

There are a few studies which demonstrated that lean can be used to achieve green using measurable and quantified benefits. Only articles that quantified the environmental performance improvement using experiments, simulation or other similar research methods are discussed in this section. Studies using survey and questionnaires to quantify the benefits of lean and green are excluded.

King and Lenox (2001) quantified the contribution of lean to emissions reduction from 17,499 manufacturing facilities from 1991-1996 and found that lean production is complementary to environmental performance. Besseris (2011) applied the lean concept in maritime operations and collected a series of data on vessel speed, exhaust gas temperature and fuel consumption. The results show that desirable results on all three key factors have been achieved.

From 2014, the number of publications discussing measurable benefits of lean and green has been increasing. Pampanelli et al. (2014) proposed a lean concept model for managing environmental impacts of manufacturing cells and found that in terms of reducing environmental impact and increasing productivity, the lean and green model reduces the use of resources, on average, by 30%-50% for the cells examined. Marimin et al. (2014) used value chain analysis to map and analyse green productivity of a natural rubber supply chain and propose strategies to increase green productivity level. It is found that seven sources of green waste, including energy (1.830KWh), water consumption (900 m^3), supporting material (131.84kg), garbage (147.33kg), transportation (2769.17km), emissions (3094.30kg) and biodiversity (2715.45 ha) can potentially be reduced. Domingo and Aguado (2015) used the Overall Environmental Equipment Effectiveness (OEEE) to evaluate the measurable benefits by applying lean and green in the manufacturing system and found that significant environmental improvement was found in activities such as receiving and cutting. However, no environmental improvement was found in activities such as bending, control, labelling and shipping. Ng et al. (2015) used the Carbon-Value Efficiency indicator to demonstrate the applicability of lean and green. The results showed that Carbon-Value Efficiency could be improved by 36.3%, given that an improvement in production lead time of 64.7%

was also recorded. When measured by carbon footprint, the overall improvement was found to be 29.9%.

Many studies discussed the feasibility and necessity of integrating lean and green but failed to provide measurable benefits. The integration of lean and green has been focused heavily from the theoretical side. For example, Calvalho et al. (2011) argued that both lean and green practices have their own attributes. Some lean attributes (e.g. production lead time reduction and transportation lead time reduction) are positively related to relevant green attributes (energy consumption and carbon emissions). However, not all lean attributes are positively related to green attributes. This appears to be the reason leading to more and more articles discussing the measurable benefits of lean and green. Only upon successful implementation can relevant factors affecting the success of lean and green be identified.

UNSUCCESSFUL STORIES

There are also a few studies which found that the use of lean does not necessarily bring green benefits. These studies are briefly explained in the following section.

Rothenberg et al. (2001) found that there is a complex relationship between lean and environmental performance. This complex relationship is dependent on the environmental performance being examined. For example, when volatile organic compound (VOC) emissions are examined, manufacturing facilities need to rely more on advanced pollution abatement equipment to reduce the emissions. Lean provides little or no benefits in terms of VOC emissions reduction. Similarly, lean provides little or no benefits in reducing energy and water use quantitatively, although qualitative analysis (i.e. interview results) provides a convincing evidence of complementarities.

Mason et al. (2008) examined the supply chain of orange juice and found that modification of the orange juice or its packaging to allow ambient storage can provide greater environmental benefit than reconfiguration of any upstream supply chain step. This indirectly shows that the lean concept can help achieve environmental benefits, but at very minimal level.

De Sousa Jabbour et al. (2013) collected the manufacturing data from 75 companies and found that lean manufacturing is positively associated with environmental management. However, the explanation power of lean in green is weak/moderate.

Chiarini (2014) investigated the use of five lean tools, including value stream mapping, 5S, cellular manufacturing, single minute exchange of die and total productive maintenance in manufacturing firms and found that the success of lean and green is dependent on the technology and the intended environmental improvement areas. For example, it is found that value stream mapping does not necessarily bring about environmental benefits. However, it can be used to identify environmental impact of production processes. Cellular manufacturing can directly lead to a decrease in electricity consumption and TPM can reduce oil leakage. One interesting finding is that the use of single minute exchange of die (SMED) brings no significant environmental improvement to the manufacturing process.

At the theoretical level, Johansson and Sundin (2014) argued that lean and green have significant differences in their goals and focuses, including value construct, process structure, performance metrics and tools/techniques used. These significant differences do not support that green is lean, indicating that the use of lean does not automatically lead to greener products or the use of green does not automatically lead to efficiency improvement in product development process. It can only be concluded that both lean and green share similarities that a synergistic relationship can be expected.

FACTORS THAT MAY AFFECT THE SUCCESS OF LEAN AND GREEN

From the preliminary results of the review, it is useful to identify a few factors which may affect the success of lean and green. These factors include:

- Industry. Lean and green has been implemented in different industries. For example, Verrier et al. (2015) applied the lean and green concept to the housing industry and proposed an implementation structure to help identify and eliminate waste in the production process. According to Verrier et al. (2015), there was a strong link between lean and green in the housing industry. On the other hand, the implementation of lean and green in other industries may not have such strong link. For example, Garza-Reyes (2015) found that due to the limitations and challenges of lean and green at the individual level, the integration of lean and green would not usually achieve its full potential in the manufacturing industry. Further analysis is needed to quantify the correlation between the success of lean and green and the industry that the implementation is applied to.
- Lean technology. It should be noted that different studies focused on different lean technologies which may lead to different results. For example, Greinacher et al. (2015) discussed the use of buffering and its impact on delivering green results. It is suggested that a concept called “cost-time-profiles” (CTPs) should be used to analyse the impact of buffering on carbon emissions of the manufacturing process. On the other hand, Govindan et al. (2015) investigated a few lean technologies in supply chain and found that the most effective lean technologies are just-in-time, flexible transportation and environmentally friendly packaging. It appears that different lean technologies can have different levels of impact on the success of lean and green.
- Environmental factors. As discussed earlier in this study, lean may have different impacts on different environmental factors. Rothenberg et al. (2001) found that lean has little or no impact on VOC emissions, energy and water consumption. Chiarini (2014) found that TPM can reduce direct oil leakage.
- Processes. The implementation of lean and green was at different processes in previous studies. While some studies focus on conceptual consideration (see Verrier et al., 2015), other studies focus on a variety of processes. For example, David and Found (2015) discussed the external influences that may affect the success of lean and green. Reyes-Garza (2015) discussed the implementation of lean and green at a strategic level. Verrier et al. (2015) investigated the change management procedure that is brought about by the implementation of lean and

green. The management of these processes may also affect the success of lean and green.

It should be noted that these factors are not exhaustive, but rather illustrative of the importance of a few variables which may affect the success of lean and green. To identify a complete list of variables, further investigations will be conducted.

CONCLUSIONS

This paper provides some preliminary findings from a comprehensive literature review of lean and green. It appears that lean and green are considered as two separate frameworks which both include the consideration of waste. However, the definition of waste is not the same in lean and green. While the elimination of some lean waste sources can bring environmental benefits, the elimination of other lean waste sources does not necessarily bring about improvement in environmental performance. However, one interesting finding is that all examined studies focus on the use of lean to achieve green benefits. The investigation of the relationship between lean and green is one-way at the time of the study. It is recommended that future studies should be conducted to see whether the use of green development can achieve efficient and lean benefits.

Another finding from the literature review is that there are very limited number of studies which investigate the measurable benefits of lean and green. Only five studies are identified from a list of 97 journal articles. It appears that majority of the studies is focused on investigating the synergistic relationship between lean and green from the theoretical perspective. As noted previously, the integration and lean and green aims to bring measurable benefits to industry. As such, future studies should focus on quantifying the two-way relationship between lean and green, which appears to be a large research gap.

In addition, the unsuccessful stories of lean and green prove that the success of lean and green is dependent on a few factors, including the lean technology used, the industry and the process that the concept is implemented in, as well as the environmental performance measured. It cannot be concluded that the use of lean can achieve green benefits and the use of green development can lead to efficient and lean production. From the theoretical development, the relationship between the lean attributes and the green attributes have been mapped. However, the mapping should be evaluated against the aforementioned factors so as to understand the impact of technology-, process-, industry- and environmental-related factors on the success of lean and green.

This study has several limitations. The findings are based on a preliminary examination of evidence and a quantitative examination of these studies has yet been provided. From this study, it can be found that the lean implementation in various industries can lead to different results. How will the characteristics of different industries affect the implementation requires further investigation. In addition, the sample is obtained by searching lean and green in Scopus, which may overlook some of the valuable contributions from the IGLC society. The papers published by the IGLC society will be included in the future to provide a more complete list of lean and green studies.

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THE CONFLUENCE OF LEAN AND GREEN CONSTRUCTION PRACTICES IN THE COMMERCIAL BUILDINGS MARKET

Kelsey Maris[1] and Kristen Parrish[2]

ABSTRACT

Lean and Green construction methodologies are prevalent in today's construction industry. Green construction implementation in buildings progressed quickly over the last 10 years due to the popularity and development of building rating systems, such as LEED. Similarly, lean construction has become more popular as it often results in efficient construction and improved owner satisfaction.

The goal of this study was to assess whether or not practitioners reported the same thoughts on the interaction, or lack thereof, of lean and green construction as reported in academic literature. The authors identified common elements of each methodology through semi-structured interviews with five construction industry professionals with extensive experience with lean and green construction. Interviewees report lean and green construction are different "flavours" of the industry; however, interviewees also state if implemented together, these processes often result in a high-performance building. The authors note that the number of interviewees is small by design – this small sample size allowed the authors to test this research method for validating academic findings reported in literature. This work also brings the practitioner perspective to the conversation about the confluence of lean and green.

KEYWORDS

Lean construction, green construction, waste reduction, efficiency.

INTRODUCTION

Construction professionals typically implement tenets of lean and green construction separately, as they are viewed as two different methodologies; indeed the IGLC community supports this claim with the works of Carneiro et al. (2012), Campos et al. (2012), and later, Valente et al. (2013). The Lean Construction Institute defines lean construction as a "production management-based approach to project delivery" that extends from the objectives of maximizing value and minimizing waste (2016). Lean

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construction practices are slowly becoming standards in the industry; they are used to "optimize project results and maximize efficiency through all phases of design, fabrication, and construction" (jmcmahon 2014). Kibert defines green construction, also known as sustainable construction, as "the practice of erecting buildings and using processes that are environmentally responsible and resource efficient" (2012). The green building outlook continues to accelerate, growing almost $70 billion in just 6 years, from 2005 to 2011. The Dodge Report states, "by 2016, this number is expected to reach $204 billion to $248 billion" (Dodge Data & Analytics 2013). Given the popularity of both methods, this paper builds on existing work about how the methods compare, contrast, and complement through interviews with US practitioners experienced in both systems.

This paper begins with a definition of lean construction and green construction in terms of their practical application on commercial building projects, and discusses the perceptions of each within the construction industry. The authors interviewed five construction professionals in a semi-structured interview format to determine how practitioners implement lean and green and to find common practices among lean and green methodologies. This paper describes the research method and presents results from interviews. After comparing the results to literature review, three different theories emerged, representing a departure from existing literature, which characterizes the relationship without the consultation of practitioners.

LITERATURE REVIEW

This literature review focuses on the literature commonly read in the construction industry, rather than in academic literature. The authors selected these sources in order to relate definitions to those that the interviewees would be familiar with and likely to incorporate in their own personal definitions of lean and green construction.

LEAN CONSTRUCTION

Lean construction is an operational process that employs practices aimed at reducing effort, increasing production, and eliminating waste. Lean construction experts define waste not only in the physical form, but also as non-productive time and activity during construction projects. The Lean model was codified in the 1950's based on the Toyota Production system: it focuses on process efficiency through techniques including just-in-time, load leveling, and suggestion systems (Liker 2004; Morgan and Liker 2006).

While construction is not a manufacturing process, per se, as each construction product is unique (compared to producing thousands of a single product, e.g., cars), construction does involve repetitive processes that suggest manufacturing process improvements may be applicable. Researchers state that promised work is often not completed on time (Lichtig 2005; Howell and Lichtig 2008; Teicholz 2013), leaving room for improvement and reduced waste. Lean construction offers a method to reduce wastes and improve productivity in the construction industry. Thus, most lean construction applications focus on communication and reliability. For instance, scheduling practices put in place, such as the Last Planner System and pull planning, require project teams to "think in terms of flow rather than optimizing discrete activities" (Howell and Lichtig 2008). Project teams may implement prefabrication, just-in-time deliveries, preventing excess material, and building information modeling to improve process flows. Teams may also use tools like building information modeling, or BIM, to facilitate clear communication. Teicholz stated that teams who use BIM reduce the project schedule for building construction; he also stated that prefabrication and efficiency have a direct relationship (2013). Another application of lean in the industry is in the continuous improvement sector, where project teams develop tools to reduce effort in different ways, e.g., once workers are trained in safe and efficient work practices, teams implement the "Plan Do Check Act" cycle (Shewhart 1939; Deming 1986; HCi 2008; Parrish 2013) to improve these practices. The construction industry is accustomed to solving problems as they arise to maintain schedule, but they may not be as familiar with documenting the success or failure of the solution. By implementing PDCA, companies can better assess which solutions work well when given issues arise; thus, companies can be more proactive and more quickly implement proven solutions on future projects, saving time and cost (Howell and Lichtig 2008). At its core, lean construction implementation counters low productivity and supports a more efficient industry.

GREEN CONSTRUCTION

Kibert documents seven principles to sustainable (green) construction: (1) reduce resource consumption, (2) reuse resources, (3) use recyclable resources, (4) protect nature, (5) eliminate toxics, (6) apply life-cycle costing, and (7) focus on quality (2012). Green projects often address the social, environmental, and economic bottom lines.

Project teams can assess green buildings to determine their impact on the environment using a variety of rating systems. The LEED (Leadership in Energy and Environmental Design) building rating system is the most popular system in the United States, and it has helped green construction gain traction; given its popularity in the US, where the authors conducted their study, this work focuses on LEED rather than another rating system. LEED provides a framework for building a "holistic green building," using energy and water efficient materials, diverting waste and recycling materials during construction, and in operations, using strategies to provide a healthier building; LEED awards credits for building on a sustainable site near public transportation amenities (USGBC 2015). The environment is increasingly considered in building design and construction, in the lean context, the environment could be considered a "customer."

RESEARCH METHODS

The goal of this study was to assess whether or not practitioners reported the same thoughts on the interaction, or lack thereof, of lean and green construction as reported in academic literature. To do so, the authors adopted a semi-structured interview approach (e.g., (Wengraf 2001). Based on the literature review described above, the authors developed an interview protocol. The authors determined a list of interviewees with the help of Arizona State University's (ASU) Office of the University Architect. That office provided a list of contractors that successfully implemented lean and green construction on campus projects. They solicited input from leading practitioners in the fields of lean and green construction, where "leading" refers to lean and green construction experience on the Arizona State University (ASU) campus. The semi-structured interview approach allowed the authors to begin with a list of questions, but divert and allow new ideas to enter the conversation during the interview as appropriate (Wengraf 2001). As mentioned previously, the authors take an industry-based approach, rather than an academic one; the authors compare their results to those of other academic studies in the Discussion section.

The sample size for this study was 5 separate interviews with representatives from 4 general contractors. The small sample size allowed the authors to test the efficacy of the method and their interview protocol. Each organization represented has revenues over US$1Billion annually; respondents draw from this wealth of experience in their responses. Table 1 documents the interviewees. Each interview was recorded, transcribed and coded using nVivo software (qrsinternational.com) that facilitated comparison between interviewee's responses.

Table 1: Interviewee Profiles

Name	**Role**	**Organization**	**Experience**	**# of lean ASU projects**	**# of green ASU projects**
Lew Laws	Sr. Project Manager	DPR Construction	25	3	3
Phil Macey	Collaborative Project Delivery Expert	JE Dunn	23	1	1
Brooke Coffin	Lean Specialist II	JE Dunn	12	3	3
Tom Dobson	Vice President	Holder Construction	17	4	4
Steve Clem	VP, Pre-construction	Skanska	19	0	0

RESULTS

The authors compiled all of the interview transcripts in the nVivo Word Cloud generator to create Figure 1. Figure 1 comprises 110 words that were used more than 5 times across interviews. The words that were used most frequently signify the different Lean and Green construction practices implemented on projects. The following sections describe results from the interviews on lean and green construction, respectively.

LEAN CONSTRUCTION

The synthesis of the qualitative data from the interview questions discussing lean construction produced the following themes: 1) collaboration, accountability, and effective scheduling; 2) process and effort reduction, continuous improvement; and 3) set-based design and design-construction integration.

Collaboration, Accountability, and Scheduling

Laws emphasized that the most prevalent connection between Lean and Green construction is in the collaboration and accountability. Employing lean practices enables the project team to "keep score" and hold team members accountable for their responsibilities (2015). He stated an effective way to do so is enable the Last Planner System for scheduling; "…this system provides a framework for the subcontractors onsite to get behind the 'I get, I give' philosophy of lean" (2015). Another positive to the Last Planner system is it utilizes a pull planning schedule that essentially builds the project backwards (Clem 2015). DPR keeps a whiteboard updated with the activities for the day so the entire project team can see what is going on, which puts positive pressure on the subcontractors to honour the commitments they made to each other and the broader project team (Laws 2015).

Figure 1: Word Cloud generated from interview transcripts. Researcher produced. 31 Mar. 2015.

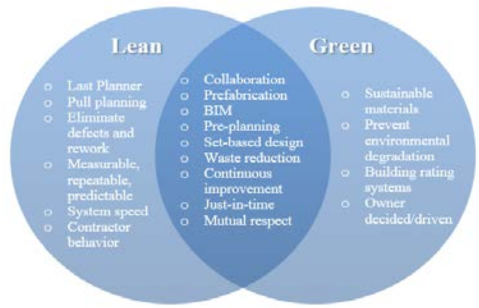

Figure 2. Venn Diagram for Lean and Green practices. Researcher produced. 31 Mar. 2015.

Process and Effort Reduction and Continuous Improvement

To reduce effort and provide the same results is an ultimate goal of implementing lean practices (Dobson 2015). Holder Construction has an initiative for de-cluttering to rid wasteful processes that use too much time or too many resources. Another effort reduction practice is implementing a strategy to provide what is needed and not to bring excess material to a jobsite (Dobson 2015). A general contractor knows what is coming to the jobsite through planning and this enables less waste on the jobsite and less wasted time due to transporting and handling unnecessary materials or equipment. The other effort reduction piece comes from continuously improving, such as Skanska offering improvement workshops for associates to assess the current stage of how a process is working, for example, subcontractor prequalification (Clem 2015). Project teams can also track variances in the schedule activities and use Five Whys analysis to promote continuous improvement in daily activities. The Five Whys is an effective questioning method to determine what the root cause of a problem is in lieu of making excuses. This is particularly helpful when a task is delayed due to an issue that is not directly related to that task (Coffin 2015). These continuous improvement changes can make an associate or company leaner and in result, more efficient and productive. The industry needs changes that will allow contractors to deliver a project faster (Clem 2015), and implementing lean can be an answer for many companies.

Set-Based Design and Design-Construction Integration

The process of set-based design is focused on considering several possible solutions and gradually narrowing the sets down to decide on a final solution without backtracking. The project team also keeps project file of considered solutions and decision reasoning

(Parrish 2009; Tuholski and Tommelein 2010). Dobson stated, “set-based design focuses on defining goals and pushing each goal to the extreme to see what the result is” (2015). In an effort to move forward with a project and promote productivity, set-based design may be employed. Macey emphasized an effective lean concept is to restructure the design process to work with the construction process in an effort to produce constructible drawings (Dobson 2015; Macey 2015). In order to build lean, the project team needs to be the right fit for the project type; “to get the best people working on the task at hand is the most efficient practice”, though not always the most cost efficient (Clem 2015).

GREEN CONSTRUCTION

The synthesis of interview data from discussing green construction yielded the following: 1) using a building rating system and installing sustainable materials; 2) building morally for the environment and waste reduction; and 3) creating respect for peers.

Rating Systems and Sustainable Materials

Green construction is a “subset of sustainability” (Clem 2015) in which the owner, builder, and design team collaborate on design and construction in an effort to build sustainably. A typical practice of building green is to leverage a building rating system, such as LEED, Green Globes, or the Living Building Challenge, to shape the design (Clem 2015). The owner typically selects the rating system and requires the design and construction teams execute their processes in compliance with the rating system. Most rating systems award points for using sustainable materials in the building, such as FSC certified wood, low-flow fixtures, and flooring or paint with low VOCs. These materials are typically decided in the design phase and specified by the design team (Clem 2015; Laws 2015). In other cases, the contractor can select these materials. For instance, Skanska Construction is certified through the ISO 14001 standard that enables Skanska to identify particular environmental risks for operations and mitigate and minimize their environmental impact during construction (Clem 2015).

Moral Building, Waste Reduction

Using the ISO 14001 standard also relates to designing a green building and the quality that goes into the process. Macey states that in order for a building to be high-performing, it must have high quality first. Building a project conceptually should first begin with quality, then performance, and then sustainability (2015). Building a highly sustainable project is also building morally for the environment. Laws stated that green buildings are built “with the future in mind” (2015). During the construction process, all activities need to have a positive impact on the future rather than a negative one. This is where waste reduction practices onsite become a key to successful project delivery. Few contractors consider building a project without developing an efficient recycling and waste plan with efforts to divert as much waste as possible from the landfills (Dobson 2015).

Respect for Peers

A less obvious method of green construction is the respect and opportunity found in the green building method. Clem immediately answered the question about what green construction is by stating, “green construction is treating our employees with respect and opportunity and providing an industry leading safe environment" as well as "providing opportunity to the project team that enable sustainable interactions" (2015). Further, all interviewees noted that more and more clients prefer, and often require, green construction experience; organizations with it gain respect from contractors and owners.

CONFLUENT TENANTS OF LEAN AND GREEN CONSTRUCTION

In an effort to find the confluence between lean and green construction practices, the authors reviewed interview transcripts to find words and themes discussed in response to **both** the lean and green construction questions. Prefabrication and pre-planning as well as continuous improvement, emerged as confluent practices (Figure 2).

Prefabrication and Pre-Planning

Prefabrication, and the preplanning it requires, is a confluence of lean and green construction. Prefabrication is green and lean due to reduced wastes, and particularly lean due to the decreased need for onsite labour. If products are manufactured offsite in a warehouse, the controllability and quality of the result is more likely as compared to fabricating it onsite, therefore reducing waste (Dobson 2015). Prefabrication also allows the general contractor to build a strategy during the pre-planning phase, in which manpower can be decreased since fabrication will be done offsite. The green aspect to reduced manpower is reduced transportation to and from the project site. Having fewer workers requires less gas and reduces fossil fuel effects on the environment (Coffin 2015).

Continuous Improvement

The concept of building greener and more sustainable materials is a practice of lean in and of itself. Lean is focused on continuously improving, while green building is also focused on finding the next greatest product that will reduce the environmental degradation impact from building construction. For example, there is now a toilet that uses 1.6 gpf (gallons per flush), who says we can't have a toilet that is 0.5 gpf? There are constantly improvements in technology and manufacturing that will enable green construction to thrive due to lean construction practices (Coffin 2015).

DISCUSSION

Through the interview analysis process, a few different schools of thought emerged on the synergies, or lack thereof, of lean and green construction implementation in projects. Academic literature to date illustrates clear overlap. The authors found that while this overlap exists and is recognized in industry, practitioners interviewed still felt lean and green were quite different, in terms of fundamental ideology and their driver on a project.

LEAN VS GREEN: DIFFERENT IDEOLOGIES

Two of the interviewees stated that the two methodologies are different and not simply relatable; rather, they are two different "flavours" of construction. Practices of each can be derived and applied to the other, but it is not a confluent or synergistic relationship. Although there may not a direct connection between the methods, Laws stated that it seems general contractors and subcontractors become more sophisticated, in terms of technology use, when using practices from lean and green (together or separately) (2015).

LEAN VS GREEN: LEAN IS COMPANY DRIVEN, GREEN IS OWNER DRIVEN

The overall impression of lean construction among interviewees is that it is a behavioral and cultural mindset for a company. In order to be lean, participants need to adopt certain attitudes. Adopting lean principles encourages continuously improving methods and de-cluttering initiatives. This is the main difference between Lean and Green construction. Green construction is a choice to implement, typically decided by the owner or client. It is not so much behavioral, as it is documentation and product based.

Coffin stated that some owners do require contractors to implement lean practices in the project via the contract; requirements range from utilizing prefabrication to BIM to Last Planner scheduling to having associates analyze the root cause of problems by asking the Five Whys (2015). Asking a project team to become lean differs from asking them to build green. Building green can range from working with the design team to determine benefits analyses of certain types of equipment, tracking points on a building rating system score card, or coordinating green materials and techniques with the subcontractors. Essentially, respondents felt that due to the party in charge of implementation of these methods, these methods fundamentally differ and can be synergistic, though they doubt the methods will ever reach confluence.

LEAN VS GREEN: SYNERGISTIC IN NATURE

Interview responses suggest another school of thought: lean and green as synergistic without one being dominant. That is, these methods work together hand-in-hand. Dobson stated that pre-planning is a theme between the two, in that if lean and green strategies can be implemented in the beginning phases, then the contractor can build a package for the owner that includes a strategy for utilizing the lean practices, such as prefabrication and just-in-time delivery, to deliver a green project. Another emergent theme is in the design phase, where the building is designed to be constructible and efficient. In this phase, contractors in a CMAR or design build delivery system are able to work closely with the design team to produce constructible drawings, essentially skipping the design development phase of the project (2015). Macey stated that when there is a purposeful integration from a project's inception, lean and green come together (2015).

Overall, implementing the two methodologies together sets up the potential for a successful project, although there may be a few caveats of comparing the efficiency of green construction practices to lean principles. Dobson stated that design members tend to run with experimental products and techniques, and try to be the "bleeding edge" of the industry, which is not necessarily the most efficient method. Implementing experimental design and equipment can cause field installation issues, confusion for the contractor, and eventually re-work. Another green construction technique, pointed out by Clem, is requiring the specifications to reflect the desired properties of the product in its "green" composition, whether it is durability, maintenance or other factors. It is not a lean practice to include standard specifications in lieu of choosing a palette of sustainable material that can be used and meets the environmental standards. This could require the project team to submit substitution requests, which can waste time that could have been saved upfront had the design team developed new specifications (Clem 2015).

CONCLUSION

The implementation of lean and green construction can produce varying results, however, research shows that these methodologies work together and separately to create high-performing buildings with a reduced schedule, collaborative project teams, and continuously improving performance. Through implementing lean practices, such as prefabrication, Last Planner scheduling, and pre-planning, green buildings can be built more efficiently. Vice versa, utilizing green construction practices, such as implementing a building rating system, waste reduction techniques, and using sustainable materials, can be effectively managed by using lean practices. The theories that emerged in this work reflect an industry viewpoint of lean and green construction, and show that there is no black and white answer to whether or not lean and green is the *right* way to build, but the practices the authors analysed reflect the overall efficiency of implementing both. The authors hope that in asking the question about confluence, and finding a research method that addresses such a question, the IGLC community and others will continue to collect more data to better understand how these two methods support an improved industry.

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THE PROCESS OF GREEN BUILDING CERTIFICATION: AN EXAMINATION REGARDING LEAN PRINCIPLES

Nina Weinheimer [1]

ABSTRACT

The United Nations Climate Change Conference in November 2015 resulted in the Paris Agreement where 196 countries agreed to the common goal of reducing the global anthropogenic emissions of greenhouse gases during the second half of the 21st century to zero. The building sector has a large impact on the worldwide production of greenhouse gases as buildings are major consumers of energy from construction through to operations and finally, demolition. Consequently, this considerable potential for savings in emissions will have to be realized. Against this background, sustainable building will receive more attention. Green Buildings, with the emphasis on resource efficiency, comfort and high quality are very challenging for the project participants. In addition, these high demands are even increased due to the requirements of a certification system.

This document is intended to provide insights into how to best meet the above. First, by using the example of the German Sustainable Building standard, the process of Green Building certification and its realization in practice are described. Second, after giving a theoretical overview of the principles of sustainability and Lean Thinking through literature review, a practice-oriented examination of the certification process is carried out. And third, sources of waste during the certification process are revealed and an approach for improvement regarding Lean Principles is proposed.

KEYWORDS

Lean Thinking, process management, sustainability, Green Building certification.

ITRODUCTION

There is no far-reaching consensus about what attributes make a building sustainable. This is due to different statutory provisions, standards and nationally recognized guidelines. Certification systems or Green Building Labels were developed to show guidelines for sustainable construction and to brand a building as sustainable, in effect giving visibility to the public. Many other approaches to integrate sustainable aspects in the construction industry, e. g. Menezes Degani/Ferreira Cardoso (2002), Furtado (2002),

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Luo et. al (2005), Bae et. al. (2007), Klotz/Horman (2007), Rosenbaum et. al. (2012) have also been made. As an example of Green Building certification systems this paper focusses on the German Sustainable Building Certification (DGNB). This certification system consists of a criteria catalogue which provides credit points for achieving specific requirements. The criteria concern the fields of ecology, economy, social and functional quality, technics and processes, with all points being weighted differently. Site factors are evaluated separately. The total amount of credit points determines the level of certification.

As customers have shown an increased interest for sustainability, Green Building Labels have become a marketing instrument creating the chance of competitive advantages and earning higher profits in the market (Miller and Pogue 2009; Holloway and Parrish 2013). Thus, the value added by labelling a building as sustainable can often be compensated due to its bringing a higher value in the market.

However, a Green Building certificate does not guarantee the sustainability of a building to its full extend (Deutsche Hypo AG, 2011, Mehaffy/Salingoros 2013). Considering Kaizen and continuous improvement, the question if a Green Building certificate represents the optimal performance of sustainability arises. Are the fundamental ideas and principles of sustainability completely covered in the DGNB certification system or can Lean Thinking possibly contribute to an enhanced sustainability? This contribution is intended to reveal particular weaknesses of Green Building certification systems aiming for full sustainability by the example of the DGNB Certification System. Process inefficiencies to be diminished using Lean Principles are shown.

THEORY OF LEAN THINKING

Lean thinking is a philosophy that aims at reducing waste in all its manifestations within a production process (Liker 2004, Shah and Ward 2003, Shah and Ward 2007, Scherrer-Rathje et al. 2009, Herrala et al. 2012). Since the first adaption of Lean Production in the construction sector by Koskela (1992) many successful efforts have been made to apply Lean Production in the particular phases of construction projects beginning with the project drawing via designing and construction through to operating and redevelopment or demolition and the need for change has been emphasized (e. g. Koskela et al. 2003).

Womack and Jones (1996) and Liker (2004) define Lean Thinking as a philosophy that mainly follows 14 principles. In this contribution the 14 principles by Liker have been reduced to 5, because these are most useful and crucial to examining the processes of Green Building certification. As they describe processes of production derived from the Toyota Production system, not all of the 14 principles contribute to an efficient examining of Green Building certification processes. Regarding the following 5 principles deficiencies of a Green Building certification are revealed:

1. Specification of value from the customer’s point of view

The definition of value is the key task in developing any product which is intended to be marketed successfully. Koskela (2000) defines value as the fulfillment of a customer’s requirements. So over-fulfilment or missed requirements cannot be compensated.

Identifying the specific customer's requirements exactly is crucial to defining the value of a construction project from the customer's point of view (Valente et al. 2013). Koskela and Tommelein (2009) state that the client's requirements are not clearly defined at the beginning of a construction project, but are evolving through the process of a Real Estate development project. The project goal is seen here as "moving targets to be managed throughout the production process". Involving the project participants in an early stage of the design and planning process can help to better define the customer's requirements and leads to an optimized result by integrating the experts' experiences.

Given that the equivalent value that the customer is willing to pay for a building is limited to a cap, the need to improve the internal processing to produce profit is obvious.

2. Analyzation of the production processes (value stream)

The analyzation of the production processes aims to identifying the value stream. This is considered to be an array of production stages which all add value to the product and lead to its completion (Womack and Jones 1996, Rother and Shook 1999, Herrala et al. 2012).

Real Estate development projects are special in terms of their production processes. They are, unlike the stationary industry, usually divided into particular sub-processes, e. g. design, construction and maintenance under the responsibility of different project participants. In addition, the interdisciplinary participants typically are not a well-functioning and seasoned team, but working together for the first time and creating a prototype that hasn't been built before. Consequently, a well-structured, conversational project management is eminently important to achieve the defined value and project aims in an optimal way.

3. Ensuring an effective process flow

Womack (2006) defines an ideal value stream as a constant process flow in which one value-adding step is followed by another without waste, e. g. waiting (Womack and Jones 1996, Rother 2010, Herrala et al. 2012).

4. Pull production: produce what is demanded by the customer when it's demanded

The core message of the principles of pull production is producing only what the customer wants when he demands for it (Womack and Jones 1996, Rother 2010, Herrala et al. 2012). In practice, this theory can be implemented as an array of requests for resources along the production chain, but in reverse. One production unit "pulls" a request for e. g. material or information defining exactly its amount from the downstream (or supply-)unit. This procedure allows savings in resources by avoiding overproduction storage (Womack 2006, Herrala et al. 2012).

The theory of pull production implies an exact definition of the customer's requirements. This target requirement has to be translated into subsidiary aims and instructions forming an efficient entire production chain. Efficient processes can only be achieved if the formalities and standards of "pulling" resources are determined at the beginning of the project and are obeyed by every project participant.

***5.* Continuous improvement of all processes**

Crucial for continuous improvement is a working atmosphere which allows the participants and employees to develop new ideas and approaches. A conversational interdisciplinary project team can achieve great improvements of the product and processes by combining the participants' particular know-how. However, in Germany this discourse and knowledge exchange is not common practice, but rather an exception. The project participants often only consider their own success and profit instead of the overall purpose of an optimized production process and valuable final building. Many project members worry about losing competitive advantages by revealing their know-how in the common tendering and award procedures. Other forms of contracts, e. g. partnering, could counteract these apprehensions and lead to a more constructive cooperation in favour of the project's success (e. g. Howell et al. 1996).

THEORY OF SUSTAINABILITY

The basis of the concept of sustainability is the statement that most resources are finite and thus should not be exhausted, but re-used. Resources which are are replaced by nature continuously, e. g. insolation or wind, should be used intensely as "natural income energy". Another basic principle of sustainability is avoiding releases of toxins from resource processing into the environment (Langenwalter 2006). The "triple bottom line" expresses an approach which adds economic and social criteria to the environmental aims of sustainability (Elkington 1997).

The Brundtland Report (WCED 1987) stated the concept of sustainable development. It says that sustainable development should "meet the needs of the present without compromising the ability of future generations to meet their own needs". This report was a valuable stimulus for all industries to rethink their production processes. In fact, incorporating sustainability principles into the business processes can pay off and also improve a company's finances by emphasizing resource efficiency (Langenwalter 2006). The construction sector, as a resource-intensive and great waste-creating industry (Pinheiro 2003) throughout all production stages, has accepted the challenge of adjusting the production processes to sustainable principles.

Kibert (2007) defines the principles of sustainable buildings as reducing and reutilizing resources, utilization of recyclable resources, protection of the environment, elimination of toxic elements, involvement of lifecycle costs and aiming for quality. Sustainability can also be seen as a strategy to achieve a building which is in accordance with its environment taken into account social, economic, biophysical and technical aspects (Asiedu et al. 2009). In a greater context, sustainability in the construction sector cannot be considered an issue of one single building, a town or a country, but as the result of an interaction of all Real Estates on the planet (Augenbroe and Pearce 1998, Huovila and Koskela 1998, Salvatierra-Garrido et al. 2010).

PROCESSES OF DGNB-GREEN BUILDING CERTIFICATION AND LEAN PRINCIPLES

Real Estate development projects which aim to achieve a Green Building certification usually are complex, innovative, pursue a high quality standard and furthermore have to fulfill certain criteria and requirements of the certification system. Lean Thinking, as a philosophy of managing processes efficiently and eliminating waste, can possibly contribute to optimizing the development processes of sustainable buildings with these especially high challenges and thus even increase the building's sustainability. This is to be examined by analyzing the processes of Green Building certifications (DGNB) based upon the aforementioned 5 principles of Lean Thinking.

1. Specification of value from the customer's point of view

Achieving a Green Building Label itself can be a value required by the customer. One of the main reasons for a Green Building certification is marketing. The aims can be to establish a sustainable business strategy by showing Corporate Responsibility and certifying corporate Real Estates or to achieve better marketing opportunities in Real Estate development projects. Most Green Building certifications are thus not obtained because of environmental protection and the responsibility for further generations, but rather based on a careful consideration of economic factors. The basis of the decision which Green Building certificate to choose often is a comparison of the efforts and estimated costs to achieve the highest level in each case. Quite often, the least expensive one is chosen.

In the development of sustainable buildings according to a Green Building certificate, the fulfillment of the certification system's criteria plays a major role. By deciding to strive for a Green Building certificate, usually a certain standard, e. g. DGNB Gold, is targeted. This target has to be achieved in the course of the project to recover or justify the additional costs and efforts of the certification process. This may lead to the neglect of the real customer's requirements and even replace them by the system's criteria catalogue. Consequently, the detailed determination of the customer's requirements can be impaired leading to a failure of performance and operational problems.

The focus during the certification process is often on achieving credit points, rather than on adding value to the building and developing a useful concept for it. Quite often in aiming for a high number of credit points, the least expensive measures to achieve them are chosen, e. g. building bicycle stands instead of expensive technical innovations. This fact is also mentioned by Parrish (Parrish 2012). Furthermore, measures to improve the building performance at times are not realized, specifically in cases where there are no credit points to be gathered in order to limit the already high project costs. Furthermore, not receiving credit points for an effort is frustrating to the project team and may result in lower performance.

Increased costs due to the usage of innovative building materials or building services and installations and higher expenses for documentation may compromise the profitability of the construction project if these investments cannot pay off during the lifecycle of the building. (Klotz et al. 2007; Koskela 1999; Mogge 2004) Mainly, such buildings are realized as "flagships" or to make an example, but are not efficient. After Lean principles, a waste of financial resources is created.

Design modifications can be a result of changed customer requirements, including the situation where the modification is directly related to the achievement of a Green Building certificate. It is not uncommon that the decision to get a Green Building certificate is made at a time when the planning is nearly finished. Integrating the certification system's criteria can be difficult at this planning stage and results in changes in the building's characteristics. These modifications of planning lead to inefficiencies in the developing process of the Real Estate and, given that the original planning was based on a precise determination of the customer's requirements, can contradict them. Thus, it is possible that the customer's requirements are not completely fulfilled in favour of achieving a Green Building certificate. In fact, it can occur that value which is actually required is not realized, but measures are taken which do not contribute to an optimal building operation, e. g. the integration of artworks.

Especially under difficult conditions on the market, Green Building certificates cannot only be a competitive advantage, but also a risk. To market the floor space successfully, sometimes significant individual adaptions to the designs according to the customer's requests have to be made. These modifications impair the process planning and may contradict the criteria catalogue. This can lead to a conflict between the value definition of the Green Building Label and the value appreciated by the customer which either threatens the achievement of a Green Building status or the project's profitability.

2. Analyzation of the production processes (value stream)

The DGNB certification system takes all production stages into account. Therefore, all sub-processes, e. g. design, construction, operating etc., have to be analyzed and organized in order to meet the requirements of the criteria catalogue to achieve credit points, e. g. the kind of interdisciplinary working together and project culture, emissions and noise production during the production work or user guidance in the phase of building operation. Furthermore, certain tests, e. g. Blower Door Testing or the measuring of pollutant emissions, and additional requirements and restrictions are required and have to be integrated into the production process.

3. Ensuring an effective process flow

The participants in Green Building projects are often not used to working according to the certification system and their normal business processes don't meet the requirements. As construction projects are usually time sensitive, there is often no detailed explanation of the relevant criteria to the executors. Without a well-structured communication flow with the persons performing the work, process inefficiencies and waste are produced when actions and measures are not done according to the criteria and have to be redone and adjusted. An example is the utilization of not "permitted" process materials, e. g. adhesives, on the site due to the unawareness of the workers and consequently the necessary removal.

During the certification process, the interdisciplinary project team often is unsure of their functions and responsibilities. Especially the form of the documentation of all measures – crucial to achieve credit points – often is unclear. Due to failed communication, evidence and documents frequently are not of the requested form or are not recorded at all. Setting them up once again or afterwards can be very time-consuming and thus creates a waste of human resources.

4. Pull production: produce only what is demanded by the customer when it's demanded

In Green Building certification projects, the information process flow is often not efficient due to inexperience and a lack of awareness amongst the project participants. It is often not defined, who has to deliver what information when and in which way or quality. Unclear responsibilities and tasks and an unorganized project structure plan cause inefficiencies and a waste of time, material and human resources.

5. Continuous improvement of all processes

The inflexible criteria catalogue of Green Building certification systems does not much encourage the project participants to think out of the box. Thus, the fixed criteria can inhibit an improvement of the building performance in the planning phase and can lead to reduced proactivity and personal initiative where they are only "fishing" for credit points.

CONCLUSION AND DISCUSSION

Process inefficiencies occur in every construction project due to failed communication, problems concerning the practical and technical feasibility of the planning, site conditions, legal restraints etc. Green Buildings due to the goal of a high level of quality, innovation, resource efficiency and comfortability are especially challenging. This is not only because of the ambitious targets, but also a result of the numerous project participants and experts and the requirements of the certification system. The outlined difficulties in the process of obtaining a sustainable building certification show that there is waste which can be reduced by the utilization of Lean principles. Eliminating a waste of resources thus can increase the sustainability of a Real Estate.

Yet, there is not enough attention on the development and production processes of Green Buildings in certification systems, e. g. DGNB. Fulfilling some criteria in the system's checklist does not represent a project culture of a well-structured communication and information flow. Without a well-organized project management, a waste of resources in all possible forms can result which is not in conformity with the principles of sustainability.

Waste during the process of Green Building certification mostly results from inexperience of the project participants in the procedure and requirements of the certification system. Detailed information and training with regard to the characteristics, systematics, formalities, requirements and opportunities of the certification system can help to achieve an efficient process flow. In this training, not only the responsible, but also the executing persons should be included.

The above-mentioned boundary conditions of Green Building projects and the coordination of the interdisciplinary project team necessitate a well-organized and structured project management. An effective process flow can only be achieved if all project participants in every sub-process know exactly their task and the needed quality of their contribution to the production of the sustainable building. If this prerequisite is fulfilled, a process flow can be planned where one value-added production step follows another without creating waste, e. g. overproduction, incorrect quality or timing.

The target requirement of creating a sustainable building has to be translated into subsidiary aims and instructions. These can be developed into "puzzle pieces" of production – units of information or material specified in their form und quality to be demanded by higher production steps. It is crucial to define these units of the production process thoroughly so that every project participant knows what his due is. Thus, an efficient pull production is created in which every unit has its defined parameters and can be pulled at the exact time when it is needed. A continuous improvement of the processes leads to a higher efficiency and is the basis of all progress. The defined units and standards of the development, certification and production processes should not be considered as fixed, but following Kaizen, analyzed, rethought, improved and renewed to achieve a greater efficiency.

Without a well thought out design and construction, taking into account local conditions, user behavior and the avoidance of resource waste, no sustainable building can be achieved. It is not enough to fulfill the criteria catalogue of a Green Building Label, but the building as a system with all its influences has to be considered and lead to an optimum. Involving the customers in the development of the building concept is crucial as the user behaviour has a significant impact on the actual resource efficiency and sustainable building performance. However, it cannot be assumed that the customer is always able to anticipate the impacts of his decisions on the building operation. Thus, a precise determination of the customer's requirements and a constructive dialogue are essential. Measures which the customer does not value or which he cannot use (correctly) during the building operation should not be included as this creates waste. If the customer mainly aims for achieving a Green Building certificate, e. g. as part of his marketing strategy, then not just the way of least efforts, but the most reasonable one should be chosen. It may at first sound correct in terms of Lean principles to only deliver what the customer values, in this a Green Building certificate with a minimum resource input, but in the original meaning of sustainability it is not.

Especially Green Buildings as "flagships" of sustainable and responsible building should be drivers of innovation and reach for the best quality, resource efficiency and user satisfaction possible. This can only be achieved by working together across all disciplines, while creatively combining the expertise of all of the project participants. However, strictly following a criteria catalogue choosing the line of least effort does not lead to sustainability at large. This can inhibit the advancement of creative and efficient building concepts and blight initiatives to improve the building performance.

As a conclusion, to encourage the project participants to enhance the resource efficiency and sustainability of the building by developing innovative ideas, a Green Building certification system could be created in which there is no criteria catalogue to fulfill. Instead, guidelines for sustainable building with the integration of Lean Thinking as a maxim for design, planning, construction, operations, refurbishment and demolition as well as for project management, working culture and communication/information flow could be introduced. Thus, the development philosophy and strategy would be certified as a way of project realization. Following this approach, waste in the development processes could be eliminated and better overall building concepts could result through an optimization oriented working methodology of the entire project team. As an incentive, the Green Building Label in different levels could be awarded to a sustainable, efficient building concept after a detailed examination. In this case, the actual building performance should be regarded in terms of theoretical parameters and calculations, e. g. especially related to the heating demand and heat balance, which can differ a lot in the real building operation.

Deregulating, simplifying and making the certification processes more open could contribute to an increased number of Green Buildings. As sustainability must be seen as a sum of the global performance of all Real Estate, the current small number of Green Buildings does not realistically help in reducing the greenhouse effect. In addition, the numerous existing buildings have to be energetically modified and adjusted in terms of the sustainable use of resources.

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SECTION 11: SAFETY AND QUALITY

Saurin, T.A. (2016). “The FRAM as a Tool for Modelling Variability Propagation in Lean Construction.” In: *Proc. 24th Ann. Conf. of the Int’l. Group for Lean Construction*, Boston, MA, USA, Sect.11 pp. 3–12. Available at: <www.iglc.net>.

THE FRAM AS A TOOL FOR MODELLING VARIABILITY PROPAGATION IN LEAN CONSTRUCTION

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ABSTRACT

Although the control of variability is a key concern for lean construction, there is a lack of tools for modelling how variability propagates throughout functions. This paper discusses how the Functional Resonance Analysis Method (FRAM) can be useful for this purpose. So far, the FRAM has been used mostly by the resilience engineering community, which is concerned with safety management in complex systems. In order to support this discussion, an example of applying the FRAM to safety inspections carried out by government officers in construction sites is presented.

This example draws on sources of data (e.g. participant observation) used by the author in a recent study of systems thinking applied to inspections. The case of safety inspections suggests that the FRAM can encourage managers to appreciate the variability of functions and agents apparently unrelated to the function in which the detrimental effects of variability are visible. Also, results point out that the FRAM might be useful for anticipating the impact of small intentional and non-intentional changes on the functions involved in a construction project.

KEYWORDS

FRAM, variability, safety inspections, systems thinking.

INTRODUCTION

Lean construction (LC) is well-known for being concerned with the management of variability, in internal processes and external suppliers. According to Hopp and Spearman (1996), variability is the quality of non-uniformity of a class of entities, which can be designed into a system (e.g. product variety) or be random (e.g. the time when a machine fails). Story (2011) offers a similar notion, defining variability as the range of performance measurements, values, or outcomes around the average which represents all the possible results of a given process, function or operation.

Both definitions, by Story and Hopp and Spearman, are neutral in the sense that variability is not necessarily associated with outcomes. Indeed, random variability can be

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positive (e.g. an unexpected business opportunity), while designed variability can create waste – e.g. product variety can make workflows more confusing. Regardless of this ambiguity, there seems to be a consensus in the LC community (e.g. Tommelein et al., 1999) that *workflow* variability is detrimental to the reliability of production plans, quality, and safety, creating mismatches between capacity and demand.

Nevertheless, there is still a gap related to the modelling of variability propagation in construction sites, since the theoretical foundation for construction project management, and the practical tools based on it, do not account properly for complexity (Brodetskaia and Sacks, 2007). Of course, this is in conflict with the nature of construction projects, in which uncertainty, physical proximity between processes, and the use of resources shared by many processes (Perrow, 1984), among other factors, create interactive complexity not anticipated by designers. Furthermore, the emphasis placed by LC on process simplification ultimately leads to tightly-coupled processes and, as a result, greater complexity. Therefore, both unintended interactions induced by the nature of construction and the LC objective of creating flow make the modelling of variability propagation a topic of theoretical and practical relevance.

Complexity science (CS) may be a source of insights into variability propagation, as conveyed by the notion that small changes trigger partially unpredictable interactions in a complex socio-technical system (CSS), creating emergent behaviour with disproportional consequences (Cilliers, 1998). In this paper, the Functional Resonance Analysis Method (FRAM), whose theoretical foundations are based on CS and resilience engineering (Hollnagel et al., 2006), is investigated in terms of its usefulness for modelling variability propagation in construction. The FRAM was developed by Hollnagel (2012) as a tool for the modelling of CSSs, and so far it has been used mostly with a safety management focus, in sectors such as healthcare and aviation. In fact, the FRAM has an underlying theory of how accidents occur in CSSs (Hollnagel, 2012). It assumes that accidents are emergent phenomena arising from the combination of everyday variability of functions (i.e. functional resonance); thus, there is no need for broken parts as an explanation for accidents.

In construction, the use of the FRAM is incipient. Rosa et al. (2015) applied the FRAM as a risk assessment tool for the task of reusing demolished concrete in a construction site. Von Buren (2013) used the FRAM to analyse the fall of a crane in a construction site. The remaining of this paper is structured as follows: (i) first, the FRAM principles are presented and an analysis is made of their implications to LC; (ii) second, an example of applying the FRAM to construction is presented, using the case of safety inspections carried out by government officers; and (iii) the conclusions summarize the main insights and opportunities for future research.

THE FRAM PRINCIPLES AND IMPLICATIONS FOR LC

Hollnagel (2012) presents four principles underlying the FRAM: **(i)** failures and successes are equivalent in the sense that they have the same origin - this means that things go right and wrong for the same reasons; **(ii)** everyday performance of socio-technical systems, including humans individually and collectively, always is adjusted to match the conditions;

(iii) many of the outcomes we notice, as well as many that we do not, must be described as emergent rather than resultant; and **(iv)** relations and dependencies among the functions of a system must be described as they develop in a specific situation rather than as predetermined cause-effect links. This is done by using functional resonance.

Principle **(i)** conveys the idea that variability, especially in terms of human performance, is always present in CSS, whether the outputs are desired or undesired. Of course, variability that leads to desired outcomes may involve latent conditions, which eventually may play a key role in the occurrence of wastes and accidents. However, such variability could not be, per se, *the* "cause" of said wastes and accidents, since it was always present. As applied to the Last Planner system of production control, principle (i) means, for instance, managers should not take for granted that a percentage of plans completed equal to 100% means that no relevant variability occurred. In fact, 100% may have been achieved precisely because there was relevant variability that managers should be aware of.

Principle **(ii)** conveys that adjustments are necessary because plans are inevitably underspecified and because resources are scarce. Adjustments will be approximate, but usually good enough, rather than precise (Hollnagel, 2012). LC, and more specifically Last Planner, accounts for this principle by using hierarchical planning that progressively details plans from a long-term to a short-term horizon. In fact, the idea that the "last planner" is the front-line worker recognizes the need for approximate adjustments. As a drawback, LC has not focused on how to close the feedback loop, by learning how the last planner adapts.

Principle **(iii)** relies on the concept of emergence, which is central to CS. Emergent phenomena arise from the interactions among several variables, and they have unique properties that are not found in any of the interacting variables (Cilliers, 1998). Such phenomena may be either desired or undesired, and while they cannot be fully controlled they can be influenced to some extent (Cilliers, 1998). For LC, principle (iii) implies that investigation of successes and failures should place less emphasis on finding "causes", and more stress on finding factors, and their interactions, that "set the stage" for performance. This proposed emphasis also has implications for action plans derived from said investigations, since it discourages reductionist interventions excessively focused on improving specific parts of a system.

Principle **(iv)** is based on the concept of functional resonance, which is "the detectable signal that emerges from the unintended interaction of the everyday variability of multiple functions" (Hollnagel, 2012, p. 29). The assumption is that the combination of multiple sources of everyday variability may create functional resonance, thus producing an unexpected outcome. This outcome can be, for instance, a project´s time and cost overrun, a workplace accident, or a defective product. Principle (iv) means that, in order to anticipate threats and opportunities, LC should have tools for modelling how normal variability can combine. In fact, apparently benign intentional changes introduced in a project by LC itself may trigger functional resonance.

APPLYING THE FRAM IN CONSTRUCTION: SAFETY INSPECTIONS

CONTEXT

This section presents an example of applying the FRAM in the context of safety management. The FRAM is used to model the reaction of construction companies to prohibition notices issued by a labour inspectorate. In many countries, such inspectorates are in charge of enforcing health and safety regulations, and construction sites are frequently targeted by inspectors given the poor safety record of the construction industry. The reported example uses data from a recent study by the author (Saurin, 2016), who over six years acted as a participant observer in 13 cases of prohibitions in construction sites in Southern Brazil. Over this period, other sources of data were also used, such as interviews with two inspectors, about 80 h of direct observations of construction sites with prohibited works, analysis of prohibition reports prepared by the inspectors, and analysis of reports containing the corrective measures implemented by contractors. The projects were mostly high-rise residential or commercial buildings executed by medium-sized contractors.

The labour inspectorate was widely regarded by contractors as very demanding, and the length of time of prohibitions ranged from two to eight months. In seven out of the thirteen cases, the contractor appealed to court in order to end the prohibition, usually after two or three rounds of unsuccessfully trying to end the prohibition through administrative means. Mixed outcomes resulted from the inspections, such as incremental innovations in safety equipment and time and cost overruns. A more detailed presentation of project characteristics and outcomes is made by Saurin (2016), who frames outcomes as emergent phenomena and institutional waste. According to Sarhan et al. (2014) this type of waste refers to "institutional systems, structural arrangements and cognitive undergirding assumptions that support and encourage wasteful activities in construction".

STEPS FOR APPLYING THE FRAM

Execution of the FRAM followed steps from Hollnagel (2012):

(i) To define the purpose of the FRAM analysis: the three usual purposes of applying the FRAM are accident investigation, risk assessment, and evaluation of design changes (Hollnagel, 2012). In this study, the FRAM was applied to assess the effectiveness of actions taken by companies after the prohibitions were enforced;

(ii) To identify and describe the functions: functions are the acts or activities that are needed to produce a certain result, and the identification of functions should be preceded by the delimitation of the boundaries of the system of interest. Given the aforementioned objective of applying the FRAM, the presented example only accounts for functions involved in the processes that follow the prohibitions. Each function is described by a verb, and it has six aspects (described as nouns): input, output, precondition, resources, control, and time (Hollnagel, 2012). Not necessarily all aspects must be described, provided they do not impact on the variability of the output. Table 1 shows how functions <analyse report from inspectors>, <design corrective measures>, and <prepare report with corrections>

were described. Functions and aspects were identified from the databases produced in the study by Saurin (2016).

Table 1: Description of functions. * Ndi: Not described initially

Aspect/function	Analyse report from inspectors	Design corrective measures	Prepare report with corrections
Input (I)	New report received	Report analysed	Corrections designed
Output (O)	Report analysed	Corrections designed	Report prepared
Precondition (P)	Ndi*	Ndi*	Ndi*
Resource (R)	Ndi*	Proper H&S knowledge and skills	Proper H&S knowledge and skills
Control (C)	Ndi*	Areas and experts involved; regulations defined	Corrections implemented; Areas and experts involved
Time (T)	Ndi*	Strong time pressure by top management	Strong time pressure by top management

(iii) To identify the potential variability: the analysis of the potential variability of each function should account for what is reasonably expected to happen (Hollnagel, 2012). It is concerned with how the outputs of each function could vary in terms of time (too early, on time, too late, not at all) and precision (precise, acceptable, imprecise), from the perspective of the needs of downstream functions (Hollnagel, 2012). Table 2 presents the potential variability of some functions.

Table 2: Identification of potential variability. Note: + V = variability increases; - V = variability decreases

Function	Output	Variability of the output
Analyse report from inspectors	Reports analysed	On time: analysis starts immediately after receiving the written report informing the prohibition notice Acceptable (+ V): demands by inspectors can be ambiguous and unclear. Thus, the analysis of reports may also be flawed
Design corrective measures	Corrections designed	Too late (+ V): a number of factors, internal (e.g. slow decision-making regarding which and how corrections will be made) and external (e.g. lack of availability of designers) to the construction site may cause delays in the design of corrective measures Imprecise (+ V): the design may be technically flawed
Involve support areas and experts	Areas and experts involved	On time: support areas and experts are usually called up by the project manager soon after the prohibition notice is enforced Acceptable or imprecise (+ V): sometimes the experts do not have the expected skills. Furthermore, collaborative work among experts is not always fostered by management
Implement corrections	Corrections implemented	Too late or not at all (+ V): factors internal (e.g. low productivity) and external (e.g. inclement weather) may cause delays Imprecise (+ V): errors during the implementation of corrections Precise (- V): it was observed that workers, sometimes, fill in the gaps of incomplete design in an effective way
Prepare report with corrections	Report prepared	Too early (+ V): although the inspectors do not set any deadlines for receiving the report from contractors, these are often in an hurry to end the prohibition and therefore an incomplete report may be sent to the inspectorate, sooner than it should Imprecise (+ V): a report prepared in an hurry is more likely to be technically flawed

(iv) The aggregation of variability: this step involves an assessment of whether the actual variability of the output of a function, in a certain scenario, may affect the aspects of the other functions (Hollnagel, 2012). The scenario imagined in this study refers to work prohibitions in high-rise commercial or residential buildings, in which the construction company has financial, human, and technical resources to comply with, and perhaps question, the demands imposed by inspectors.

Table 3 illustrates the reasoning followed for analysing the aggregation of variability. Whenever an output of one function provided (impacted) an aspect of another function, a coupling between two functions is established, and therefore there is a path for variability propagation. Thus, couplings always involve links between the output of a function and any of the other aspects of other functions. The couplings are graphically represented in Figure 1, which shows the instantiation of the FRAM model for the analysed scenario. The software FRAM Model Visualizer 2.0 (available at www.functionalresonance.com) was used.

Table 3: Excerpt from the aggregation of variability (adapted from Von Buren, 2013)

The variability of the output of the function <design corrective measures>	
May propagate to the function <implement corrections>	
Affecting one or more of the aspects below – explain when and how	
Input (I)	Once corrections (e.g. repairs in physical protections, new safeguards, etc.) are designed, and approved by management, they can be implemented in the construction site. A flawed or late design may contribute to errors in implementation.
Time (T)	
Precondition (P)	
Control (C)	
Resource (R)	

Based on the aforementioned Tables (1, 2, and 3) and Figure 1, the conclusion can be made that functional resonance, with a negative outcome (i.e. corrective measures are partially or fully rejected by inspectors), is a plausible outcome of the process following the prohibition. In fact, in all of the 13 case studies of prohibitions, partial or full rejection of corrective measures occurred after the first round of changes made by the construction company. Moreover, sometimes inspectors identified new problems in their follow-up inspection, which had not been spotted in the original visit.

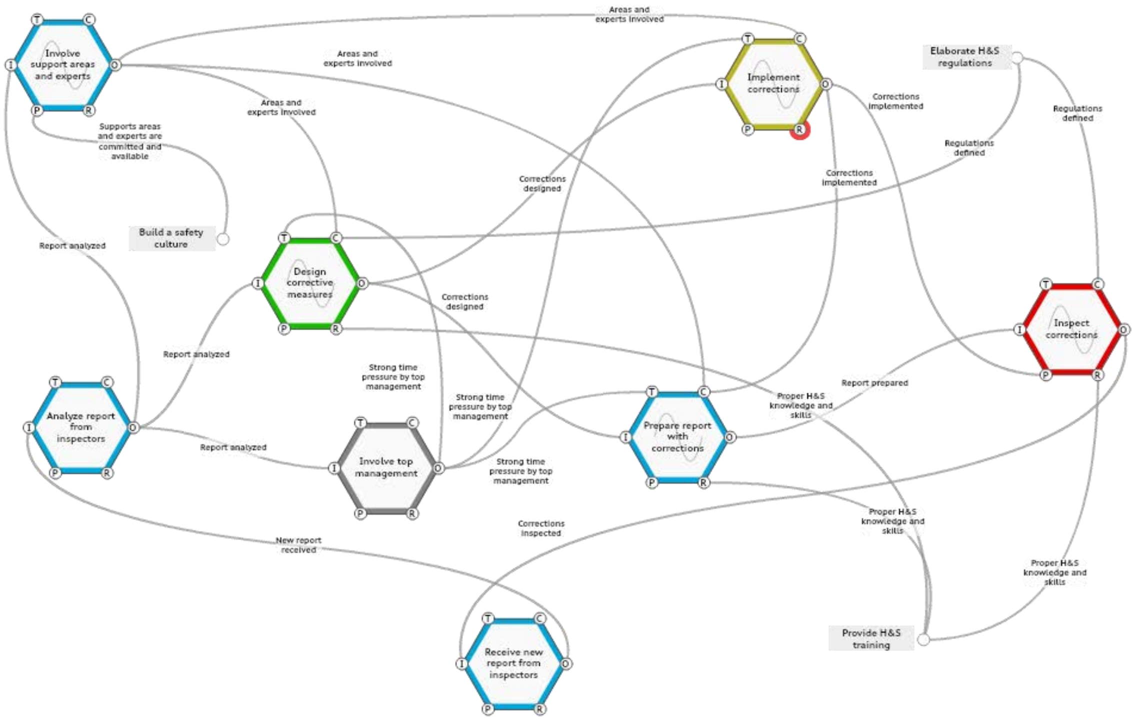

Figure 1: Instantiation of the FRAM model. Notes: (i) blue, functions primarily carried out by managers of the construction company; (ii) red: inspectors; (iii) green: outsourced designers; (iv) yellow: workers and supervisors; (v) grey: top management; (vi) rectangles: functions that are out of the boundaries of the focused system, but which may introduce variability into the system; (vii) the wave symbol inside the hexagon indicates the function has significant variability; and (viii) aspects in red circles are provided by the outputs of other functions, not represented in the model

This outcome may arise from the combination of the normal variability of functions, in a number of ways. For instance, an imprecise output of <involve support areas and experts> may be due to the involvement of low qualified or low committed experts in the design team, leading to late and technically flawed design solutions. Figure 1 indicates this variability will propagate to <implement corrections> as these will be based on a poor design. Of course, the output of <implement corrections> may be imprecise due to the variability of its own aspects, such as ineffective supervision and defective materials (resource aspect). According to Figure 1, failures in design and/or execution will also impact on the report prepared by managers. In fact, independently on the variability of upstream functions, the output of <prepare report with corrections> may also vary due to the variability of its own aspects – e.g. lack of clarity and organization of the written report, since some managers have little experience in writing this type of document (i.e. resource aspect). Eventually, the output of <inspect corrections> may also vary due to the technical background and approach used by some inspectors (i.e. resource aspect), who sometimes do not care to discuss corrective measures with managers and workers, and do not adopt consistent assessment criteria. Thus, the variability of upstream functions may be ultimately amplified by <inspect corrections>.

The mentioned couplings between functions were observed by the researcher in some of the case studies, indicating that no single failure or outstanding factor was the responsible for a negative outcome. Rather, interactions and couplings between functions, associated with everyday variability, made the outcome an emergent phenomenon.

(v) To identify consequences of the analysis: in this step, the objective is to propose ways to manage the possible occurrences of functional resonance that have been found by the preceding steps (Hollnagel, 2012, p.87).

Over the case studies, the researcher identified several countermeasures adopted by contractors in order to control variability. In order to evaluate whether the assumptions underlying these measures are theoretically sound, they are checked against six guidelines for the management of CSS (Saurin et al., 2013; Righi and Saurin, 2015): (i) give visibility to processes and outcomes; (ii) anticipate and monitor the impact of small changes; (iii) encourage diversity of perspectives when making decisions; (iv) design slack; (v) monitor and understand the gap between prescription and practice; and (vi) create an environment that supports resilience. These guidelines are in line with lean production principles, as discussed by Saurin et al. (2013). Table 4 lists four countermeasures adopted by contractors, from the perspective of the guidelines.

Table 4: Analysis of the impact of countermeasures

Countermeasures	Guidelines affected	Propagation throughout functions
Hire consultants and lawyers to review the report before sending it to inspectors	Consultants and lawyers work as extra resources (design slack) and provide an outsider perspective (encourage diversity of perspectives), spotting mistakes and errors in the report. Also, in reviewing the report, consultants and lawyers pay heed to apparently minor issues that may cause a delay in ending the prohibition (anticipate the impact of small changes)	The control and resources aspects of three functions (<design corrective measures> <implement corrections> <prepare report with corrections> may benefit from this solution. Variability of outputs of these and other downstream functions might be reduced
Implement corrections (and prepare corresponding reports) in small lots, in order to shorten the prohibition length of time	Working in small lots is mostly a lean principle. It also creates slack and supports resilience to the extent that it reduces time pressure on managers, so they can take the necessary time to design the more complex corrective measures, while at the same time the prohibition may be partially lifted	This solution seems to affect, mostly, the time and precondition aspects of <implement corrections> and <prepare report with corrections>. As a result of lower work-in-process, variability in downstream functions may be spotted early
Meet with the inspector before implementing the corrective measures, in order to get a pre-approval	This meeting(s) makes it visible to inspectors that the company is committed to find effective corrective measures, and it is also a means of obtaining the perspective of the inspector on the solution	This solution implies the creation of a new function <meet inspector before implementing corrections>), which does not appear in Fig. 1, since it does not always happen. New interactions would be triggered by the outputs of this function, which could be too late and imprecise.
Exchange experiences with other contractors in the region, which had similar prohibited works by the same inspectors, in order to learn what counted as "good enough"	Information on prohibitions usually spread quickly between construction companies. This supports resilience (i.e. quick adaptation) and offers different perspectives	This solution may be interpreted as adding more resources to <involve support areas and experts>. Based on the case studies, exchanging experiences tends to reduce the variability of downstream functions.

While Table 4 suggests that the countermeasures make sense from a theoretical viewpoint, data from the case studies indicate they are not always sufficient. As previously mentioned, contractors often need to go to court in order to end the prohibitions even if the countermeasures are in place. This may be due to the high variability of some functions, the diversity of agents, the strong time pressure involved in the process, and the fact the construction company has no control over <inspect corrections>, whose output is decisive for ending the prohibition.

Of course, a fundamental limitation of the countermeasures is their reactive nature. Saurin (2016) proposes that preventive actions should be focused on managing interactions between the: inspectorate and contractors (institutional level); inspectors and project management team (operational level); workers and managers; contractors and designers; contractors and federal government; and contractors and suppliers. For instance, concerning this last interaction, a function <purchase safety equipment from external suppliers> could have, as part of its control aspect, the use of checklists to evaluate whether the equipment complies with regulations.

CONCLUSIONS

This study was concerned with the use of the FRAM as a tool for modelling variability propagation in LC. Principles of the FRAM and LC were found to be compatible, and the analysis indicated that the insights from FRAM are valuable to LC. For instance, the FRAM makes it clear that emergence, instead of cause-effect relationships, provides a more realistic explanation of project outcomes. A focus on emergence also suggests that LC practices should place an emphasis on managing interactions, rather than fixing individual parts of the system.

The case of applying the FRAM to safety inspections was based on an ethnographic investigation of the system under analysis, which seems to be an appropriate approach for identifying variability and couplings between functions in CSS. In relation to previous studies of applying the FRAM, both in construction and other sectors, this case study made a contribution by proposing the use of six guidelines for the management of CSS as a quality check of the measures to contain variability.

Further applications of the FRAM in construction will be possibly more fruitful if focused on complex processes whose performance offers significant risks, either in terms of safety or other business dimensions. Of course, the LC community could also make a contribution to the improvement of the FRAM itself, by devising innovative ways of integrating it with other tools and principles. For instance, production planning could be modelled through the FRAM, supporting the identification of how small intentional or non-intentional changes (e.g. changing the sequencing of work packages) could provoke disproportional consequences. Quantification of variability and computer simulation of how it can propagate in different scenarios also poses opportunities for future research.

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COUNTERFEIT MATERIALS IN THE NORWEGIAN AEC-INDUSTRY

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ABSTRACT

The literature states that counterfeit materials can have major implications in particular concerning competition between suppliers, between contractors as well as general challenges regarding cost, time, quality and safety. Counterfeited materials are defined as unauthorized materials which special characteristics are protected as intellectual property rights, patents and copyrights. This paper seeks to answer the following questions:

1. What does counterfeit materials mean in the context of the Norwegian AEC-Industry?
2. Does counterfeit materials exist in the Norwegian AEC-Industry?
3. What are the potential consequences of counterfeit materials?
4. Which methods are suitable to detect and mitigate counterfeited materials?

This is a qualitative research study. The methodology consists of a review of literature and the research is carried out using explorative interviews with the purpose to gather experiences and examples of specific cases. This approach is chosen to encourage discussion with interviewees and thereby collect information that would otherwise go under the radar by more structured forms of interviews and surveys. Counterfeiting is a well-known problem, but there are limited literature addressing this phenomenon in the construction industry. This is a pilot study and the limitations include a limited number of interviewees. The nature of the counterfeit phenomenon limits the study in regards of accessibility, amount of previous research and literature addressing this phenomenon. By illuminating the scope of the problem possible consequences and evaluating the current strategies for dealing with the problem, this study could lead to an increased awareness within the industry. The study works as a basis for further research within the field.

Keywords Counterfeit materials; Supply Chain Management; Safety and Quality; Anti-Counterfeiting Strategy

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INTRODUCTION

The aim of a construction project is to create unique products that create value for the participators. For the contractors and suppliers this value is typically economic profit. To maximise profit and win tendering competitions, construction companies generally aim to lower their costs. Cost reduction can be achieved by globalizing supply chains, which usually means by buying construction products from the lowest cost source (Wang and Wang, 2010). Construction projects are, however, characterised by variety of constraining factors such as project complexity, limited time horizon and profit opportunities. Such factors render the industry vulnerable to counterfeited products entering the supply chain. Another important factor is the quality of the construction project. Quality can be defined as meeting the legal, aesthetic and functional requirements of a project (Arditi and Gunaydin, 1997).

For more than three decades, researchers have investigated the possibility of counterfeit products circulating in various industries. Consequently, literature on counterfeit products exists from a broad range of sectors, including such as the pharmaceutical, electrical and the fashion industry (Grossman and Shapiro, 1988); (Stevenson and Busby, 2015). The construction industry, on the other hand, has had far less research carried out on counterfeiting than other industries. The International Chamber of Commerce estimates that roughly 7-8% of world trade every year is counterfeited goods, equalling approx. US$600 billion (CIB, 2016). The effect of counterfeit trade surpasses, however, simple losses/increases in sale revenues. Counterfeiters are unfair competitors in that they do not have the same expenses as genuine producers (Berman, 2008). In the context of the construction industry, counterfeit materials will influence tendering competitions between contractors, suppliers and producers alike. It also leads to increased quality assurance activities such as controls, inspections and documentation in all parts of the supply chain (UNICRI, 2011).

The first step in this explorative study of the counterfeit phenomena was to look what counterfeiting could mean in the context of the construction sector. The second research question explores the existence of counterfeit materials. The study aims to expand the awareness surrounding this phenomenon. The third research question aims to identify potential consequences and the final research question examines strategies, methods and other anti-counterfeiting activities. In sum, this paper addresses the following research questions:

1. What does counterfeit materials mean in the context of the Norwegian AEC-Industry?
2. Does counterfeit materials exist in the Norwegian AEC-Industry?
3. What are the potential consequences of counterfeit materials?
4. Which methods are suitable to detect and mitigate counterfeited materials?

METHODOLOGY

The research carried out in this pilot study explored the phenomena of counterfeiting materials in the Norwegian Construction Industry. The study consist of a qualitative approach according to the prescriptions of Yin (Yin, 2013). The aim is to gain an understanding of the existence of and the reasons for the phenomena. The ambition is that this insight will work as a fundament for further research, with the aim to quantify the magnitude of the problem. The presented results stem from a literature review and from ten semi-structured interviews.

The interviews comprised a predetermined sequence of semi-structured questions (Interview-Guide), with options for follow-up questions. The sample consis of personal with management responsibilities, quality assurance, procurers and researchers with responsibilities regarding legislation, verification and control of materials entering the Norwegian market. Dialogue with the interviewees was encouraged. Questions were designed to explore the phenomena with the research questions in mind. The questions were all qualitative of nature (i.e. no questions involving numerical information or other quantitative approaches). Seven of the interviews were conducted face-to-face and three were carried out over the telephone. All interviews were audiotaped and transcribed. Resumes were sent to the interviewees for acceptance before the process of data analyses.

The aim of the literature review was to create a context for the research. Reviewing existing research and literature created a basis for the theoretical framework and to relate previous findings, theories and ideas to the problem (Blumberg et al., 2011).

The research theme of counterfeited materials came with some challenges. The first was the lack of knowledge on the subject in the industry. Furthermore, due to either a lack of knowledge or problems concerning communication, acquiring interviewees proved to be a challenge. The challenge of acquiring interviewees could be a result of counterfeiting being a sensitive subject. Another challenge was the scarcity of literature.

Regarding the sampling size, the population of personal with such professional roles, compared to the industry as a total, is quite small. Ten interviews were therefore considered as a necessarily convenient sample size. The approach of using a diversity of professionals from a small population made it difficult to determine whether each of the interviewees fulfilled the selection criteria. The solution was to contact each person to talk loosely about the subject, and then make a mutual evaluation of the candidate's further relevance for the study.

THEORETICAL FRAMEWORK

Increased globalization challenges the traditional supply-chain in construction projects. Import of products from emerging markets tosses an extended stress on producers, suppliers and contractors concerning quality assurance. The seller has to know about the local legislations in the market they want to trade their products in. The customers need to verify that the products they buy meet their requirements.

All flows of materials in the construction projects are typically categorized as forming part of a supply chain. A supply chain can be categorised according to three main axis; First, the flow of materials to the construction site, second, the temporary nature of the supply chain i.e. it is unique for each project, third, that the supply chain is designed to produce a specific product for one specific customer (Vrijhoef and Koskela, 2000).

Counterfeiting is generally understood to mean the "act of producing or selling a product containing an intentional and calculated reproduction of a genuine trademark"

(Launer and McCarthy, 1996). Grossman and Shapiro (1988) divide counterfeits into two categories, deceptive and non-deceptive. Deceptive counterfeits are products believed by the customers to be authentic and/ or according to the requirements requested. The non-deceptive are those products which customers know are counterfeits due to factors such as price, quality and lack of documentation.

The Construction Industry Institute uses the following categorizing of counterfeit materials (CII, 2010):

Class A – Goods produced by means of patent piracy; high-end goods that are as close as possible to real merchandise.

Class B – Goods that look nearly identical to genuine product, but that possesses sub-standard internal components and may cause catastrophic failures.

Class C – Obvious junk, poor quality goods that are easy to spot.

Being of an explorative nature, this paper does not limit its scope to parts of such categorisations. Rather, it defines counterfeit materials as materials that do not meet the specifications. This could be quality deviation, lack or insufficient documentation, unauthorized or not authentically certificates or reproduction of genuine trademarks. Thereby encompassing all occurrences within the Norwegian construction industry.

The Counterfeit Intelligence Bureau (CIB, 2016) states that counterfeiting is one of the fastest growing economic crimes worldwide. There is a great amount of cases of counterfeits worldwide spanning all sorts of industries. At one point the US Air Force, for instance, found counterfeit microprocessors in their F-15 fighter Jets. This could affect safety, operational readiness and costs (Journal of the IEST, 2010). A study published in 2014 did a search in three relevant databases (Counterfeit Intelligence Bureau, Federal Bureau of Investigation and Nexis). They found a number of 1,283 reports on counterfeiting (Stevenson and Busby, 2015). The reports ranged from pharmaceuticals, automotive parts and electronics to children´s toys. There are also examples of counterfeit products having fatal consequences; in 1989, a Convair 580 airplane crashed in the ocean on their way from Oslo to Hamburg, with 55 casualties resulting. The Aviation Accident Reports concluded counterfeited fasteners in the airplane tale caused the accident (HSL, 1989)

The construction industry is characterised by diversity. Construction projects range from commercial housing to large skyscrapers, from petroleum installations to bridges and other infrastructures. This implies that the industry face a diversity of potential counterfeit products. Previous research, such as Minchin et al. (2013), have identified cases of counterfeiting within the construction industry involving cranes, drywall, fly ash and pipes to mention some.

The potential impacts of counterfeiting are considerable. Construction projects are sensitive to changes in cost- and time schedules. Cunterfeiting can also potentially affect quality and safety. For many, a loss in reputation could be more devastating than a loss of profit. Recent example of economic consequences; a Wisconsin-based Architectural Firm was found guilty in repacking materials and falsify documentation in order to hide their use of noncompliant construction materials. The firm entered a guilty plea and paid $3 million in fees (USDJ, 2016).

There are a variety of gaps where counterfeit materials can be introduced into the supply chain of a construction project. Cheta (2008) identifies 5 common gaps where counterfeits potentially could enter the supply chain. Such gaps could be inadequate processes for approving suppliers or procurement being performed by third party contracts without adequate oversight from user. The contract itself could serve as a gap when liability and requirement to verify the authenticity of products are not emphasized or specified. Another gap is actors in the supply chain that does not apply adequate processes for verifying the authenticity of products. Such processes could be lack of inspections or verification of documentation on receiving materials.

Naderpajouh et al. (2014) has proposed a catalogue of risk mitigation strategies as a reference point for the construction industry. This catalogue consists of 19 different strategies ranging education of personnel to developing databases. The American National Standards Institute identifies four main topics in the fight against counterfeiting (ANSI, 2010). The first was collaboration and public-private partnerships. To share experiences, best practices and the use of common standards were all mentioned. The next point is education. Customers and consumers must understand the true impact of counterfeited products; as well as to learn how to avoid purchasing them. The third point was enforcement. This means that cases of counterfeited materials should be reported and then the authorities commit to follow up. It also means implementing proper security assurance programs, continually testing critical components, certification and other assessment activities. The fourth point is developing proper standards; Standards play a critical role in spreading best practices and assuring safety and quality.

FINDINGS

A consensus of the interviewees is that counterfeit materials are construction products that do not fulfil their requirements. Furthermore, the interviewees believe in a distinction between those who intentionally deliver products that do not meet the requirements and those who are not aware that the products do not meet the requirements. Some of the interviewees highlight the very broad aspect of the term counterfeit materials or the use of "fake" materials. This can be a product with right quality, but with deficient or lacking documentation. The term can as well be understood as a problem regarding quality and products that mislead the customers. The interviewee´s believed that the range of products that potentially could be counterfeit is broad. Among the product groups, most frequently mentioned were precast concrete elements, steel-reinforcements and other steel products such as fasteners. Products related to building facades such as glass, windows, fastening systems and others were equally mentioned. Table 1 shows the three major types of counterfeits identified from analysing the findings:

Table 1: Categorizing and characterizing counterfeit materials

Types of deviation	Explanation
Specification (Intentional/ unintentional)	Does not fulfil specifications according to contract, legislations, standard etc.

Documentation and certification	Does not have the required documentation. Not necessary a problem with product performance or quality
Quality	The product quality does not correspond with project specifications, product legislations or product standards

The majority of the interviewees had experienced counterfeited materials. One of the responders stated, ***"I have not experienced manufacturers who deliberately tried to deceive us or selling us fake products. In the cases experienced we have not had enough expertise to check that foreign manufacturers follow Norwegian requirements or have proper knowledge of them."***

Concerning the question of what the interviewees *think about the state of the industry today regarding counterfeit materials*, the answers varied. The majority pointed at an increase of awareness regarding documentation of construction products, but the awareness regarding intentionally deceiving products seemed to be lacking. Table 2 shows cases of counterfeits the interviewees had experienced:

Table 2: Counterfeited products

Products	Explanation
Assorted steel products	Deviation in quality, wrong treatment, thickness, galvanization
Anchor bolts	Lack of compliance between certificate and test result
Fixing bolts	Deviation in quality
EPS-Foam Insulation	Wrong values according to specifications
Precast concrete	Wrong steel quality in the reinforcement Lack of control systems in the production
Insulation boards	Lack of certification/ documentation
Faucets and pipes	Lack of certification/ documentation
Building modules	Lack of certification/ documentation
Prefabricated Bathroom Modules	Lack of certification/ documentation
Facade cladding systems	Lack of certification/ documentation

Regarding the existence of counterfeited materials, the interviewees were also questioned about the potential reasons. One interviewee stated that the tough competition could be an incentive for some producers to take shortcuts. Among different reasons, two reasons stood out; one of them was profit; ***"There is a financial reason. Inferior products cost less to produce. You also have producers producing a full-fledged product, but it costs too much to verify it. Then some might falsify documentation."*** The other reason was lack of competence, such as competence on Norwegian legislations.

The consequence that nearly every interviewee mentioned was the potential of structural failure and the structures' resistance over time. Lower quality might increase the construction owner's expenses during the course of the structures lifetime. ***"The consequence is largely on the customer side, precisely because it is only in the future that you see if the quality of the product is right in regards of what you actually paid for."***

On the contractor side, consequences like delays, cost overruns, safety and loss of reputations were all mentioned. There was a consensus among the interviewees that projects were indeed vulnerable. Tight time- and financial budgets, lack of competence regarding procurement were mentioned as reasons. To the question regarding which consequences counterfeiting *should* have, one interviewee answered; ***"You must distinguish between conscious and unconscious. If you deliberately tried to deceive anyone there should be major consequences. If the reason is negligence, such as when a buyer has chosen to only look at the price, there should also be some consequences."***

The interviewees described a variety of methods for discovering and mitigate the risk of counterfeited materials. The contractors empathized on developing competence on procurement; ***"The general procurer who buys everything in a project is on its way out. The reason why we think that is because one procurer will not be able to have the necessary overview of the specifications of all the products needed"***

Many addressed increased awareness, better communication, and exchange of experience. Some mentioned the advantage of developing a database with approved suppliers. A quality manager mentioned use of risk analyses: ***"What I think is the most important measure is the risk analysis, where one takes a multidisciplinary review of what can go wrong and how to control this."***

There was a broad consensus among the interviewees that the regulations surrounding construction products today was (in some way) not good enough. The reasons were different; some want more oversight from the authorities. Others pointed out that the rules were unclear or cumbersome. The industry is much based on self-regulation and that could be problematic in relations to counterfeiting.

Table 3 shows different methods mentioned as potentially effective to combat counterfeit materials.

Table 3: Strategies

Types	Explanation
Use of tools; Databases, archives	Databases showing legitimate suppliers and producers
Competence	Train and educate personnel both in the procuring process and controlling process Know what questions to ask Know the requirements and legislation
Inspections	Inspect the supplier/ producer Inspection on deliveries
Partnering	Partnership and commitment between contractors and suppliers
Risk analyses	Plan and analyse which deliveries are critical and should be inspected/ tested
Reporting	"Whistle blowing" Report to government or other institutions
Demand documentation	Product documentation needs to be controlled and verified
Supervision	Third party control Active supervision from government

DISCUSSION

The findings show that the industry has a very divergent perceptive on counterfeiting, and counterfeited materials. For some, this was a completely new concept. No cases of imitations, product violating intellectual property or trademarks were discovered. It is interesting that few of the interviews regarded imitations as a category of counterfeit. From other industries, producers producing imitations of genuine products are a large part of the problem. The reason could be many; the construction industry has not been exposed to these kinds of cases and thereby the lack of awareness. Another reason could be the types of personnel interviewed with their personal competence and awareness.

All of the interviewees had in some way experienced counterfeited materials. New types of products such as building modules seem to be vulnerable. The development of prefabricated modules has increased in recent years but it seems that the product standards have not had the same kind of development. This means that neither the producers nor the customers know what documentation that is required. The same can be said about new products, and new types of products entering the market. There are reasons to believe that in the majority of the cases, the involved parts have not deliberately tried to deceive the customer. It is a matter of lack of knowledge, on both customer and supplier side.

None of the interviewees reported having encountered serious consequences to any of the cases of counterfeit materials. Since the intentions in most cases were not perceived to be deliberately deceptive, the consequences are typically rework or resupplies. This implicates economic consequences. For the contractor, rework can be critical whether the project succeed or not. In cases where materials lack documentation, the customer typically grants special permission to continue using the product. This occurs in cases were the product is not critical for quality, safety or durability. The amounts of evidence needed to convict a contractor or supplier for knowingly have used or delivered counterfeited materials are extensive, making the clients hesitate to use legal measures.

In cases such as those with precast concrete elements, fixing bolts and anchor bolts, the client demanded testing for verifying the quality. As a consequence, they started to control every delivery on that specific project. The probability of counterfeited materials affecting structural integrity is fairly low, because structural integrity is a well-regulated part of a construction project. Counterfeited materials will still affect the overall quality because the clients do not get what has been paid for. This resulting in increased cost regarding management, operation and maintenance of the building.

Reducing the risk of being victim of counterfeited materials requires companies to implement an effective anti-counterfeiting strategy. Step one is to increase the awareness; you have to know the problem before you can solve or prevent it. The next step that both literature and the interviewee's points out is to develop competence. For example, a contractor should be using specialized procurers, cost should be avoided as the only factor in procuring and the industry will have mutual gain on increasing the focus regarding documentation of construction products. The procurer should have adequate knowledge about the products they procure such as related specification and legislations.

As the literature states, several gaps exist where counterfeit materials can enter the supply chain. In combination with a lack of awareness, a lack of anti-counterfeit strategies, and a constant time- and cost pressure, this renders the industry vulnerable.

CONCLUSION

The purpose of the present study has been to examine the phenomena of counterfeit in context of the Norwegian construction industry. There were relevant findings to all of the initial research questions. The research found that the industry categorizes counterfeited materials as a problem regarding lack of documentation and delivering of products with wrong specifications according to the requirement. Counterfeited materials as imitations of genuine materials was not regarded a problem by the interviewees, even although this is considered a major problem in other industries.

As for the existence, counterfeited materials should be considered an existing problem in the industry. The magnitude of the problem is unknown. The difficulty in judging whether the documentation or the product itself is fabricated or genuine poses a major obstacle for the industry.

A variety of consequences stem from the use of counterfeited materials. Increased quality assurance, inspections, testing and other activities are consequences. Rework or resupply is common for contractors and the suppliers. The client consequently gets a product with quality that differs from what expected. The sum of it is much unnecessary stress on the supply chain and an increase in overall cost in the industry. Counterfeit materials may cause waiting, rework and increased need for control of the supply chain; all of those activities could be categorized as "necessary waste” (Koskela, 2000).

According to the research, the most effective way to discover and mitigate the risk of counterfeited materials entering the supply chain is to increase awareness. With awareness comes development of competence, attitude and ethics regarding the phenomena. Companies should take counterfeit materials seriously and implement an anti-counterfeiting strategy to mitigate the risk of counterfeit products in their supply chain. The anti-counterfeiting strategy should be implemented with the aim of minimizing waste and securing built in quality.

This paper proves of the existence of phenomenon in the industry. The magnitude of the problem is unknown; a quantitative research regarding the magnitude should consequently be carried out. There is equally a need for research regarding anti-counterfeiting strategies. Developing a framework for effective methods and implementation of anti-counterfeiting activities in the supply chain management would be essential to prevent further cases of counterfeited materials within the industry. The sample size of ten in-dept. interviews was considered suitable to initially explore the phenomena. This study should be used as an introduction to more formal and extensive research in the future. Regarding consequences, unknown chemical composition possesses a threat to health and safety; this should be addressed in further research.

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EVALUATING THE PERFORMANCE OF UNMANNED AERIAL VEHICLES FOR SAFETY INSPECTION

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ABSTRACT

The potential use of Unmanned Aerial Vehicles (UAS) has come to the attention of the construction industry. However, its use still demands investigations for a better understanding of how this technology can be fitted to construction management tasks. This paper aims to evaluate the application of UAS for safety inspection on site, focus on its utility, equipment performance and risks associated with the use of that technology. For this, two case studies were performed in Brazil. Data was collected from flight tests on site for visual assets gathering and regular meetings with project personnel for feedback were held. The safety inspection analysis was based on the visualization of the safety requirements in the visual assets collected. Document analysis and interviews with project personnel and workers were performed for supporting the performance evaluation. As a result, the application of UAV could provide the visualization of 87.2% (Project A) and 58% (Project B) of the safety inspections items selected, providing detailed information for safety monitoring on jobsites. Barriers such as meteorological factors and pilot training influence the technology use for safety inspection. Further studies are under development in order to evaluate the impact of the safety inspection with the support of UAV in a systematic way.

KEYWORDS

Unmanned Aerial Vehicles/Systems (UAV/UAS); Safety inspection; Visual assets; Construction management.

INTRODUCTION

Unmanned Aerial Vehicles/Systems (UAVs/UASs) are defined as any aircraft that works without a human pilot onboard (Puri, 2005). Initially, UAVs were used in military applications, but more recently, the potential use of UAS in engineering environments has gained significant attention in domains such as Remote Sensing systems, field monitoring,

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infrastructure projects, urban planning, road inspections, jobsite management (Puri 2005, Irizarry et al. 2012, Themistocleous et al. 2014, Wen and Kang 2014).

In Brazil, commercial aviation activities are regulated and monitored by the National Agency for Civil Aviation (ANAC). The experimental operation using UAV requires authorization from the ANAC and its legal operation varies according to the classification of the Remote Pilot Aircraft (RPA), based on its Maximum Take-Off Weight (MTOW), the purpose of operation (experimental, commercial or corporate) and the visual grading criteria (Visual Line of Sight or Beyond Visual Line of Sight) (ANAC, 2015).

In construction projects, safety is a very important managerial task. In Lean terminology, poor safety is a form of waste, since injuries are costly not only in terms of human suffering but also in terms of worker compensation costs, lost time, lost productivity, and higher employee turnover (Nahmens and Ikuma 2009). Safety inspection, which is part of the safety management, has the role for hazard detection and correction of unsafe conditions (Irizarry et al. 2012; Woodcock, 2013; Lin et al. 2014). However, it is possible to identify some failures in process, especially related to non-standardization of inspection routine, difficulties to access jobsites in remote areas and real time management (Lin et al. 2014, Saurin et al. 2002).

Some emerging technologies have been used for accident prevention in construction jobsites, such as Technology of Information and Communication (TIC); Building Information Modeling (BIM), Global Positioning System (GPS), Geographic Information System (GIS), Radio-Frequency Identification (RFID) and Virtual Reality (VR) (Han et al. 2009, Lin et al. 2014, Jaselskin et al. 2015). For example, Teizer (2008) shows that construction safety can be improved by using emerging technologies such as 3D Range Imaging Cameras to improve safety in heavy equipment operation. Golparvar-Fard et al. (2011) state that the interactive zooming ability allows cases to be remotely analyzed by safety inspectors and can potentially lessen the frequency of on-site safety inspections.

The application of UAS for safety inspection and some other managerial tasks on jobsites has been the focus of exploratory studies as well (Irizarry et al. 2012; Wen and Kang 2014; Irizarry et al. 2015; Kim and Irizarry 2015; Irizarry and Costa 2016; Ham et al. 2016). Studies in other engineering areas show that UAV application can resolve the need for visual information and real time monitoring (Zhang 2008; Themistocleous et al. 2014). In addition, UAS potential can be related to low cost, high mobility, safety support, high speed visual assets acquisition and data transfer (Kim and Irizarry, 2015).

Therefore, despite those recent studies, the effective and systematic application of UAS for safety inspection still requires investigations that aim for a better understanding of how this technology can be fitted to construction management.

This paper presents an ongoing study which aims to evaluate the application of UAS for safety inspection on construction sites, focusing on the its utility for safety inspection, equipment performance and risks associated with the use of that technology. This research is part of a collaborative project between the Federal University of Bahia-Brazil and the Georgia Institute of Technology-USA, and the main outcome is the development of a set of guidelines for the application of UAS for safety inspection. This paper seeks to contribute to the identification of the role of UAS to support managerial tasks on site, especially concerning safety inspection, detection and correction, with the aim of preventing accidents, improving worker health, reducing costs, and increasing value.

RESEARCH METHOD

This work adopted a case study strategy, according to the following stages: (a) literature review on the use of UAS in engineering, monitoring and safety inspection and the Brazilian regulations for UAS flights, (b) case studies, and (c) UAS performance evaluation for safety inspection. These stages will be detailed below.

The location of the projects selected follows the criterion established by ANAC, allowing flights with a minimum radius distance of 5km from airports and heliports. Two residential projects were studied and Table 1 describes the main features of each project.

Table 1. Features of Project A and B

Project	Description	Safety inspection focus
Project A 	Residential low income housing project Land Area: 150,000m² Built Area: 91,000m² Total of 1880 units: 91 5-story buildings and 5 3-story buildings Construction time: 24 months 600 labor workers	Concrete pouring process, Roof process, Assembly and disassembly of steel form works, and Assembly and disassembly of safety pavement template works House keeping, temporary installation and wastes
Project B 	Residential high rise building Land Area: 2,500m² Built Area: 151,578m² Total of 104 units: 1 26-story building Construction time: 26 months 220 labor workers	Façade process Collective Protective Equipment and Individual Protective Equipment House keeping, temporary installation and wastes

The equipment used in the study was DJI Phantom 3 Advanced equipment, with Sony EXMOR camera ½.3", with 12.76 pixels, image size of 4000x3000, creating pictures in JPEG and DNG format and videos in MP4. A set of forms for the application of UAS for safety inspection was used based on Irizarry, Costa and Kim (2015), as following.

- **Planning Meeting Form**: form to determine information needed and workflow with project safety personnel and managers. The data is related to general project information, safety management process information, flight plan information.
- **UAS Mission Check List and Flight Log Data Form**: form used for pre-flight, during-flight, and pre-landing operations in order for an efficient flight, considering safety requirements and the appropriate use of the equipment.
- **Safety Checklist by Snapshot Types – Full version**: form used for identifying the safety requirements which might be visualized using the UAS technology. It was

adapted to the Brazilian Safety Regulation, called NR 18 Working and Environmental Conditions in the Construction Industry (Brasil, 2015). Initially, the NR 18 requirements which could be visually verified outside of the buildings were selected (a total of 60 items). These items could be associated with physical causes (e.g. scaffolding is not plumb and square), unsafe condition (e.g. unprotected workers from falling) and unsafe acts (e.g. workers not wearing protective equipment). The safety requirements were classified in three shot types: (a) **Overview**, including a general view of the site, focusing on organization and housekeeping, temporary installation and wastes, (b) **Medium Altitude View**, involving requirements related to Collective Protective Equipment and Individual Protective Equipment, and (c) **Close Up View**, which was established by processes, such as roof and waterproofing, concrete pouring and masonry, earthwork and foundation, equipment operation and façade.

- **Safety Checklist by Snapshot Types – for field**: form involves a summary of the safety requirements, with a total of 25 items, in order to guide the pilot and the observer during the data collection with the UAS.

A total of 23 flight tests were performed with an average time of 9 minutes each, and the number of pictures, video recording and flight parameters were catalogued (Table 2). For all flights, at least three members of the research team were involved: the pilot, the observer who guided the pilot for the safety inspection data collection, and a second observer to focus on the safety of flight (aircraft and surrounding area, such as airplanes, and birds). It is important to note that each flight had a purpose stated before takeoff, defined together with project personnel (use of Planning Meeting Form). Examples of this include flight for safety inspection based on the checklist, flight for examining the construction process in detail for safety purpose and flight for data collection for 3D modeling generation. This last item is not the focus of this paper. For the flight tests with the UAS the Pre- Flight Checklist and Safety Checklist by Snapshot Types – four field forms were used. After the flights, a feedback meeting with project personnel for the immediate assessment was organized.

Table 2. Visual assets data collection

Project	Period	Number of visits	Number of Flights	Number of Pictures	Time of Video recording	Maximum Distance(m)	Maximum Altitude(m)	Total Flight Duration(h)
A	Oct/15 to Mar/16	4	14	579	39:02	734.0	120.0	2:07:43
B	Nov/15 t Mar/16	3	9	722	09:48	173.5	76.8	1:15:43

At Lab, the data was fully processed based on the Safety Checklist by Snapshot Types Full Version. Due to the exploratory nature of this study, statistical analysis concerning visual assets sample size used for Safety Checklist were not performed. The analysis consisted of verifying if each safety item of the checklist could be visualized using any of the visual asset collected. A data base of safety inspection items and visual assets was created. A total of 7 Safety Checklist by Snapshot Types was applied, with 4 for Project A and 3 for Project B.

Additional data was collected during the studies aiming to gather the user's perception in terms of the utility and the risks associated with the UAV technology. A questionnaire for evaluating the degree of importance of the safety requirements used in the Safety Checklist by Snapshot Types Form was applied to 12 project personnel in Project A and B (2 Project Managers, 1 Field Engineer, 1 Trainee 3 Safety Personnel, and 5 Safety Trainees). The answers of the questionnaire were analyzed using the Relative Importance Index (RII), according to Ferreira and Brito (2015).

$$\text{Formula 1. (RII)} = \frac{\Sigma W}{AxN}$$

Where:

W is the weight given by the participant for each element using Likert Scale in 5 levels (1 - Very Low up to 5 - Very High);
A is the highest level, in this study it is 5;
N is the sample size (12 participants).

In addition, interviews to gather the manager's user perception concerning the utility of the visual assets to support decision making related to safety inspection were conducted for a total of 10 interviewees in Project A and B (1 Director, 1 Safety Director, 3 Project Managers, 2 Field Engineers, 1 Trainee, and 2 Safety Personnel). Finally, a questionnaire aiming to collect worker's perception concerning the interference of the UAV in their tasks during the flight, the privacy and the perception about the risks, such as falling, was given to a total of 18 workers from Project A and B who had the experience of working during a UAS flight. The evaluation of the UAS performance was based on the constructs, variables and sources of evidence presented in Table 3.

Table 3. Definition of Constructs, Variable and Source of evidence

Constructs	Definition	Variables	Sources of evidence
Utility	Means to evaluate to what extent the information provided using UAS technology supports safety management users	Meeting the information needs for safety inspection Applicability for safety inspection	Level of Importance Questionnaire Safety Check list data collection and visual assets from UAS
Equipment Performance	Means to evaluate to what extent the UAS specifications adopted are applied for safety inspection	Flight autonomy Device stability System reliability Easy use for users	Feedback meetings with project personnel and Interviews with project personnel Document analysis
Risks associated with technology use	Means to evaluate to what extent the risks associated with the technology might influence the application for safety inspection	Interferences in project activities Acceptability from workers Hazards such as falling and collisions	Direct and participant observation Mission check list data Visual Assets from UAS Flight log and note data Interviews with project personnel Workers' Questionnaire

RESULTS AND DISCUSSION

This section presents the results related to the utility of the UAS for safety inspection, equipment performance, and risks associated with the use of UAS technology.

UTILITY OF UAS FOR SAFETY INSPECTION

Table 4 presents the results of the Relative Importance Index, representing to what degree the safety items selected meet the information needed for safety inspection according to the managers' viewpoint.

Table 4. Relative Importance Index for the Main Safety Inspection with UAS

	Overview	N	W	RII
1	Perimeter fencing	12	51	**0.85**
2	State of all equipment, material, and personnel traffic routes	12	50	**0.83**
3	Rebar and formwork pre assembly area	12	49	**0.82**
4	Material laydown areas	12	47	0.78
5	Parking and emergency evacuation routes	12	45	0.75
6	Waste containers provided	12	44	0.73
7	Erosion control	12	44	0.73
	Medium Altitude view			
8	Workers protected from falling	12	52	**0.87**
9	Safety nets or planked floors	12	51	**0.85**
10	Ramps or runways protected by guardrails and free of obstruction	12	51	**0.85**
11	Workers wearing protective equipment	12	45	0.75
12	Waste removed by chutes closed	12	44	0.73
	Close Up View			
13	Exposed pieces of reinforcing steel capped	12	52	**0.87**
14	Aerial work platform protected by guardrails	12	52	**0.87**
15	Assembly and disassembly of the forms	12	51	**0.85**
16	Area on refueling and maintenance of equipment	12	50	**0.83**
17	Scaffolding is plumb and square, and with cross bracing	12	49	**0.82**
18	Cargo handling area signaling	12	48	**0.80**
19	The stalls for sand, gravel are close to the concrete mixer and winch	12	47	0.78
20	Working areas free of waste and detritus	12	47	0.78
21	Lifting loads protected by fall	12	47	0.78
22	Stocks of materials are close to the winch or cranes	12	45	0.75
23	Isolation of the area of crane operation	12	43	0.72
24	Heavy equipment	12	43	0.72
25	Stocks of materials are protected from rain	12	40	0.67

From the users' viewpoint, the most important requirements of the Overview snap shot are perimeter fencing, state of all equipment, material, and personnel traffic routes and rebar and formwork pre assembly area. For Medium Altitude View snap shot, the most important requirements to monitor are workers protection from falling, safety nets or planked floors, and ramps and runways. From a close up view, the most important requirements for safety inspection are whether stocks of materials are close to the winch or cranes, assembly and disassembly of the forms, cargo handling area signaling, area for refueling and maintenance of equipment, scaffolding is plumb and square, and with cross bracing, and aerial work platform protected by guardrails. Analyzing the results obtained with the association of the visual assets collected with the UAS during site visits, 87% and 58% of the applied items of the Safety Checklist could be visualized in Project A and Project B, respectively (Figure 1).

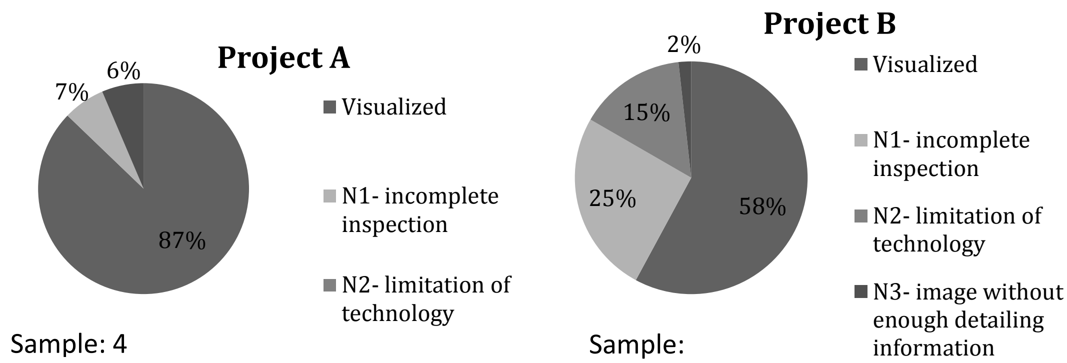

Figure 1. Results of the analysis of the cklist and visual assets

At Project A, the reason that 7% of the safety in ms were not visualized was due to a failure in the inspecting procedure, meaning that despite the fact that the item could be inspected, the information required was not collected during the flight (N1 - incomplete inspection). Examples of items which were not properly inspected during some of the 14 flights are the assembly and disassembly of the forms, lifting loads protected from falling, signaling and isolation of cargo handling area and the stalls for sand, gravel are close to the concrete mixer and winch. These failures happened due to the ample extension of the construction site (150,000m²) and the amount of tasks being developed simultaneously (structure activity cycle time is 10 apartments per day in this project). Also in 6%, the visual asset did not provide enough information for the inspection (N3 - image without enough detailing information), such as a ramps or runways protected by guardrails and free of obstruction, aerial work platform protected by guardrails and lifting loads protected from falling. These two findings indicate a need for a more accurate inspection during flights, including better pilot and observer training.

At Project B, due to the vertical characterization of the building and the focus on façade, 15% of the non-visualized safety inspection items, such as rebar and formwork pre assembly area, ramps or runways protected by guardrails and free of obstruction and stocks of materials, were related to the limitation of technology. Furthermore, 25% of the non visualized safety inspection items were related to incomplete inspection. Some examples of this problem are workers protected from falling (guardrails and toe board, lifeline and harness), workers wearing protective equipment especially in work at high elevation, waste removal by chutes and assembly and disassembly of the forms. Several factors contributed to those failures, as the fact that the protecting net along the façade was a barrier against detailing inspection, the limited altitude of 60m for urban area was a barrier to inspect the top of the 80m tall building, the constrained construction site as well as the strong winds in the location limited the use of the technology for safety reasons.

Analyzing the results of the Safety checklist by snapshot (Figure 2), 95.8% and 88% of the overview safety items applied for Project A and Project B, respectively, could be visualized, which include organization and housekeeping, temporary installation and wastes. For the items proposed for the medium altitude view, including Collective Protective Equipment and Individual Protective Equipment, 96.2% and 71% items applied for Project A and Project B, respectively, could be visualized. However, the inspection related to the close up view was a challenge, mainly for Project B, and it was only possible to inspect 42% of the items. The items 17, 18, 21 and 23 presented in Table 4 were especially difficult to inspect due to the short distance between the neighboring buildings and the building which was being inspected and the limited altitude of 60m for urban area contributed to the non-visualization of the items before mentioned.

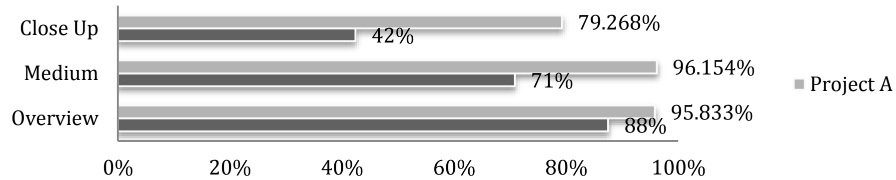

Figure 2: Percentage of safety inspection items visualized by snapshots

UAS EQUIPMENT PERFORMANCE

During the 23 flight tests in Project A and Project B, the average time was 09min08sec per flight, while the autonomy of the battery is between 15-18 minutes. However, for safety reasons, the research team used to start the landing process with 35% of the charge remaining, mainly when the aircraft was at a relatively high altitude or far from to the taking off location. The manufacturer recommends the return of the aircraft with 30% of battery charged. The average number of pictures taken per flight was 57. Depending on the purpose of the flight, more pictures or intense use of video recording were used. In general, the battery autonomy was not a constraint for data collection, since two or three batteries were used for each construction site visit, but the flight plan for each battery was essential to establish the point of interest for data collection. In the 23 flights in Project A and B any stability problem which could reduce the quality of visual assets was noted.

Concerning the reliability of the equipment, during the 23 flight, 15 failures along the system were identified. 11 of these were related to signal loss during flight, and it necessary to use the Return to Home Bottom 6 times, but in the other situations, the system was recovered during the operation. The difficulty to identify GPS satellites before the taking off were noted in two flights in Project B, however soon after the take off, the minimum number of satellites for operation was identified by the UAS. Also, the wind speed (over 5.5m/s) was an impediment for two flights in Project B, despite the fact that the wind speed presented was below the manufacturer's recommendation for flight (10m/s). These two problems happened because the take off location was very constrained and surrounded by tall buildings.

RISKS ASSOCIATED WITH THE UAS TECHNOLOGY

Table 5 presents the users' perception concerning the risks associated with the technology and the influence of the application for safety inspection. According to the survey, for the workers, the degree of privacy invasion was relatively low (1.94), the distraction from working was relatively low (2.00) and the concern about the hazards of falling and collision was relatively low too (1.89). For the managers, the UAS seems easy to use (3.89), has low interference on the project site (1.44), as an example the stoppage of crane or heavy equipment is highly accepted by the workers (4.56) and caused low concern to the hazard of falling or collision. Furthermore, for these managers the adoption of UAS for safety inspection depends on the purchasing cost of equipment, the availability of technical support services nearby, pilot training or hiring a trained person for operation of the UAS and principally the interest and perception of cost benefit of the leadership for its adoption.

Table 5. Workers' and Managers' Perception concerning Risks associated with UAS

Workers' Perception During the flight, what is your degree of...	N	Average	Standard Deviation
Perception of privacy invasion	18	1.94	1.11
Distraction from working	18	2.00	0.69
Concern to hazards of falling or collisions	18	1.89	1.18
Managers' Perception During the flight, what is your degree of...	N	Average	Standard Deviation
Ease using of the UAS by the research team	9	3.89	1.05
Interferences of the UAS in project activities	9	1.44	1.01
Perception of acceptability of the UAS from workers	9	4.56	1.33
Concern to hazards of falling or collisions	9	2.22	0.97

Note: Likert Scale 1 - Very Low up to 5 - Very High.

CONCLUSIONS

The aim of this study was to evaluate the performance of UAV for safety monitoring based on visual assets obtained. A database of 1301 photos and 48min50sec of video recording was collected by flights at two active construction sites in Brazil.

The application of UAV could provide the visualization of 87.2% and 58% of the safety inspection items established in Project A and Project B, respectively, especially concerning organization and housekeeping, temporary installation and collective protective equipment, providing outside information which was not very clear beforehand and with high quality. Based on the visualization of the items, non-conformities related to unsafe conditions and unsafe acts could be identified, such as workers were not using PPE, inadequate guardrails and scaffoldings. Most of the safety inspection items established in this study was considered important by project personnel, with the average of the Relative Importance Index of 0.79, considering 25 safety items. The identification of the reasons for non-visualization of the safety items and the analysis of them by snapshot showed that the size of the site (constrained or wide), the location of the site (high or low population density area), meteorological factors (high wind speed) and pilot and observer training influence the application of the UAV for safety inspection and its accuracy up to this point.

The performance of the equipment during the 23 flight test in terms of flight autonomy, device stability, system reliability, and ease of use met the needs of the DJI Phantom 3 Advanced system for safety inspection according to the flight log data base developed. No major problems were identified during the flights which may cause damage to goods or people, and the application of UAV did not interfere significantly in the construction activities, except the need to stop the crane in Project B during a few flights. Concerns of privacy or risk of collision and falling were not highlighted by project personnel and workers.

The findings point out the potential of UAV application for safety inspection, providing real time information and allowing the visualization of safety issues in remote and difficult areas. There is an expectation that these results can contribute to the decision-making process and increase the effectiveness of the safety inspections, however these impacts have not been measured so far. Therefore, new studies are under development in order to evaluate the impact of the safety inspection with the support of UAV in a systematic way, focusing on fast feedback, allowing immediate corrective actions, reducing the safety inspection time and simplifying the safety inspection process.

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APPLICATION OF CHOOSING BY ADVANTAGES DECISION-MAKING SYSTEM TO SELECT FALL-PROTECTION MEASURES

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ABSTRACT

The construction industry is one of the most dangerous industries in the United States. According to the U.S. Bureau of Labor Statistics, one in five work-related fatalities in the U.S. occur in construction. Safety managers are frequently faced with a dilemma when making safety decisions and typically surrounded by overwhelming boundaries that affect their safety selections. Yet, literature does not provide safety practitioners with a sound decision-making system to be used during the process of specifying safety solutions that is not mainly based on subjective judgments using personal experience. Making sound safety decisions is crucial toward ensuring worker safety. This paper presents a detailed case study example of how a lean thinking concept called Choosing by Advantages (CBA) can be implemented on a construction project to make safety design decisions regarding the permanent features of a facility. In this case study, three fall-prevention measures on a one-story physical utility building on a medical facilities campus are examined. The present research builds upon previous research to extend the use of the CBA tabular method to the safety arena of the construction industry for the first time. The result indicates that CBA is a sound decision-making system that can be used by project teams to make safety decisions during early stages of design.

KEYWORDS

Choosing by Advantages, decision-making, lean thinking, fall-protection, safety.

INTRODUCTION

The construction industry remains one of the most hazardous industries in the United States. According to the U.S. Bureau of Labor Statistics, the number of fatal work injuries in the U.S. construction industry in 2014 was 874 (BLS, 2015). Falls from heights are still the leading cause of fatal occupational injuries in construction (BLS, 2015). While several safety measures have been identified, their effectiveness in reducing the rate of fatalities remains uncertain. Safety managers are frequently faced with a dilemma when making safety decisions and typically surrounded by overwhelming boundaries that affect their

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safety selections, such as construction cost, project schedule, and other critical factors to project success. Yet, literature does not provide safety practitioners with a sound decision-making system to be used during the process of specifying safety solutions that is not mainly based on subjective judgments using personal experience. Safety practitioners are desperately in need for a systematically sound decision-making method. Making sound safety decisions is crucial toward ensuring worker safety.

POINT OF DEPARTURE

Lean thinking offers many strategies that can be used to enhance collaboration between project teams. For example, the process of set-based design (SBD) typically involves generating as many design alternatives as possible up-front to allow for optimal trade-offs. The SBD process involves delaying the decision regarding which design alternatives to choose until the last responsible moment to enable cross-functional teams (CFTs) to make design decisions with more flexibility and less subjectivity. Design decisions have greater impact on building performance than decisions made during the construction process (Abraham et al., 2013). Design decisions do not only impacts aesthetics and cost of the project, but also safety performance, construction schedule and other outcomes of the building process. However, the process of SBD may lack formal and sound decision-making that ensures the selection of the best design alternative. The Choosing by Advantages (CBA) decision-making system can fill this gap as a sound and congruent decision-making system. Parrish and Tommelein (2009) claimed that the CBA process can enhance the implementation of SBD. Other research reveals that CBA methods and lean thinking are aligned in many ways (Arroyo et al., 2012). For instance, the CBA process defers subjective judgments until the end of the decision-making process, as will be discussed, which is consistent with lean thinking strategies especially the concept of SBD.

The aim of the present study is to examine the practicality and feasibility of applying CBA by safety practitioners in practice to make safety design decisions regarding the permanent features of the facility. A detailed case study example is selected to explain the process of implementing CBA tabular method on a construction project to make early design decisions that impact occupational safety.

CHOOSING BY ADVANTATAGES (CBA) AND LEAN THINKING

CBA is a lean decision-making system (Arroyo et al., 2012) originally developed by Jim Suhr (Suhr, 1999). Even though CBA is a form of multiple-criteria decision analysis (MCDA), it was found to be superior to other MCDA methods, such as Weighting, Rating, and Calculating (WRC) (Suhr, 1999) and Analytic Hierarchy Process (AHP) (Arroyo et al., 2012, 2015; Kpamma et al., 2015). CBA encourages the use of correct data as well as using data correctly by basing decisions on anchoring questions, relevant facts, and the importance of differences between advantages of alternatives (Suhr, 1999). This process leverages and facilitates the achievement of lean thinking by improving the work-flow when translating the activity of generating design alternatives into construction operations through a more consistent (Arroyo et al., 2012) and less subjective (Suhr, 1999) decision-making process when deciding among alternatives. CBA vocabulary must be clearly understood before using the CBA system in the process of evaluating alternatives (Suhr, 1999). Definitions of CBA vocabulary are available in Suhr (1999).

CBA's fundamental rule is to initially identify only advantages of alternatives as opposed to traditional thinking of weighting both advantages and disadvantages of alternatives to avoid double-counting and omissions (Suhr, 1999). Advantages and disadvantages are exactly the same except for their perspective (Abraham et al., 2013). The second rule is to separate cost from value. Cost is a constraint, not a factor, and thereby should be given special attention when making a decision. It should be noted that other confounding variables may also be considered constraints such as contractual requirements. Most importantly, CBA relies on a major cornerstone principle which calls for basing decisions on the importance of differences between advantages of alternatives, rather than the importance of factors as is the case in other conventional MCDA methods (Suhr, 1999). This distinction helps decision-makers to limit personal judgment by providing a point of reference, so a decision can be rooted to its relevant facts instead of primarily relying on factors which may be irrelevant as when two alternatives possess the same quality and/or quantity of attributes.

RESEARCH METHOD

The focus of the present study is to explore the use of the CBA decision-making system in evaluating potential safety interventions for implementation on construction projects. Through a case study project, three fall-prevention measures on a one-story physical utility building on a medical facilities campus are examined. Six key participants were chosen to participate in the study, in which all were Ph.D. students in the School of Civil and Construction Engineering at Oregon State University (OSU), based on their background and qualifications. Practical construction site experience among the participants ranged from zero to twelve years. All of the students are doctoral researchers working on safety related topics. All of the participants have completed a design for safety course taught as part of the Construction Engineering Management program at OSU. Even though safety and lean knowledge were taken into consideration in addition to experience when inviting students to participate in the study, the sample size was conveniently selected.

A three-day workshop, facilitated by the research team, was conducted to train the participants and to explore the potential of incorporating CBA into safety design solutions. A similar protocol to those used by Arroyo et al. (2015) and Kpamma et al. (2015) was followed. The workshop was divided into three sessions. In the first session, background information including the importance of sound decisions and the bridge design experiment (see Suhr, 1999) was covered. In the second session, applications of different forms of MCDA were applied on a detailed case study example to provide participates with the fundamental knowledge of different insights of the decision-making process. In the final session, participants were asked to implement the process of the CBA tabular method to choose a safety measure on a flat roof for a particular case study project. During the workshop, which was videotaped to enable interaction between participants to be recalled for further analysis, participants critically discussed the assumptions behind CBA and other MCDA methods. A short questionnaire survey was also distributed at the end of the workshop to document the participants' perception on the use of CBA and to investigate potential barriers and enablers of implementing CBA in selecting safety designs. Although some work has been carried out in the application of CBA in the Architecture, Engineering, and Construction (AEC) industry (Abraham et al., 2013; Arroyo et al., 2012, 2014, 2015; Kpamma et al., 2015; and others), no work has been conducted on the application of CBA in the safety area of the construction industry. The outcome of this research is expected to provide safety practitioners with a systematic sound procedure to make safety decisions using the CBA tabular method.

CASE STUDY DESCRIPTION

A detailed case study example adapted from Rajendran and Gambatese (2013) was selected to perform the CBA analysis. The project included the construction of a single-story 930 square meters (10,000 SF) physical utilities building on a medical facilities campus. The project involved extensive mechanical construction operations within the facility and on the rooftop of the building. A concrete foundation with structural steel core and shell was selected for this building by the design team. Metal panels with steel stud backup system along with glazed curtain wall covered the exterior envelope of the building structure. The original design called for a 30.5-cm (12-inch) tall parapet around the perimeter of the roof, which does not meet Occupational Safety and Health Administration (OSHA) guardrail height requirements.

In the case study, three safety solutions were identified to be implemented on the jobsite to mitigate the risk of falling from the roof edges. The first option was to install a temporary guardrail system that meets OSHA guardrail height requirements on the roof during construction and maintenance operations to protect the safety of workers, as shown in Figure 1-a. Specifying permanent roof anchors to provide laborers working on unprotected edges with tie-off points was the second option. The original design included the installation of six roof anchors on the building rooftop, as shown in Figure 1-b. These two options are widely adopted on construction projects that include a flat roof due to affordability and ease of implementation. However, these practices do not necessarily eliminate the risk associated with construction and maintenance operations. Prevention through Design (PtD) solutions have been identified as being more effective in preventing occupational injuries (NIOSH, 2016) than administrative (e.g., worker training) and engineering (e.g., roof anchor system) controls.

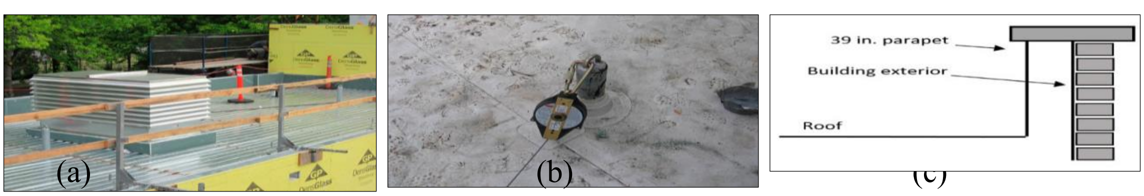


Figure 1: Suggested fall-protection systems (Rajendran and Gambatese, 2013)A typical example of PtD is to increase the parapet height on a flat roof to 99-cm (39-inch), so that it meets OSHA height requirements and eliminates the need for a temporary guardrail/roof anchor system during work operations. Therefore, the implementation of a 99-cm (39-inches) roof parapet was considered as the third option, as illustrated in Figure 1-c.

However, in order to successfully incorporate PtD strategies into a project, early involvement of designers is required to specify unique modifications in construction plans and specifications of the permanent features of the facility. In the United States, current laws and regulations do not encourage or require designers to design for worker safety (Gambatese et al., 2005), and thereby such implementation remains sporadic. Despite the fact that PtD strategies are not frequently implemented in construction, there is a strong ambition to facilitate the use of PtD within the AEC industry.

A STEP-BY-STEP PROCESS OF CBA TABULAR METHOD

Differences in complexity of a decision call for different CBA approaches. Selecting a fall-protection measure for the presented case study is a complex decision that involves a careful examination of three safety design alternatives using a lifecycle approach and consideration of nine factors which will be described later that account for different components of the project. For a moderately complex decision like this one, Suhr (1999) recommended the use of CBA tabular method. The CBA tabular method involves six steps as described below and shown in Table 1.

STEP 1: GENERATING POSSIBLE ALTERNATIVES

Three fall-protection alternatives were identified as described previously.

STEP 2: IDENTIFYING FACTORS AND CRITERIA

Extensive literature review was conducted to document possible factors having potential impact on the selection of a rooftop fall-protection measure. Next, a brainstorming session was held with the participants to decide on the most important factors contributing to the final decision regarding the selection of a fall-protection system. As a result, nine factors (described below) were selected to be the components of the decision for this case study. In addition to factors, the participants identified criteria (left column of Table 1) that they would use to judge the attributes of each alternative.

- Factor 1 (Reliability of safety measure): One of the primary reasons of using the CBA process is to investigate the reliability of the proposed safety measures. The hierarchy of controls, which includes five levels of controls with elimination being the most effective control and personal protective equipment (PPE) being the least preferred control, was used as a mean of determining the feasibility of each safety measure;
- Factor 2 (Ease of implementation): Ease of implementation is a crucial factor when designing a safety program. As discussed previously, safety managers are typically surrounded by many considerations that eventually affect their safety selections. For instance, measures involving the concept of PtD are most likely to require early involvement of designers, while administrative/engineering measures can be solely implemented by the contractor or safety staff;
- Factor 3 (Construction site safety): The construction workforce is "the most valuable resource" involved in the process of constructing a facility (Hinze et al., 2013); therefore protecting the safety of construction workers must be the priority of any planning effort. Any failure to guarantee worker safety may cause serious injuries or illnesses and lead to possible litigation that impacts the project success. The attribute

of each of the alternatives varies in its influence on construction site safety. For example, while a temporary guardrail significantly reduces the risk of falling, it does not eliminate the hazard altogether. Even with such implementation, it is still possible that a guardrail might break during a work operation allowing a serious injury. Similarly, fall-protection gear does not eliminate the hazard even though it may catch workers and prevent them from falling to the ground level. On the contrary, a 99-cm (39-inch) roof parapet eliminates the hazard of falling over the sides of the roof;

Table 1: CBA tabular method

Factors	Alt.1: Temporary Guardrail	Alt.2: Roofing Anchor System	Alt.3: 99-cm (39-inch) parapet
1.Reliability of safety measure Criterion: Elimination is the most preferred, Eng. control is the least	Att: Engineering control. Ad: More reliable and a little safer. IofA: 15	Att: Engineering, PPE, Administrative. Ad: IofA:	Att: Elimination. Ad: *Much more reliable and safer.* IofA: 20
2.Ease of implementation Criterion : The easier to implement, the better	Att: Easy to install; Only contractor involved. Ad: *More known; fewest people involved; less technical.* IofA: 70	Att: Two parties involved in implementation; Easy to install. Ad: Fewer people involved. IofA: 60	Att: Three parties involved in implementation; Moderate to install. Ad: IofA:
3.Construction site safety Criterion: Eliminating hazard is preferred	Att: Significantly reduce falling over the side; Requires installation while no barrier is present; Requires admin. control. Ad: IofA:	Att: Prevents falling to the ground; Reduces severity of injuries; Requires PPE and admin. control; Partial permanent control. Ad: Permanent over portion of construction phase. More structurally stable. IofA: 35	Att: Prevents falling over side; Permanent control. Ad: *Permanent during portion of construction phase. "It's there." Fewer admin. controls needed.* IofA: 100
4.Safety of maintenance personnel Criterion: Eliminating hazard is preferred	Att: Significantly reduce falling over the side; Requires installation while no barrier is present; requires admin. control. Ad: IofA:	Att: Prevents falling to the ground; Reduces severity of injuries; requires PPE and admin. control; Partial permanent control. Ad: Permanent. More structurally stable. IofA: 25	Att: Prevents falling over side; Permanent control. Ad: *Permanent. "It's there." Fewer administrative controls needed.* IofA: 50
5.Safety of end-users Criterion: Enhancing end user's safety is preferred	Att: Unlikely to be used by end-user. Ad: IofA:	Att: Unlikely to be used by end-user. Ad: IofA:	Att: Permanent protection provided. Prevent falling over side. Ad: *Allowing user to conduct work safely without installing another system or using PPE.* IofA: 35
6.Aesthetics Criterion: The nicer, the better	Att: No impact. Ad: IofA:	Att: No impact. Ad: IofA:	Att: Taller exterior wall. Prevents seeing equipment; Nice looking from below. Ad: *Nicer looking (hiding maintenance equipment).* IofA: 10
7.Productivity of workers Criterion: Higher productivity is preferred	Att: Some impact on productivity due to distraction Ad: Higher productivity IofA: 50	Att: Decrease productivity for construction and maintenance workers by 15% due to wearing fall protection gear Ad: IofA:	Att: No impact Ad: *Highest productivity* IofA: 55
8.Effort needed before maintenance/installation Criterion: Less effort is better	Att: Significant extra effort required to install if work near edge. Ad: IofA:	Att: Some extra effort required to attach lanyard if working near edge. Ad: Less extra effort required. IofA: 13	Att: No extra effort required. Ad: *No extra effort required* IofA: 15
9.Construction schedule Criterion: The faster, the better	Att: No impact Ad: IofA:	Att: No impact Ad: IofA:	Att: No impact Ad: IofA:
Total IofAs	**135**	**133**	**285**

- Factors 4 and 5 (Safety of both maintenance personnel and end-users): The safety of maintenance personnel and end-users are considered in a similar manner to the safety of construction workers, but weighted differently;
- Factor 6 (Aesthetics): Building aesthetics is an important element when designing a building not only for designers, but also for owners. The contractor and designer want to ensure a nice looking building to keep the owner satisfied. A tall parapet can improve the building aesthetics by keeping maintenance equipment unseen (Gambatese et al., 2005). Because extensive mechanical construction operations are expected to be carried out on the one-story building's roof, this factor may have a substantial impact on the selection of decision-makers represented by participants in this case study;
- Factor 7 (Productivity of workers): The safety measures may potentially impact productivity which, if negative is considered a type of waste. Any task that generates waste should be undesirable, and clearly distinguished during the decision-making process. Rajendran and Gambatese (2013) quantified the impact of a roof anchor

system on the efficiency of workers as opposed to working on a well-protected roof, and found a 15% reduction in worker productivity due to the use of fall-protection gear as it restricts worker movement and requires greater effort to tie-off. It has also been decided that the temporary guardrail system can impact worker productivity negatively due to distraction. In contrast, PtD solutions improve the quality of the final product and productivity of construction workers (Gambatese et al., 2005);

- Factor 8 (Effort needed before maintenance/installation): Preparation needed before carrying out maintenance/installation operations may substantially affect the total task duration. For instance, the extra effort required to install a temporary guardrail is significant compared to the effort needed when working near protected roof edges; and
- Factor 9 (Construction schedule): The construction schedules required for different designs can differ greatly depending on the complexity of the design as well as the construction means and methods used on the jobsite. The original design of the case study building calls for a 30.5-cm (12-inch) tall parapet, while alternative #3 involves an increase in the parapet height by about 68.5 cm (27 inches), which may affect the construction schedule. However, due to the inherent design of the case study building, the participants decided that there would be no impact on the project duration no matter which alternative is selected. A review of literature equally revealed the same finding, indicating that there are only minor changes in construction means and methods when increasing the height of a parapet (Rajendran and Gambatese, 2013). However, these fall-protection systems greatly impact construction cost differently.

STEP 3: SUMMARIZING THE ATTRIBUTES OF EACH ALTERNATIVE

In this step, the participants summarized the attributes of each alternative in response to each of the nine factors (defined in step 2) using the criteria as a rule of judgment. Some of the attributes were described above.

STEP 4: DETERMINING THE ADVANTAGES OF EACH ALTERNATIVE

In this step, the participants identified the advantages of each alternative, relying on the criterion and attributes for each factor. The following procedure was followed: (1) select the least preferred attribute (shown in underlined font) for each factor; (2) determine the differences between the least-preferred attribute and the other attributes; and (3) decide the most-preferred advantage of each factor (shown in italics). In this step, the determination of the advantages of the alternatives should be an objective task.

STEP 5: DECIDING THE IMPORTANCE OF EACH ADVANTAGE

In this step, the participants assigned a level of importance to each advantage. A scale from 1 to 100 was selected to provide the participants with flexibility in assigning different levels of importance. The paramount advantage, defined by Suhr (1999) as the most important advantage among all, should be determined first and assigned a score of 100. The next task is to weight the rest of the advantages using the paramount advantage as a point of reference. The final stage of this step is to compute the total importance of advantages (IofAs) of each alternative (bottom row of Table 1).

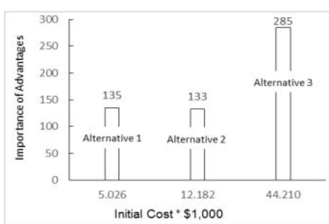
STEP 6: SELECTING THE BEST ALTERNATIVE

In this step, the alternative that provides the greatest value to the stakeholders/decision-makers should be selected. If funds are unlimited, a cost analysis will not be needed. In the case study example, alternative #3 (a 99-cm parapet) will be selected because it was identified as having the greatest value (IofAs). However, cost is seldom unlimited (Suhr, 1999), and thus cost should be considered in the decision-making process. Table 2 summarizes both the initial and lifecycle cost assessments of implementing each system. The cost of maintenance operations includes those cost associated with a full-body harness, self-retractable lifeline, lanyards, and fall protection training program as required by OSHA. These considerations need to be provided regularly (assumed every 5 years) due to aging, obsolescence, and turnover when the roof anchor system is adopted.

Table 2: Cost assessment analysis (data from Rajendran and Gambatese, 2013)

Temporary Guardrail		**Roofing Anchor System**		**99 cm (39-inch) Parapet**	
Work description	Cost	Work description	Cost	Work description	Cost
Material cost of a guardrail system	$1,173	Material cost 6 eng. roof anchors	$2,638	Walls & celling	$19,533
Installation & removal: 24 work hrs	$1,205	Installation of 6 roof anchors/davits	$1,706	Roofing	$4,475
Fall protection equipment	$2,048	Base plates: supply & installation	$1,082	Exterior wall panels	$20,020
Delivery costs & miscellaneous	$600	Miscellaneous expenses	$6,756	Extra design fees	Included
Total initial cost	**$5,026**	*Total initial cost*	**$12,182**	*Total initial cost*	**$44, 210**
Maintenance and training cost	-	Maintenance and training cost	$1,100	Maintenance and training cost	-
Lifecycle cost assessment (50 years)	**$125,650**	*Lifecycle cost assessment (50 years)*	**$23,182**	*Lifecycle cost assessment (50 years)*	**$44, 210**

Figure 2 illustrates a value-cost evaluation of each alternative in the long/short run. Based on the comparison, the temporary guardrail is the most expensive option in the long run even though it is initially inexpensive. The temporary guardrail possesses almost the same value of the roof anchor system, but from a benefit-cost analysis, the roof anchor system is more desirable than a temporary guardrail at least in the long run. On the other hand, the 99-cm parapet possesses a high value (IofAs = 285), but also costs more than the other two systems initially and eventually.



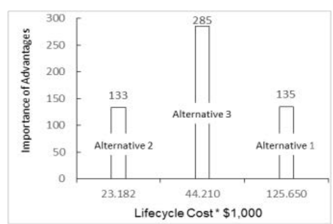


Figure 2: Cost vs. value charts

FEEDBACK FROM PARTICIPANTS: STRENGTHS AND LIMITATIONS

The application of the CBA decision-making system revealed several advantages expressed by the participants during the workshop and in the survey distributed afterward. The most important advantage recognized by the participants is that CBA anchors decisions to relevant facts to produce objective judgments even though determining the IofAs (step 5) is entirely subjective. No decision can be free of personal preference (Parrish and Tommelein, 2009), but it is important that judgments be built upon facts to avoid a high-order of abstraction. The decision-making process of CBA calls for carrying out objective tasks before subjective tasks (Suhr, 1999), so that subjective judgments (deciding IofAs) can be anchored to objective data revealing a valid and sound decision.

Separating cost from value was viewed by participants as a superior advantage of CBA compared to other MDCA methods. This feature enables a value versus both initial and lifecycle cost analysis to be made prior to making a decision which creates more transparency (Arroyo et al., 2014, 2015), clarity, and significance to the decision-making process. Moreover, considering differences between alternatives when making decisions is a unique characteristic of CBA compared to other MCDA methods.

That is no to say that CBA has no disadvantages. Participants identified the inherent complexity of the CBA process as the main shortcoming, contending that the procedure used in the tabular method was complicated and time-consuming. Additionally, CBA is not capable of evaluating a single alternative because the decision stems from a comparison between advantages of alternatives. Arroyo et al. (2014) contended that CBA is inappropriate when decision-making is required in conceptual building design. CBA is also invalid when there is uncertainty in the process of identifying attributes of alternatives. In the end, more positive comments were received from the participants. The participants acknowledged that CBA is a sound, congruent, and effective decision-making system that can be used effectively in the AEC industry to entrench lean thinking, especially in regard to safety.

STUDY LIMITATIONS

Before proceeding to the conclusions, it is worthwhile to mention the limitations of the present study. First of all, participants may lack practical experience in the field of safety even though some of them have worked in the industry. Another potential limitation is that participants were not actually experts in using CBA. The participants were taught how to use CBA in a short time. Suhr (1999) indicated that in order to obtain a sound decision, decision-makers must "learn and skillfully use" CBA. However, the aim of the present study is to explore the potential of introducing CBA to safety practitioners, rather than generalizing a conclusion regarding the most desirable fall-protection system.

SUMMARY AND CONCLUSIONS

The CBA decision-making system is a sound method used to make informed decisions when deciding between alternatives. The use of CBA in the safety field can help safety professionals and project teams select effective measures to protect worker safety. The present research extends the application of CBA to safety for the first time by analyzing the components of a decision involving the selection of a fall-prevention measure on a case study. Through the application of CBA on the case study, it is concluded that CBA is an applicable and sound decision-making system that can be practically used to make safety design decisions about the permanent feature of a building. The case study can be used as a starting point for future safety decisions that involve the use of the CBA method.

The result of the application of CBA revealed both strengths and limitations of using the CBA system in making safety decisions. However, advantages, such as the ability to make informed decisions that account for both initial and lifecycle cost assessment and basing subjective judgments on relevant facts and objective data, were found to outweigh the disadvantages. As the use of CBA maximizes value to project teams, it should be fully incorporated into the application of lean thinking. CBA can be linked to lean thinking in numerous ways; both defer decisions to the last responsible moment to enable project teams the flexibility of making informed decisions by eliminating uncertainties resulting from early assumptions and subjective judgments. The authors recommend that future research explore the benefits of incorporating the CBA method into the Last Planner System (LSP) on lean projects.

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IMPACTS OF DEFECTS ON CUSTOMER SATISFACTION IN RESIDENTIAL BUILDINGS

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ABSTRACT

Impacts defects have on customer satisfaction are hard to quantify, but they should not be ignored because of poor understanding of the intangible costs related to quality may lead to poor decision-making. However, data about building defects and customer satisfaction surveys are not usually analyzed together. This study used a database of the technical assistance department in a Brazilian construction company and results from their customer satisfaction surveys. The study seeks to address the lack of in-depth analysis of issues concerning customer satisfaction and defects, and how they are related. By cross-analyzing data from the defects database and the customer satisfaction surveys, on a unit-by-unit basis, relationships between the occurrence of defects, the customer perception of these defects, and the impact they have in customer satisfaction were found. Results revealed that some customers can be dissatisfied with the building quality and are still satisfied with the project, which indicates that the overall satisfaction is a complex variable that is related to a number of features. Moreover, the occurrence of defects did not seem to impact the customer satisfaction negatively if defects were fixed under the warranty period, and the non-occurrence of defects had a positive impact on the customer satisfaction.

KEYWORDS

Quality, defect, customer satisfaction, value, waste.

INTRODUCTION

Koskela (2000) proposes a production model – the TFV theory – that integrates three points of view: product transformation (T), flow (F), and value generation (V). To generate value and deliver it to the customer, production units must incorporate customer requirements in their processes and manage them to assure the product is delivered as expected. Defining customer's requirements and checking them against the customer's perception of the product's value should be an integral part of the production/construction

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process. It is also worth noting that these requirements and what the customer values are in constant evolution, and production processes should be designed and managed accordingly. According to Salvatierra-Garrido et al. (2012), the concept of value is ambiguous, has different interpretations, and subjective aspects. The value generation view has an important role in the value conceptualization and often the value of a product/service is associated with the fulfillment of the customer requirements. Research about value generation in construction focuses mostly on product development and design management, and not so much on the production process and the product handover to the client (e.g., Salvatierra-Garrido et al. 2012, Alves et al. 2009).

Construction quality is an important attribute for customers of residential buildings, and it is related to how the building conforms to specifications, and how reliably the building functions (Othman, 2015). One way to objectively measure the quality of buildings is by measuring the occurrence of defects in the final product (Ng, at al., 2011).

Defects in residential buildings are a significant problem for the construction industry worldwide (Rotimi at al., 2015). The occurrence of defects generates rework and extra costs with repairs, which are the most evident drawbacks of this problem, but it might also impact the customer satisfaction. Customer satisfaction can be broadly defined as how well a company matches what the customer expects from a product. The customer has requirements and expectations that s/he expects to be fulfilled when a product is acquired and used. The customer satisfaction may be a good performance metric for a project and represents one of the factors that lead customers to be loyal to a company, allowing them to pay more when buying again from a specific company, and recommending a company to relatives and friends. Conversely, the non-fulfilment of customer's expectations plays a greater role than their fulfillment, accordingly, companies should deliver what the customer expects in a reliable and consistent fashion to avoid losing customers and market share (Anderson and Sullivan, 1993). Having loyal customers is important for companies' reputation, and for their overall success (Othman, 2015).

Quality programs are supposed to improve processes in the construction industry, reducing the occurrence of defects. The theory of the cost of quality addresses the concept of economic level of quality (ELQ), which is obtained when the sum of prevention costs, appraisal costs, and the cost to deal with the defects are minimal. The ELQ is the cost of quality model most frequently used, but these costs are only the most visible and easy to account for (Schiffauerova and Thomson, 2006). The cost of opportunities lost and other intangible costs, e.g., loss of customers due to defects or depreciation of the company's image, are difficult to account for and can only be estimated, but they are equally important and can be costlier than expected. Poor understanding of the cost of lost opportunities and intangible costs related to quality may lead to poor decision-making (Heagy, 1991). Malchi and Gurk (2001) show that companies perceived by the customers as high-quality companies are much more profitable than companies seen as low-quality companies. Moreover, the negative impact of customer claims has increased with the increasing use of social medias, including medias specialized in customer complaints. Therefore, dissatisfied customers can easily and negatively impact other potential customers (Kärkkäinen et al., 2012).

Although defects are supposed to impact customer satisfaction, there is a gap in the literature on the topic, which lacks consistent data to test this hypothesis. The construction industry needs to understand how defects in the use phase of projects (those that actually reach customers) impact their satisfaction, so companies can use this information to enhance their value generation. The objective of this study is to investigate how defects impact the customer satisfaction using data collected through interviews with customers of residential units.

DATA COLLECTION ABOUT DEFECTS IN CONSTRUCTION

Studies about defects occurrence in residential buildings usually have a major limitation: the data collection process (Brito et al. 2011). Most construction companies do not generate reliable data for research purposes about the defects in their buildings due to lack of resources, poor process design (to generate and collect data), or little importance given to this problem. The companies that do generate useful data about these defects may not provide it to researchers, worried about potential liability implications. To address this problem, previous studies asked users of buildings about defect occurrences in their units (Jiboye 2012, Fauzi et al. 2012, Ng et al. 2011), or used databases provided by building managers with information about the defects as described by users (Brito et al., 2011). However, using the user's description of defects has limitations: lack of training/knowledge about defects by the user, and reliance on the customer's memory. One way to address these problems would be collecting data from databases in technical assistance departments (TADs) of construction companies. TADs deal with customer claims, and their database documents the technical inspections that are done to identify the defects claimed by the customers and determine whether or not the defect is covered by the builder/supplier warranty. By crossing information from reported customer's claims and surveys, when the companies actively reach out to the customer, it is possible to evaluate the consistency of the data and obtain a more reliable method to collect data.

RESEARCH METHOD

Data were collected in a medium size construction company that does both development and construction in the state of São Paulo, Brazil (Company A). Company A established in the market 35 years ago, it is ISO 9001-certified since 2009, and it is one of the biggest players in its region (northwestern part of the state). This study had access to their Customer Satisfaction Surveys (CSSs) and their database from the TAD. Eight projects were included in this study, and they will be referred to as Projects 1 to 8, categorized according to the date of project handover to clients.

Company A's CSS consists of an interview. The Customer Care Service calls the customer and talks about the survey's purpose. If the customer agrees to answer the survey and meets the requirements defined to qualify as a respondent, the attendant starts the interview; if not the caller will call the next unit. For the purpose of the CSS, the customer is defined as the person who bought the unit (signed the contract), and might or might not live in the unit. All the answers are documented in an online spreadsheet, and the caller is trained to clarify any questions the customer may have about the survey. The CSS is divided into three parts. The first part was used to survey all projects, and its pre-defined questions are shown in Table 1. To capture more objective elements that influence customer's satisfaction and to obtain the main concerns of the customers, Company A's CSS was improved in the last two projects of this sample, Projects 7 and 8. After being asked about their overall level satisfaction with the project (Part 1), customers were asked openly to cite positive and negative features of the project (Part 2). The features cited in Part 2 were grouped by the Quality Department in representative groups. For instance: the item "building quality" groups citations like defects, poor paintings, unlevelled tiles, and any other problem related to the construction quality. The "unit design" groups citations like "small living room", "poor tiles specification", and any others related to the unit design. Part 3 was implemented in Project 8's CSS aiming to investigate the impact of defect occurrence in customer satisfaction.

Analysis of the data was done by investigating potential correlations between the *overall satisfaction* (Q.8) stated in Part 1 of the CSS and the *satisfaction with the building quality* (Q.3) and with the *technical assistance service* (Q.7).

Table 1: Survey questions and related areas

	Question
Part 1	Q1. Did the design of Project X fulfill your expectations, yes or no?
	Q.2 If not, which of these items did not fulfill your expectation: the unit design, the finishing specification, or the common areas?
	Q.3 Regarding the building quality, are you satisfied or dissatisfied?
	Q.4 Regarding the sales service, are you satisfied or dissatisfied?
	Q.5 Regarding the commercial service, are you satisfied or dissatisfied?
	Q.6 Regarding the service during the construction site visiting, are you satisfied or dissatisfied?
	Q.7 Regarding the TAD service after the handover, are you satisfied or dissatisfied?
	Q.8 Overall, are you satisfied with the Project X, yes or no?
Part 2	Q.9 Cite features of Project X that you like?
	Q.10 Cite features of Project X that you dislike?
Part 3	Q.11 Did you had any defects in your unit, yes or no?
	Q12. What were the defects? (if answer to Q.11 is yes)
	Q13. Did the defects were fixed under the warranty, yes or no? (if answer to Q.11 is yes)
	Q14. How did the occurrence/non-occurrence of defects impact your satisfaction: positively, neutrally, or negatively?

The results of CSS Part 2 were cross-checked against those of Part 1 to verify the consistency of customers' answers. If answers to questions in Part 2 appeared incompatible with those in Part 1, the transcription of the customer's speech was reviewed to verify whether or not there were inconsistencies in the data collected, i.e., when a customer declares to be satisfied with *building quality* in Part 1 - Q.3 but cites the *building quality* as a feature that s/he dislikes in Part 2 - Q.10.

Company A's TAD receives the claims from their Customer Care Service and inspects units to verify and/or identify the claimed defects. This process defines whether or not these defects are covered by the project's warranty policy, before they can be fixed by

Company A. The results of the CSS Part 3, where customers are asked about the defects occurrence in their units, were cross-checked against the database from the TAD, where all the defects identified in the technical inspection are documented. This cross-check investigated the relationship between the defects identified by the TAD, customers answers about the defect occurrence in their units, and the impact of the defects on their satisfaction.

RESULTS AND DISCUSSION

Table 2 presents the summary of CSS – Part 1 (company and project-specific). From all eight projects analyzed, totaling 948 residential units, 255 customers agreed to participate on the survey. The *overall satisfaction* of customers is mostly high across all eight projects (Q8 – column G, min=75%, max=97%, avg=87%), and it is higher than the *satisfaction with the design* (Q1 – column D, min=40%, max=90%, avg=73%) and with the *building quality* (Q7 – column E, min=50%, max=94%, avg=70%). The analysis shows that the *overall satisfaction* of residential buildings customers is a complex variable, composed of a number of aspects as indicated in the literature (Othman, 2015). It is somewhat surprising that some customers are not satisfied with the *building design* and with the *building quality* and, at the same time, present high levels of *overall satisfaction* regarding the project. The literature points out to some particular aspects of residential projects which are more relevant to customers than others, e.g., location (Alves et al., 2009), and that might carry more weight in shaping customer satisfaction regarding the project. Local aspects and characteristics of the construction industry/market also influence the customers *overall satisfaction*. In Brazil, where the study was developed, delays in the delivery of residential projects are usual, and sometimes delays are measured in months or even years. In more extreme cases, companies might go bankrupt, and neither deliver the project nor the money paid by customers. Such characteristics of the local market, not covered in the survey, might also help explain the results.

Table 2: Customer Satisfaction Survey – Company A – Part 1 (N = 255)

Project (A)	Handover (B)	Survey (C)	Design Q1 (D)	Building Quality Q7 (E)	Technical Assistance Q6 (F)	Overall Satisfaction Q8 (G)
Project 1	Apr., 11	Sep., 11	80%	53%	42%	75%
Project 2	Sep., 11	Mar., 13	72%	77%	77%	97%
Project 3	Jul., 12	May. 13	90%	88%	76%	95%
Project 4	Dec., 12	Sep., 13	89%	94%	94%	94%
Project 5	Nov., 12	Sep., 13	80%	53%	42%	73%
Project 6	Dec., 12	Sep., 13	68%	73%	86%	86%
Project 7	Feb., 14	Jun., 15	40%	50%	90%	85%
Project 8	Jun., 14	Feb., 16	68%	73%	86%	86%
Average (avg)			73%	70%	74%	87%

Analysis of the relationship between the *overall satisfaction* and satisfaction with the *building quality* revealed a weak correlation between these items (0.37). The same weak correlation was observed between the *overall satisfaction* and the *technical assistance* *service* (0.30). Thus suggesting that these items, in this market, might not be good predictors of customer satisfaction when looked in an isolated fashion.

A more detailed analysis revealed that 66% of the customers dissatisfied with the *building quality* also declared to be satisfied with the project (high levels of *overall satisfaction*); and that 70% of the customers dissatisfied with the *technical assistance* service are *overall satisfied* with the project. These findings align with Fauzi et al. (2012), who found no correlation between the building quality and the customer satisfaction in Malaysia: customers with high level of defects in their houses were still satisfied with them.

Table 3 shows the results obtained from Part 2 (project-specific) of the survey, for projects 7 and 8 only, when customers freely indicated positive and negative features of the project. Analysis of Table 3 results shows that the *building quality* is the most frequently cited negative feature. The *technical assistance service* is ranked in both projects as a negative feature as well. It is worth noting that customers only contact the technical assistance if they have a defect in their units. In Project 8 it is worth noting that the *building quality* was cited six times as a negative feature and two times as a positive feature (values differ from person to person)

Table 3: Customer Satisfaction Survey – Part 2 (Positive and Negative Features)

	Project 7		Project 8	
Positive Features	Location	11	Common areas	11
	Common areas	6	Gardens	7
	On-time delivery	3	Location	4
	Entrance hall	3	Building quality	2
	Others	9	Unit design	2
			Customer service	2
			Others	6
Negative Features	Building quality	15	Building quality	6
	Floor (in general/stains/grouting)	9	Technical assistance service	3
	Wall air-conditioner unit	5	Unit design	3
	Small unit area	4	Incorrect information from realtors	3
	Technical assistance service	3	Customer service	2
	Only on entrance in the unit	2	Same garage gate for getting in and out	2
	Others	13	Finishing	2
			Others	6

Cross-checking the CSS's Part 2 (project-specific) with the results from Part 1 (company and project-specific) revealed that both customers that cited the *building quality* as a positive feature for Project 8 answered that they were satisfied with the *building quality* in Part 1, however, 2 of the 6 customers who cited the *building quality* as a negative feature answered they were satisfied with the *building quality* in Part 1. By looking at the answers provided by these customers, they complained in Part 2 about the *building quality* of the common areas, however, the Part 1 of the CSS is focused on the unit, not the common areas. In Project 7, this type of inconsistency happens 3 times out of 15 answers: in one case the complaint in Part 2 of the CSS was focused on the unit floor; in the second case the customer cited the quality of the floor and the painting of the unit as negative features; and in the third case, the bad smell in a drain in the bathroom was cited. It seems that these three customers have some complaints about the quality of the building, but they were overall satisfied with it.

The Part 3 (unit-specific) of the CSS, only conducted for Project 8, was cross-checked with the data from the TAD's database. The results are shown in Figure 1. By comparing the defects cited by customers and the defects documented in the TAD's database, it is clear that the customers are not able to remember and precisely cite the defects they had in their units. Depending exclusively on the customers' memory to report previous or current defects does not appear to be a reliable method for academic studies about defects.

The list of problems documented in the TAD database does not present defects that could risk the health and safety of the customers (e.g., structural problems). The defects documented affect the aesthetics and functionality of the residential unit; however, they still allow the users to live in the unit, even during the repairs. This result is aligned with Forcada et al.'s (2013) study about the Spanish construction industry, which showed that the builders' inspection focuses on major problems while the customers usually identify minor functional and aesthetics problems. These surveys were conducted 20 months after Project 8 was delivered. This time-frame should be enough to allow defects to manifest themselves in the units and be noticed by customers. One limitation of this database, as mentioned before, is that customers might not report defects to the construction company, especially after the warranty period expires, because the repair will probably be denied by the builder. Each element in the building has a different warranty period, for example, damages in finishes after the handover have no warranty, but the warranty period for waterproof membranes is five years.

Figure 1 reveals that the *non-occurrence of defects* affects positively the satisfaction of 10 out of 12 customers (83%). Six out of ten customers who experienced defects in their units had the defects fixed during the warranty period, and 4 of them indicated that this positively impacted their satisfaction. Therefore, apparently, customers are still satisfied with the product if they have minor problems that are fixed by the builder. One customer declared one minor defect that was fixed on its own (just pushed the aluminum frame back to its place) and had a positive impact on her satisfaction. Apparently, the customers in this specific market expect some defects in their units, and, if defects do not happen, or if they are fixed free of charge, the costumer's quality requirements are still fulfilled. Three customers who answered the survey did not live in the units surveyed (they owned the units but were not users).

The TAD failed to fulfill the customer expectations in both cases where negative impact was reported. In one case the fixed defect reoccurred. In the second case, the customer was not available to talk or to open the apartment in commercial hours, so the claim was closed twice due to lack of communication between the builder and the customer.

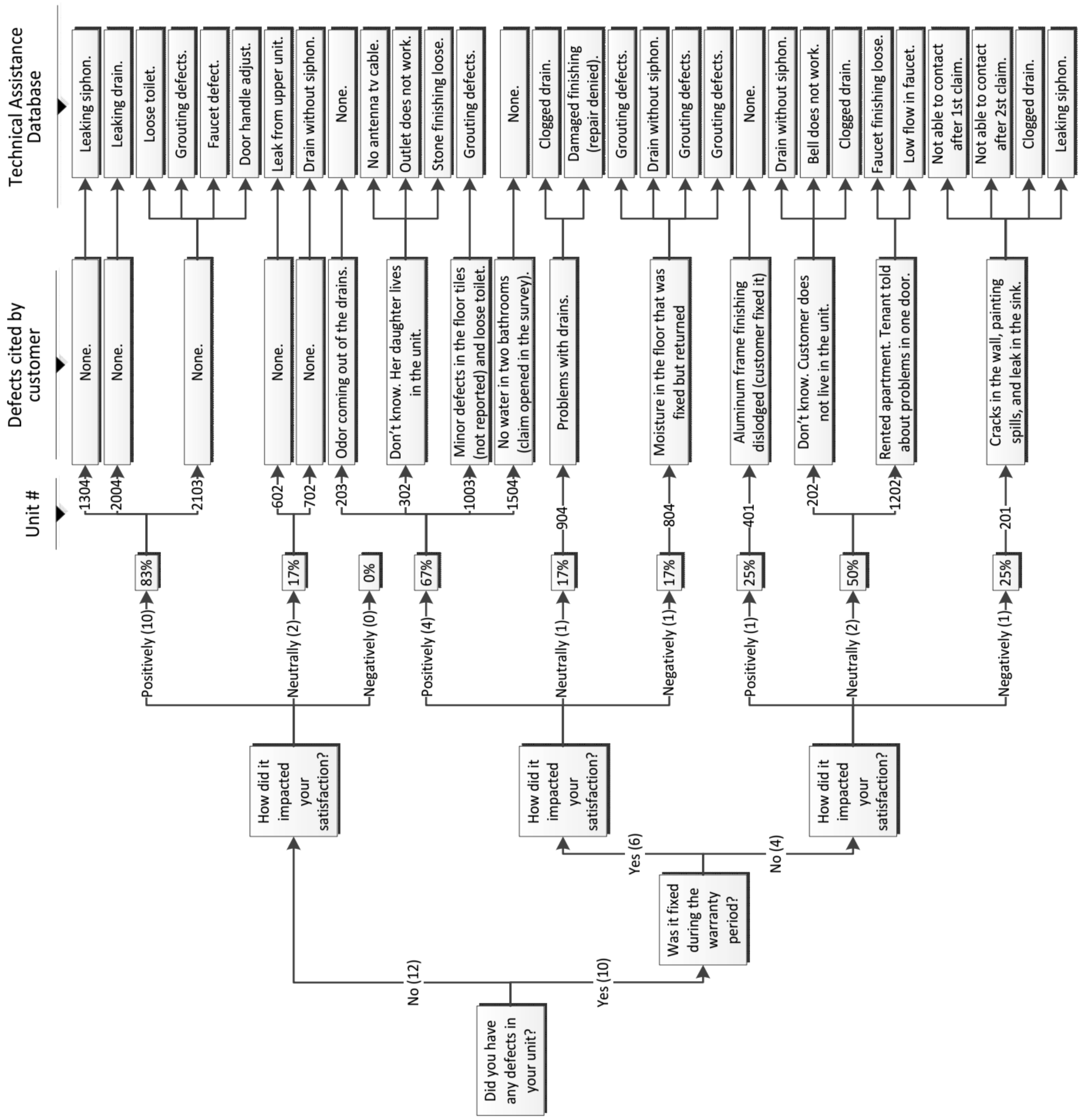

Figure 1: CSS – Part 3 cross-checked with TAD database

The customer from one of the units of Project 8 (203) reported a repaired defect that was not documented in the database. The employees of the TAD, when asked about this inconsistency, said that the solution for this defect was so simple that the customer may have met them in the building, and they fixed it immediately without documentation. This might indicate that problems might be under-reported if they involve minor repairs. For some customers, it is not clear the difference between the condominium and the builder employees, so it is possible that the customer complained about the defect to a condominium employee, who solved the problem because it was easy to solve. According to the TAD employees, these situations are possible but rare.

CONCLUSIONS

The building quality is a concern for customers of residential projects (Part 2 of the CSS) but the impact of defects occurrence in their satisfaction is not as critical as initially expected. The study revealed that customers in the studied market appear to expect some minor defects in a new residential unit, and when defects are absent or when the repairs are done under warranty terms by the builder, customers are positively impacted. The performance of the TAD seems to play an important role in customer satisfaction: customers who indicated that defects caused a negative impact on their satisfaction were the ones who had bad experiences with the technical assistance service.

Data availability is a challenge, thus reliable data about the defects should be used in the analysis to make appropriate inferences about the relationship between the occurrence of defects and customer satisfaction. Asking the customer about defects that occurred in their units is not effective, and construction companies may not have reliable data for further analysis if they rely solely on customers' memories.

One limitation of this study is that it analyzed data from a specific area in Brazil, and some aspects have to be considered. In Brazil, problems related to delays in project delivery, and companies that go bankrupt are still a concern. In this context, minor defects that neither risk the user's health nor interrupt the unit use may be given less importance. The analyzed data from the CSS and from the TAD database are consistent. Therefore, to expand this study with more generalizable findings, future research could analyze data from other companies, including companies in other countries where the mentioned problems are not a major concern.

Suggestions for future research include a more detailed analysis of Kano's satisfaction model, which categorizes product attributes as: *attractive attributes*, those that satisfy customers if met, but do not dissatisfy them if unmet; *one-dimensional attributes*, that are linearly related to the customer satisfaction, so the more they are fulfilled, the higher the satisfaction is; and *must-be attributes* which are expected by the customer to be completely fulfilled. Not fulfilling *must-be attributes* causes dissatisfaction, but fulfilling them does not impact customer satisfaction. (Yang, 2005). Although we did not use Kano's method for categorizing the attributes, the building quality represented by the occurrence/non-occurrence of defects does not seem to match a must-be attribute, as expected. Customers that had defects in their units were still satisfied with the overall project. When no defects were found, customers declared that their satisfaction level was positively impacted, so the building quality seems to fit in the one-dimensional attribute in Kano's model. Additional research is needed to test these claims.

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IMPLEMENTING ERGONOMICS IN CONSTRUCTION TO IMPROVE WORK PERFORMANCE

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ABSTRACT

Traditional construction projects suffer from several productivity-related problems that result in delays and cost overruns; consequently, projects often fall short of owner set goals. The need for investigations into the causes of these inefficiencies is crucial as poor work conditions reduce the quality and efficiency of work processes. Ergonomics, defined as the study and optimization of workers' efficiency in their work environment, brings about safety and productivity improvements through an enhancement of work conditions. However, Ergonomics has not been applied in the Middle East and specifically in Lebanon. Moreover, very little research has been performed on ergonomics planning in this region with a booming construction industry despite the pressing need to modify tools and tasks to fit workers' needs. Data from field surveys and site visits from several construction sites were analyzed to assess the use of ergonomics. Despite the positive impacts that ergonomics planning can provide, contractors are reluctant to change and are held back by cultural and social barriers. The study highlights numerous difficulties faced on construction sites, analyzes the barriers that are preventing ergonomics from being implemented in Lebanon, and discusses potential solutions. This study can be used as basis for possible future implementation plans and further studies focusing on ergonomics in Lebanon and the Middle East.

KEYWORDS

Lean construction, Safety, Visual Management, Ergonomics, Lebanon.

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INTRODUCTION

The lean philosophy revolves around the respect and appreciation of all individuals involved in the production process. Ergonomics originates from the Greek *ergon* (work) and *nomos* (laws), it is the science of analyzing work and subsequently designing; the process, equipment, tools, and methods to fit the physical, intellectual and skill-set of workers. Applying ergonomics has been shown to reduce costs associated with work-related injuries and increase value creation through an improvement in overall worker productivity and morale (Geng, 2004). Construction sites in Lebanon are known for deplorable work conditions, there is a considerable need to improve the construction environment.

In the early days of industrialization, getting the job done was more important than the well-being of the employee. Around the 1940s, it was observed that the work could be done more efficiently if the equipment was easier and safer to use; the science of ergonomics was born (Jazani & Mousavi, 2014). Construction labourers are at high risk of work related injuries due to physically demanding tasks that include working in awkward positions, lifting heavy materials, handling irregular loads, bending and twisting the body, working above shoulder height, working below knee level, and pushing and pulling (Smallwood & Ajayi, 2006). As a result, workers' performance becomes unpredictable and creates variability. The lean approach to improve production rate focuses on reducing variability in output, and work related injuries must be controlled through ergonomic planning (Thomas, Horman, de Souza, & Zavřski, 2002). Poor labour productivity on construction sites is a major contributor to delays. The reduction in productivity and increased worker absenteeism as caused by poorly designed work processes brings about; unexpected scheduling changes (Inyang, Al-Hussein, El-Rich, & Al-Jibouri, 2013). Work processes need to be modified in order to mitigate the negative impacts created by the present poor conditions on construction sites; also, activities and tasks could be tailored to accommodate workers in a way that minimizes physical discomfort.

At first sight, ergonomic planning seems to increase costs due to the need for; employee training and investment in supportive equipment. However, these are short run costs that could and contribute to a reduction in the overall cost of the project, in the same manner as a lower insurance premium does, since contractors who provide a safe working environment benefit from lower insurance rates (Inyang et al., 2013).

Injury related costs are also an important aspect to consider; worker absenteeism is considered waste and leads to suboptimal output. Engineers at the department of construction management at Nelson Mandela Metropolitan University studied how the design is conducted; they found that designers do not understand material characteristics such as weight, density etc. and lack the knowledge that needs to be injected into the design of work processes. Further, the study reported that designers do not give enough attention to construction site ergonomics, and the work tasks are developed independently of the labor force that is going to perform the work. (Smallwood, 2012).

In Lebanon, work conditions for construction workers are not necessarily conducive for safe and efficient production. Workers are often seen working on high heights with no scaffolding, bending in awkward positions, and lacking the necessary safety gear.

Nonetheless, improvements are attainable through minor modifications. The objective of this paper is to assess the application of ergonomics in the Lebanese construction industry.

METHODOLOGY

To put theory in practice, two Lebanese sites will be analyzed. The construction work will be monitored closely; identifying opportunities to make tasks smoother and workers more productive. The study aims at finding potential modifications that could improve the work conditions. The authors will have the opportunity to propose solutions and the potential benefits they produce. Interviews with site workers will be done in order to gather information regarding task details, safety measurements, crew productivities, problems encountered, and activities that could be improved. Furthermore, the study will examine the impacts of implementing ergonomics on work productivity, safety, worker morale, and employee comfort. Findings will be discussed and analyzed, displaying what is to be gained by introducing ergonomics to the construction industry in Lebanon.

ADVANTAGES OF ERGONOMICS

Within the workplace, ergonomics focuses on the prevention of injuries and the improvement of workers' efficiency through all phases of construction (Hwaiyu Geng, 2004). The main benefits of ergonomics are listed below.

Reduction in costs: Reducing costs associated with work-related injuries which might have high medical expenses. Insurance companies charge lower rates for contractors with low documented injuries. Hence, increased profits can be attained through decreased costs and earlier finish. (Hwaiyu Geng, 2004).

Higher productivity: The construction industry is physically demanding daily tasks often require; prolonged standing, bending, and lifting. A wide variety of tools may be used to provide more convenient work conditions (Inyang et al., 2013). By designing a task that incorporates less movement and a suitable reach the workspace becomes neater and workers become more productive.

Improved safety: Ergonomics helps in creating a safer environment by fitting tasks to the physical characteristics of the laborer. Studies have shown that a safer environment motivates the workforce (Koningsveld & Van der Molen, 1997). By providing the appropriate tools for specific tasks, chances of injuries are widely reduced.

Enhanced quality: According to previous studies, workers become more dedicated to their work when working in a better work environment, positively impacting employees' performances and leading to increased work quality (Jazani & Mousavi, 2014).

CASE STUDIES OF CONSTRUCTION SITES IN LEBANON

The following section presents results from case-study analysis on two different construction projects in Lebanon. These projects are medium-scale residential projects executed by local contractors and were selected to represent the majority of medium-scaled residential projects in Lebanon.

JOUNIEH CONSTRUCTION SITE

The case study is a medium scale project in Jounieh; a coastal city in Lebanon located 20 km north of Beirut. The project is an eight-storey residential building, the area of each floor is 350 m^2; the project is six month behind schedule and there is an increasing need to improve production. The aim of this study is to; identify current work inefficiencies caused by poor work planning as well as find cost effective and implementable modifications that can improve work efficiency. The site is adequately representative of typical Lebanese construction sites where; work conditions are poor, safety regulations are not enforced, and problems are magnified making them easy to spot.

The authors began by touring the workspace, observing workers as they perform different tasks. The foreman on site stated that the project was suffering from delays, identifying; poor productivity and labor absenteeism as major culprits. Subsequently, workers were asked about any work related ailments. At first workers were reluctant to cooperate out of fear of being reprimanded, this attitude shifted after explaining that the study is research oriented. The study identified a set of problems that hindered work processes; what follows is a summary of the survey that was made on site with both skilled workers and helpers regarding; back pain (BP), neck pain (NP), shoulder pain (SP), headache (H), and fatigue (F). The study was conducted on 25 workers. Percentages were rounded to the nearest five percent.

Figure 1: Percentage of Different Pains among Skilled Workers

Figure 2: Percentage of Different Pain among Helpers

During the site visit the authors recognized that many problems related to work processes could have been prevented with some creativity. Both labourers and managers were interviewed to get a complete representation.

Table 1: Selected results of Interviews with Workers

Questions to workers	Responses received
Is pain part of the job?	Yes, construction is for those that are able to handle pain and push through it.
Have you thought about different ways your job could be done?	Yes, for some tasks we wish it could be done differently, but it is hard to negotiate with the management or to get certain tools.
Are you involved in any decision making?	No, we are told what to do and we make sure to do it.
Do you think that your input would be helpful?	Yes, many times we tried to warn the superintendent and he ignored our input

Table 2: Selected results of Interviews with the Managers

Questions to managers	Responses received
Do you think the labor force is skilled?	Some of the workers have years of experience under their belts, they are great, but not all of them.
Do you think some tasks could be done differently?	Construction work is a very old occupation and has been tweaked to become optimized, things you learn in school are theory and do not apply to real life.
Do you ask workers for their input?	No, we just push the instructions that come from our superiors
Are you concerned with the injuries that happen?	Yes, we regard the workers as our own kids, but injuries are an unfortunate part of construction.

As seen in the interview responses, the problem resides in people's mentality. Workers think that pain and injury are part of the job; ergonomics suggests otherwise, Taichi Ohno strived to improve tasks so that his workers do not have to sweat. The current state is a complete disregard for employee feedback, whereas the lean approach revolves around the respect of workers. The way things are currently done on Lebanese construction sites is far from lean. The authors think that the problem lies in the way people perceive work. A shift from a traditional to a lean mentality would greatly benefit the state of the construction sector in Lebanon and would tear down those barriers that prevent efficient work and block the way for new methods that would; generate value, increase productivity, and promote continuous improvement.

KHALDE CONSTRUCTION SITE

The Khalde construction site is a medium scale project for residential buildings. Interviews were conducted with the workforce. Thirty-two workers were asked several questions and answers where based on a five point scaling system (2: strongly agree, 1: agree, 0: neutral, -1: disagree, and -2: strongly disagree).

Table 3: Survey Results for Khalde Construction Site

Statement	Rating				
	-2	-1	0	1	2
Work conditions need improvement	8	15	6	3	0
Your job is physically demanding	0	15	3	11	3
You receive proper training for your job	0	7	3	17	5
You frequently bear work related injuries	3	6	2	14	7
You suffer chronic pain because of your work?	0	11	2	13	6

The Questions were chosen in order to highlight the problems that are occurring on construction sites. For example; most workers disagreed with the statement "Work conditions need improvement"; at the same time the majority reported frequent work related injuries. In addition, workers believe that they received proper trainings for the job yet, many of them suffer from chronic pains; a typical indicator of poor work form. In a nutshell; workers are not aware of the presence of a problem despite clear indicators.

Further Elaboration on Site Visits

What follows are some problems that were encountered in the workspace.

Table 4: Problematic Practices on Lebanese Construction Sites

Problematic Practice	Comments
Bending body parts	Most redundant, especially working under knee level and bending the back in an uncomfortable position.
Lifting heavy weights	Cement bags, masonry blocks were lifted manually with no equipment aid.
Working in awkward position	Bad sequencing of tasks often forced workers to work in an uncomfortable position. Example: interior block wall completed before exterior one.

Working in restricted space	Bad site layout and work space disorder causing serious space limitations.
Heat stress and dehydration	Dizziness, blurred vision and tiredness indicating a lack of hydration strategy.
Ignoring injuries	Workers admitted that they often worked despite physical pain and discomfort to avoid repetitive absenteeism.

In order to better document and highlight these issues photos were taken and collected for further analysis and discussion. Some of the photos are reported below.

Figure 3: Involvement of a worker lifting a heavy object

Figure 4: Worker exposing his back to potential injuries

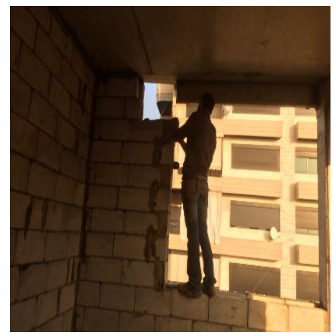

Figure 5: Dangerous work at height with no precautions

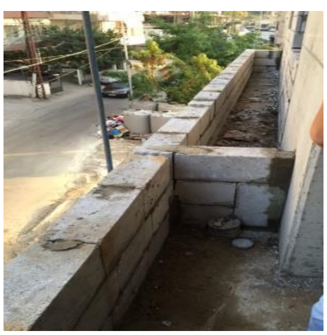

Figure 6: Restricted space creating lower productivity

Figure 7: Working in awkward and restricted space

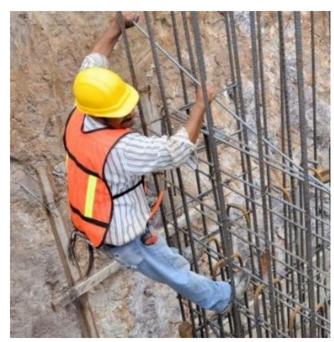

Figure 8: Working at a dangerous height with no Scaffolding

The following section elaborates on some simple and cost effective methods that can be used to improve the work environment.

Construction work requires lifting heavy material; this naturally increases the risk of work related injuries. Work on the visited construction sites relied heavily on the availability of a crane; workers stated that this equipment came as a major relief; improving their performance and the speed at which they completed tasks. For example, the transport of steel reinforcement bars from the ground floor to elevated floors was facilitated by the crane. However, workers complained that there was a need for a similar tool to move heavy materials horizontally on the same floor. A simple hydraulic scissor lift can be used; the tires at the base of the platform allow a weight of up to half a ton to be safely moved across the floor space, and the hydraulic lifting mechanism provides an effortless lifting mechanism.

Furthermore, in order to resolve the issue of working in awkward positions, the scheduling of tasks should be done with the construction process in mind. A better outcome is expected in the case where the workforce is consulted before finalizing the weekly schedules.

To solve the problem of working above shoulder height, a pecolift (lifting platform) or a similar tool could be used to facilitate the work.

Another problem arising on site is heat stress due to elevated temperatures during summer days and the absence of site ventilation. This problem should be seriously addressed since it has major consequences on safety and efficiency. The site should be equipped to handle such hot days; reflective shields could be used to reduce radiant heat and fans to ensure constant air flow, additionally water should be readily accessible.

Table 5: Comparison between Traditional Construction and Ergonomics Planning

Traditional construction project		Ergonomics in construction
Weights are manually handled	**Weights**	Handy cheap tools
Workers work in awkward position	**Positions**	Tasks are physically fit (pecolift)
Workers are unaware of heat stress and minimal preventive actions are taken	**Heat**	Safety induction, shades, fans, and other ventilation systems are provided
Workers ignore prevalent injuries	**Prevalent injuries**	Workers address prevalent injuries and take rest if needed

SYNERGY BETWEEN LEAN AND ERGONOMICS

While reviewing the benefits of ergonomics a strong similarity with the principles of lean thinking is apparent. Introducing ergonomic planning on construction sites will lead to fewer job related injuries. Furthermore, eliminating waste is at the heart of the Toyota production system (Liker, 2004). When a worker is injured, he will either stop working or work at a lower rate. This could be categorized as waste due to lost time, reduced productivity, and wasted opportunities.

In addition, variability in production is a central concept in the Toyota Production System (TPS). According to the lean philosophy, variability is a major cause of delays and production inefficiencies. By limiting injuries and standardizing work processes, ergonomics is also insuring a proper control over variability.

Finally, Ergonomics fits into one of the most important pillars of lean construction which is its philosophy. Lean advocates' stress on the fact that lean is not simply a set of tools to be applied, but rather a whole philosophy that should be cherished and lived by. Lean encourages the pursuit of long term targets even at the expense of short term financial goals. Implementing Ergonomics would come at costs but proves to be effective in the long run. The synergy between lean and ergonomics is summarized in the below figure.

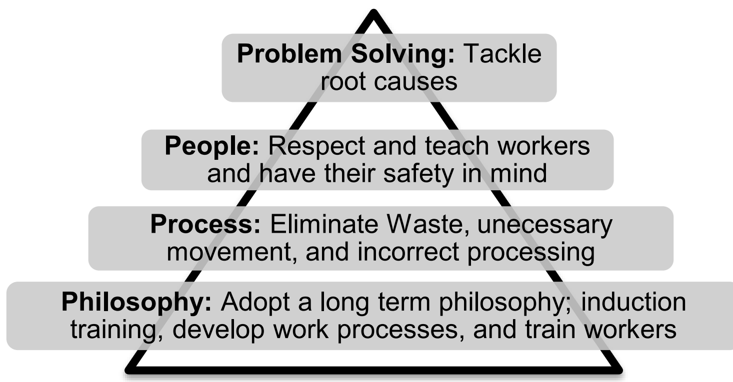

Figure 9: Ergonomics Fitting in the Lean Triangle

BARRIERS FOR IMPLEMENTING ERGONOMICS IN LEBANON

Despite the emergence of ergonomics as an advantageous work preparation approach, there exist numerous obstacles that are relevant to the case of Lebanon

Inertia: Justifications for disregarding ergonomics range from old sayings such as "this is the way we have always done it", charging problems on workers, to claims that ergonomics is not an "exact science" (Hwaiyu Geng, 2004). In Lebanon, the cultural behavior plays an important role, contractors; are satisfied with the current work methods, resist change, and view propositions as insults.

Financial: Adding a cost to the overall bill is not attractive for contractors, since contractors tend to look for cheaper construction methods that would give them a competitive edge in the bidding process (Glimskar & Lundberg, 2013). Contractors lag a long term vision, they save money where they should not but spend extra money on liquidated damages and costs related to work injuries.

Time: Ergonomics involves the addition of simple and innovative tools that enhance work productivity; however, some of these tools will require additional training for workers to familiarize themselves with the new methods. This idea of change is not attractive for workers and contractors who tend to resist change (Wiberg, 2012).

CONCLUSION

After studying two Lebanese construction sites, it was shown that ergonomics can bring successful results, help improve productivity, and reduce construction time and cost. However, for many reasons, contractors resist change. Traditional contractors believe that making workers work harder and longer will result in a lower construction time and cost. Taiichi Ohno quoted: "Why not make the work easier and more interesting so that people do not have to sweat?" Teamwork, accepting new ideas, working smarter not harder, and trust between the contractor and the workers need to be increasingly present throughout the construction phase in order to implement ergonomics.

To conclude, for a contractor to benefit from ergonomic planning, he or she should be willing to undergo radical changes at the methodical level. Contractors in Lebanon lack respect for workers where decisions are taken without the involvement of downstream player largely increasing the chances of rework and decreasing productivity

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INFLUENCE OF LEAN CONCEPTS ON SAFETY IN THE LEBANESE CONSTRUCTION INDUSTRY

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ABSTRACT

Lean management is a philosophy that aims at streamlining processes in the workplace to improve value and minimize waste. This paper examines the impact of implementing lean concepts on reducing work accidents in the construction industry in Lebanon. Three concepts will be studied and evaluated: the Last Planner System, Visualization, and the "Five S" Process. For this purpose, a questionnaire survey was prepared and addressed to professionals in the field involved in different construction projects to display their opinion towards these concepts. The conducted study indicated that most engineers and managers are interested in implementing new construction management processes, while also maximizing value and minimizing waste on their projects. The majority of respondents agreed that there is a significant influence of lean concepts on safety in construction sites. The study also identifies that the lack of knowledge and understanding of the lean philosophy and concepts, and the lack of transparency among project participants act as a major constraint against implementing the three lean concepts, addressed in this study, in the Lebanese construction industry.

KEYWORDS

Lebanon; Safety; Lean Management; Last Planner System; Visualization; Five S Process

INTRODUCTION

All construction companies adopt safety management strategies to reduce accidents and comply with safety regulations. Although these regulations do not require formal safety structures, compliance with them is not sufficient to eliminate accidents and assure a completely safe environment (Gambetese and Pestana 2014).

In fact, improving safety in construction remains a priority in almost every country around the world, since the construction industry stands out among all other industries as the main contributor to severe and fatal accidents (Ghosh and Young-Corbett 2009). Lean

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management is argued to be a viable form of safety management. It focuses on standardizing processes in the workplace to improve value and minimize waste.

Work accidents and injuries are considered a major source of waste in construction, and consequently lead to high costs. These accidents introduce variability in the production process, resulting in major disruption of the workflow, which lean construction aims to stabilize (Gambetese and Pestana 2014). In addition, lean management processes can be effective in reducing injury-related construction accidents and improving labor performance (Zhu 2014).

The objective of this paper is to examine the impact of implementing lean concepts on reducing work accidents in the Lebanese construction industry. Three concepts will be studied and evaluated: the Last Planner System, visualization, and the “Five S” process. These concepts are selected because they are major tools embodying lean philosophy, they are the closest to be implemented, and they represent basic lean knowledge that can be later built on. The first part of the paper explores lean construction practices and their relation to safety. The second part studies the implementation of these lean concepts and their impact on safety conditions in construction projects. The paper will conclude by presenting the challenges and barriers for applying the three mentioned lean concepts in the Lebanese construction industry.

LITERATURE REVIEW

The construction industry has been experiencing continuous growth in order to meet the rising expectations and needs of people throughout the world. Despite the technological advancements that this industry has witnessed, it remains a major employer for laborers often employing between 9 to 12 percent of a country’s working population (International Labour Organization, 1999). However, there have been numerous amounts of worker injuries and fatalities that have occurred onsite over the years. As a result, many companies worldwide have pushed for designing and developing enhanced safety programs to control the aforementioned problem, but the challenge remains in applying these safety guidelines throughout the construction process. Ikpe et al. (2012) conducted a cost-benefit analysis regarding accident prevention, and their findings show that the benefits of accident prevention outweigh the costs of accidents by a ratio of 3 to 1 (Ikpe et al. 2012).

Lebanon is a developing country that is still recovering from a 15-year civil war that ended in 1990, and after which the construction industry started booming. However, onsite safety was never granted the required importance as far as employing strict legislation and monitoring systems by the government to control the potential risks that this profession holds. The Lebanese workers’ compensation law grants an injured laborer full medical care, 75 % of his daily salary since the occurrence of the injury, and compensation in case of permanent damage or fatality. However, very few construction companies proceed with work-accident insurance premiums that protect the workers and cover their injuries (Awwad et al. 2014).

It is important to mention that the majority of the labor force in the Lebanese construction industry is non-Lebanese, which is a one reason why employers neglect insuring labor. In an interview with The Daily Star newspaper, two foreign workers complained about the rare provision of medical insurance by their employers, forcing them to pay out of their own pockets. They went on to recall the death of one of their colleagues while working onsite. "He was working on the sixth floor of a building fitting electricity cables. He didn't have a harness, he fell and died" (Armstrong 2012). This example is one of many which represents the malpractice of safe construction in Lebanon. Therefore, change is necessary to develop a safe working environment, and hence an improved construction process.

Poor safety is considered as a form of waste on construction sites, since injuries will be costly on several levels of the process such as: human sufferance, compensation costs, lost time, lost productivity, and higher employee turnover (Nahmens 2009).

Some researchers developed an interaction matrix between lean construction and safety management practices to further understand the underlying relationship. The results indicate evidence of the interaction between lean production practices and safety management practices (Antillón et al. 2011). Thus, using lean concepts may be useful to guarantee a safe working environment in construction sites (Basher 2011). This study will focus on three main lean concepts: The Last Planner System, Visualization, and the "Five S" process in construction sites.

Last Planner System

Some lean concepts and tools that have been used for production planning and control (e.g. LPS) can be easily applied to safety planning. For example, a performance indicator called PSW (Percentage of Safe Work Packages), similar to PPC, is potentially effective for safety control (Suarin et al. 2001). Moreover, the LPS has proven to be an effective concept for improving the productivity of the production units (Leino and Elfving 2011).

The goal of the Last Planner System is to improve the reliability of workflow using pull and reverse phase scheduling, look-ahead planning where tasks are subjected to constraints analysis, and determining the best courses of action for the execution of work (Antillón 2010, Hamzeh et al. 2015). Wehbe and Hamzeh (2013) integrated a risk assessment method into the Last Planner System (LPS) to forecast and asses the risks associated with construction tasks as part of work planning.

LPS can be considered as a complementary program for all safety measures on site. Strategies applied by LPS can be easily assigned with safety planning, thus increasing the efficiency of safety measures. A safety culture built according to the LPS standards is based on a higher involvement of the field workers, allowing them to point out the different risks they face during construction (Forman 2009).

Visualization

Visual control first started in the manufacturing industry, and is considered a prerequisite for continuous improvement and process control. Nowadays, it is recommended for the implementation in the construction industry. It includes posting signs for safety, hazards, schedules, and quality standards. One of the major causes of accidents onsite is the unsafe working condition, which is due to inadequate supervision and poor visualization (Shrestha et al. 2011). The purpose behind increased visualization is communicating key information effectively to the workforce by posting various signs and labels around the construction area (Enshassi and Abu Zaiter 2014). Visual management can be extended for safety purposes by displaying current accident rates and raising current issues in order to increase hazard and safety communication effectiveness (Antillón 2010).

"Five S" Process

The "Five S" program comprises a series of activities for reducing waste that lead to defects, errors, and injuries in the workplace. Without work organization, many wastes accumulate with time, problems are covered up, and the process becomes dysfunctional (Liker 2004). The Toyota Way translated the five S's (seiri, seiton, seiso, seiketsu, and shitsuke) to English as follows:

- Sort: Sort through items and clear out rarely used ones by red tagging
- Straighten (orderliness): Organize and label a place for everything
- Shine (cleanliness): Maintain work areas and machines clean to avoid hurting quality and machine failure
- Standardize (create rules): Develop rules to sustain the previous 3 S's
- Sustain (self-discipline): Keep a stabilized workplace in a process of ongoing improvement

Lean systems use "Five S" to support a smooth flow of information and material. "Five S" is also a process to help bring problems to the surface, and can be part of the visual control process. Recently "Five S" was modified to 6S (the above mentioned "Five S" and Safety) to give importance to safety at the workplace (Anvari A. 2011). "Six S" implementation in the construction industry would be beneficial with the addition of safety, as this industry suffers from weak implementation of safety protocols, especially in developing countries.

METHODOLOGY

In this exploratory study, a questionnaire survey was prepared and conducted with thirty professionals in the field working for fourteen different companies. These professionals were involved on twenty mid-sized projects, ranging from residential buildings, hotels, and hospitals. The chosen projects are all executed by local companies, rather than international, to guarantee that the results represent the Lebanese construction industry. Some of the professionals completed the questionnaire through an interview, while others preferred to email their response.

The respondents were briefed on the purpose of the study, and were assured that the collected information will be secured. The survey questions are based on a Likert-type scale with the neutral point being neither agree nor disagree as follows:

(1) Strongly Disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree

The questions are divided into three different sections:

- *Section 1:* This section focuses on the extent of knowledge and degree of implementing safety criteria and the studied lean construction techniques.
- *Section 2:* This section deals with the benefits of implementing lean techniques in construction sites from a safety perspective.
- *Section 3:* This section discusses the several barriers that prevent the implementation of lean construction techniques in construction projects.

The survey questionnaires and their corresponding results are presented in the following section.

RESULTS AND DISCUSSION

This section presents the results collected from the survey along with the population description.

Population Description

The following subsection will present a brief description of the sample considered for the survey. The criteria used to classify the sample were: Years of Experience, Type of Organization and Specialty, and Number of Employees per Organization.

Table 5: Distribution of Sample Based on Years of Experience

Years of Experience	Frequency
< 1	2
1-5	7
5-10	12
10-20	7
> 20	2

Table 6: Distribution of Sample Based on Type of Organization and Specialty

Type of organization	Specialty	Frequency
Owner	-	4
Site Engineer	Civil	10
	Electrical	5
	Mechanical	2
Contractor	-	9

Table 3: Distribution of Sample Based on Number of Employees

Number of Employees	Frequency
< 500	20
500-1000	8
> 1000	2

Results

Table 4 summarizes the professionals' response regarding safety programs in their companies. Most of the construction companies in Lebanon value safety in their projects, however more than 50% of the respondents claimed that field supervisors are not certified in accredited safety courses.

Table 4: Safety Conditions in Construction Sites

Statement	*1*	*2*	*3*	*4*	*5*
The company's safety program is fairly established	10.00	13.33	20.00	33.33	23.33
The company's annual safety-induction training is instructive	3.33	20.00	13.33	40.00	23.33
Most of the company's field supervisors are certified in accredited safety courses	23.33	30.00	16.67	16.67	13.33
Safety issues are given priority	10.00	13.33	16.67	23.33	36.67

Table 5 summarizes the professionals' response regarding lean construction philosophy in general, and the three studied concepts in specific. The results show that lean theory is not widely recognized by the Lebanese construction companies. In general, most of the construction professionals are interested in implementing new construction management concepts, such as employee empowerment, risk analysis, and site organization. This falls under the umbrella of minimizing waste and maximizing value in the company's projects.

The majority of the respondents were not familiar with the studied lean concepts (Last Planner System, Visualization, and the "Five S" Process), but their answers showed that some ideas within these concepts are applied in their companies. For instance, only 30% of the respondents claimed to have knowledge of the "Five S" process, while more than 60% of the respondents claimed that their companies regularly maintain the site clean.

Table 5: Lean philosophy and Safety

Statement	1	2	3	4	5
The company is familiar with lean construction management	26.67	30.67	26.67	10.00	0.00
The company exhibits interest in improving construction processes	6.67	13.33	23.33	16.67	40.00
The company is familiar with the Last Planner System	23.33	30.00	16.67	16.67	13.33
The company is familiar with the concept of PPC (Percent Planning Completion)	20.00	23.33	16.67	26.67	13.33
The is company interested in increasing the empowerment of the employees	10.00	10.00	20.00	33.33	26.67
The company involves project's participants (owner, contractor, designer) in planning	20.00	26.67	20.00	16.67	16.67
The company is familiar with the concept of Visualization in construction sites	10.00	10.00	20.00	40.00	20.00
The company promotes a safety system that aims at identifying, analyzing and controlling hazards	10.00	36.67	13.33	20.00	16.67
The company provides enough safety signs in the construction site	6.67	10.00	23.33	30.00	30.00
The company is familiar with the "Five S Process" in construction	30.00	30.00	10.00	20.00	10.00
The company is keen on keeping the site clean	0.00	10.00	26.67	26.67	36.67
The company regularly organizes, sorts, and labels a place for different items	0.00	10.00	16.67	36.67	36.67

Last Planner System

Table 6 summarizes the professionals' response regarding the influence of the Last Planner System on safety in construction sites. Most of the respondents indicated that the employment of a safety committee during the different phases of a project positively influences onsite safety. In addition, 70 % of the respondents claimed that the involvement of workers in the planning phase and their continuous empowerment help reduce construction accidents. Such results were expected, as LPS provides a minimum exposure to the inherent construction hazards when workers are involved in the preconstruction phase. Furthermore, the respondents stated that employing a weekly work plan during the construction phase is of great importance. It is worth mentioning that most of the respondents claimed that their companies do not employ a separate safety plan, rather safety is mentioned in a master plan.

As a result, an effective integration between the Last Planner System and safety planning can improve safety conditions in construction projects.

Table 6: Influence of Last Planner on safety

Statement	*1*	*2*	*3*	*4*	*5*
It is important to have a reliable safety committee responsible for workplace self-inspections, accident investigation, etc.	0.00	10.00	20.00	26.67	43.33
Involving workers in the planning phase is important for onsite safety	6.67	10.00	13.33	50.00	20.00
Employee empowerment is necessary for onsite safety	6.67	6.67	16.67	40.00	30.00
Employing a weekly work plan schedule (WWP) contributes to having onsite safety	0.00	13.33	13.33	33.33	40.00

Visualization

Table 7 summarizes the professionals' response regarding the influence of increased visualization on safety in construction projects. Most of the respondents stated that their companies use different types of instruction boards and safety signs on site, to ensure a lower accident rate. In addition, 80 % of the respondents stressed the importance of effective communication on site regarding safety. Therefore using visual tools for communicating important safety instructions is key for maintaining a safe environment in construction sites.

Table 7: Influence of Visualization on Safety

Statement	*1*	*2*	*3*	*4*	*5*
The employment of a safety system is important for onsite safety	0.00	0.00	16.67	26.67	56.67
Installing safety signs and instruction boards enhances onsite safety	0.00	3.33	10.00	30.00	56.67
Improving the communication between different parties increases safety during construction	0.00	6.67	13.33	26.67	53.33

"Five S" Process

Table 8 summarizes the professionals' response regarding the influence of implementing the "Five S" process on safety in construction. The majority of the respondents claimed that implementing "Five S" concepts improves on-site safety conditions. More than 70% of the respondents agree that designating a place for every item, sorting through materials, and reducing all kinds of waste improve onsite safety conditions. They also confirmed that many accidents resulted from wastes and chaos in the workplace.

Table 8: Influence of "Five S" process on safety

Statement	*1*	*2*	*3*	*4*	*5*
Keeping the area clean with the progression of work improves safety onsite	6.67	13.33	13.33	26.67	40.00
Associating every item with a corresponding place improves safety onsite	6.67	13.33	16.67	26.67	36.67
Storing materials leads to better safety onsite	0.00	10.00	13.33	30.00	46.67
Reducing all kinds of waste (inventory, motion, overproduction…) within the site boundaries enhances safety onsite	10.00	10.00	16.67	36.67	26.67

Table 9 summarizes the professionals' response regarding the constraints against the implementation of the studied lean concepts in the Lebanese construction industry that ultimately impact site safety. Most of the respondents indicated that the lack of knowledge and understanding of the lean philosophy, fear of implementing new techniques, resistance to change and the lack of self-criticism represent major constraints in the way of lean implementation. Additionally, the lack of transparency between the different project participants stands against lean implementation, with 70 % of the respondents agreeing to the aforementioned. Also, the traditional working behavior represents a major barrier for the implementation of the "5S" process, since workers have the mentality that they are hired to do the construction work and not to clean up the workplace.

Table 9: Constraints that have a direct impact on the implementation of the studied lean concepts in Lebanon

Constraints	*1*	*2*	*3*	*4*	*5*
Lacking knowledge of the above lean concepts stands in the way of implementing them	0.00	3.33	20.00	33.33	43.33
The traditional worker attitude stands in the way of implementing the "5 S" process	0.00	6.67	20.00	50.00	23.33
Reluctance of project participants to share risks stands in the way of implementing the LPS	0.00	16.67	23.33	30.00	30.00
Lack of transparency among different partners in a project impedes the efforts of implementing the LPS	13.33	10.00	16.67	36.67	23.33

CONCLUSION

The findings of this paper represent the extent of the application and influence of lean construction concepts (the Last Planner, Increased Visualization, and the "Five S" process) on safety in the Lebanese construction industry. There appears to be several structural and cultural barriers that stand in the way of successful implementation. By disregarding these factors, organizations will not be able to determine what improvement efforts should be taken, where they should be allocated, and which of them yield the best outcomes. The results of this study may be used to aid professionals and companies in the Lebanese construction industry to shift their attention and resources towards implementing lean construction and standardized onsite safety management systems. Providing a safe working environment in construction is paramount for a streamlined workflow and the avoidance of accidents and injuries. Lean construction concepts provide a platform for satisfying this ideal, as they aim to maximize value and minimize waste. Most of the respondents in the study agreed that the implementation of the lean construction concepts would enhance safety conditions, and would facilitate the achievement of the project in an effective and efficient way.

Lean construction is not applied in the Lebanese Construction Industry yet, as its concepts remain poorly recognized among the several project participants. Continuous training, open communication channels between participants, and the desire for change will be key for future implementation of lean construction. The analysis and discussion presented in the paper provide enough ground for establishing a link between lean concepts and safe practice. Such relationship should be a basis for construction and site management in the Lebanese construction industry. Further research is recommended to determine strategies and execution plans for overcoming the identified barriers. The proposed plans should then be tested and evaluated against quality and safety indicators.

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MODEL FOR INTEGRATED PRODUCTION AND QUALITY CONTROL: IMPLEMENTATION AND TESTING USING COMMERCIAL SOFTWARE APPLICATIONS

José Villamayor Ibarra[1], Carlos Torres Formoso[2], Cicero Lima[3], Alexandre Mourão[4] , Angela Saggin[5]

ABSTRACT

The literature has pointed out that a major problem in quality management systems is the lack of integration with production control. In fact, very often a task is considered to be completed in short-term control, but no quality checking has been performed. The aim of this research work is to propose a model for production control that integrates task completion and quality control, with the support of Information and Communication Technologies (ICT). It is built on a previous version of the model, which was strongly based on the Last Planner System®. Thus, the model was further developed and tested through the use of commercial software packages, which has also enabled the use of BIM for visualizing control data. Besides monitoring quality conformance and the completion of tasks, the model can also be used for measuring some types of waste, such as making-do and unfinished work. Two empirical studies were developed in construction sites located in Brazil. In this paper, some of the results obtained from the instantiation of the model are briefly presented, as well as some suggestions for future research on this topic.

KEYWORDS

Production control, quality control, unfinished work, informal work, making-do.

INTRODUCTION

Despite the advances in production planning and control that have been achieved by the adoption of Lean Production ideas in construction projects, especially by the dissemination of the Last Planner System®, few efforts have been undertaken by the Lean Construction community in order to improve the quality of the final product during site installation (Leão et al. 2014; Rocha 2015).

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Arentsen et al. (1996) stated that it becomes easier to ensure the delivery on schedule and efficient use of resources when quality control is properly integrated with task completion control. Similarly, for Bij and Ekert (1999), production and quality controls in industrial organizations interact in such a way that the good performance of one often influences or inhibits the performance of the other. Moreover, non-completion of tasks with quality checking stems primarily from defective execution of the preceding task, so, if the tasks are inspected by quality control while they are being executed, the defects are corrected in time, preventing propagation of the problems to the subsequent tasks (Fireman et al. 2013).

According to Akinci et al. (2006), the approaches for quality control on construction sites are not as effective as they should be in identifying defects early in the construction process. As a result, defects can go undetected until later construction or even maintenance phases (Akinci et al. 2006). Ballard (2000) states that quality control is normally invoked as a separate control mechanism from production. In this regard, previous research studies have suggested mechanisms for integrating production and quality control (Fireman et al. 2013; Sukster 2005).

Additionally, Leão et al. (2014) proposed a process and a data model to support future IT software development for assessing task completion and quality conformance. The same authors concluded that the integration between production and quality control is considered a means to reduce the incidence of informal packages and waste by making-do. However, in order to facilitate that integration, information technologies are necessary for processing the large amounts of data generated on-site and due to the need for synchronization of planning and control activities.

The aim of this research work is to propose a model that integrates production and quality control, which is strongly based on the Last Planner System® (LPS). It is built on previous versions of the model (Leão et al. 2014; Rocha 2015). This model was further developed and tested through the use of commercial software packages, which have also enabled the use of BIM for visualizing control data. Besides monitoring quality conformance and the completion of tasks, the model can also be used for measuring some types of waste, such as making-do and unfinished work.

INTEGRATED PRODUCTION AND QUALITY CONTROL

PROACTIVE CONTROLS AND WASTE ON-SITE MONITORING

Ballard (2000) states that a major weakness of traditional project controlling methods is the fact that projects may exhibit budget productivity and be on the earnings plan, but not be doing the right work in the right way at the right time. Although things appear to be on track, work is being produced that does not conform to process or product quality requirements (e.g., out of sequence).

Sukster (2005) proposed a set of metrics for assessing the degree of integration between production and quality controls. These were:

PPCQ (percentage of packages concluded with quality), which consists of the relation between the number of packages concluded with quality and the total number of packages concluded;

PPCR (percentage of packages really concluded), calculated by the ratio between the number of packages concluded with quality and the total number of planned packages. It represents a more accurate measure of PPC.

Later, Fireman et al. (2013) developed a basic model for performing these controls simultaneously in the short-term horizon of the LPS®. Furthermore, the same authors investigated the influence of this lack of integration in the occurrence of construction waste, such as rework, unfinished work and making-do. They also suggested that the generation of those types of waste are highly influenced by informal work (i.e. work that is not formally planned or controlled), which is a sign of the lack of effectiveness of planning and control systems.

Koskela (2004) defines making-do as a type of waste that occurs when a task is initiated before all items necessary for its completion are available. Informal work is usually represented by packages not included in the short-term plan that end up being done without any constraint analysis (Leão et al. 2014). Rework is a correction process for an item to enter in conformity with the original requirements or an unnecessary effort to redo processes or activities that were erroneously executed in the first time (Fireman et al. 2013). Viana et al. (2012) added that it is not clear in the literature whether rework is simply a consequence of quality deviation or if it is also a consequence of change orders or uncompleted tasks. Fireman et al. (2013) suggest that unfinished work is an incompletion that occurs when a work package (WP) is erroneously considered as concluded, postponing small finishing tasks and requiring the subsequent return of a crew to complete the work.

Marosszeky et al. (2002) criticize the fact that there often is a time delay between the completion of tasks and quality inspections. Thus, quality problems should be identified as close as possible to the time of the work being undertaken, since this would limit the generation of waste arising from the repetition of defective work. This should involve analysis, innovation, problem-solving and learning (Marosszeky et al. 2002).

Chen and Luo (2014) established three main difficulties for quality controls in construction: scattering of quality criteria in different norms and procedures, complexity derived from contracts and procedures, and controls focusing on final components rather than on the execution processes.

Considering these problems, several authors suggest that information technologies can considerably help the execution of control processes on-site as well as improve information flows related to control systems (Chen and Luo 2014; Chen and Kamara 2008; Irizarry and Gill 2009; Leão et al. 2014; Nourbakhsh et al. 2011).

REFINEMENT AND ADAPTATION OF THE CONTROL PROCESS MODEL TO THE COMMERCIAL SOFTWARE INTERFACE

Leão et al. (2014) proposed an integrated production control model, structured in three modules for monitoring task completion, quality conformance and making-do waste data collection, respectively. On a further development, Rocha (2015) devised a method for assessing the quality of work packages at different completion stages, instead of only based on the task after completion. Consequently, a division of quality criteria into two evaluation stages was proposed, i.e. starting conditions and work execution criteria. The former should be assessed before the beginning of each work package from the short-term plan, while the later, during task execution, until its conclusion.

Moreover, Rocha (2015) implemented the production control model by developing a mobile computing application, which was synchronized with a web cloud service. The same author also reported some technical difficulties in the development of the application regarding coding complexities, stability and robustness of the system, which are key issues for the maintenance of such a system. One alternative for that application is to implement the model in commercially available software tools (Chen and Kamara 2008). However, some adaptations are required, both in the software interface and in the proposed production control model. For instance, none of the existing software tools have mechanisms for monitoring making-do waste, or the incidence of informal work-packages in construction sites.

Based on the assessment of several tools available in the market, the chosen software applications were Autodesk's BIM 360 Field® (B3F) for on-site data collection and Navisworks Manage® for data analysis and processing inside BIM models. Particularly, B3F was chosen because it met the following requirements: (i) effective integration between production and quality control; (ii) flexible interface; (iii) works offline during data collection; (iv) allows taking photos and attaching documents during data collection, (v) allows data synchronization to a cloud service; (vi) exports data to a csv format, which enables the creation and management of databases; and (vii) allows the connection of the data collected to a BIM model. Other possible software alternatives were also analyzed. Nonetheless, some were not available for academic purposes (e.g. Amtech ArtrA, Bentley ConstructSim, Textura Latista, Aconex), while others did not allow an effective integration between production and quality control (e.g. Visilean, Dalux Field, BIM 360 Plan, BIManywhere).

RESEARCH METHOD

Design Science Research, also known as prescriptive research, was the methodological approach adopted in this study. It is a way of producing scientific knowledge that involves the development of an artifact to solve a real problem (March and Smith 1995; Vaishnavi and Kuechler 2013). This artefact must be assessed against criteria of value or utility (March and Smith 1995). In this research, the proposed artefact is the integrated production and quality control model, which was refined by adapting it to commercially available software.

The model was tested in two empirical studies, both of them carried out in residential building projects built by two different companies. Study 1 was a 19,700 m^2 low cost housing project being built in the South of Brazil, while Study 2 was a 32,100 m^2 higher middle class project being built in the Northeast of Brazil. The duration of those studies was 8 and 16 weeks, respectively. Both companies were chosen for the successful implementation of some Lean concepts and tools, such as the Last Planner System®, and *kanban* systems for delivering materials, and also for having a well established quality management system.

The main sources of evidence used in this investigation were: documents produced by the existing planning and control systems, participant observation during weekly planning meetings, direct observation of the construction sites (including quality problems, visual devices, etc.) and in-depth interviews performed with managerial staff.

All controls implemented by the research team were executed in parallel to the existing production controls. Due to constraints in terms of time and resources, production controls were limited to the short-term horizon of the LPS®. The checklists used for the quality inspections were established according to the quality procedures of each company. The categories for making-do waste, and informal work packages were obtained from previous works (Leão et al. 2014; Rocha 2015).The daily data collection routine was implemented in the B3F mobile app, while the information produced was visualized within Navisworks Manage®.

RESULTS

Although B3F has not been developed according to the requirements of LPS, it was flexible enough to fully incorporate the three main modules of the proposed integrated control process model, initially developed by Leão et al. (2014). Figure 9 presents the refined data collection model, including the adapted software nomenclature (i.e., see callouts in blue letters). This model allowed the systematic registration and collection of WPs planned in the short-term according to the LPS® as well as informal activities observed during the week. After registering data related to formal or informal WPs (i.e., name, type of work package, labor and location), their starting conditions, which correspond to quality controls, should be assessed. Then, the beginning of the activity is registered as well as any making-do waste associated to the WP under evaluation. Next, the general quality criteria related to the work under execution is checked. It is worth mentioning that these steps are carried out progressively during the week. The routine finishes at the end of the week with the assessment of the conclusion of each WP with quality. Moreover, feedback is sent to the weekly meeting in order to plan the activities for the following week (see Figure 9).

Regarding quantitative results, the Figure 10a summarizes the main categories of collected data and the average times for daily data collection in both empirical studies. Several analyses could be drawn from the data collected. Figure 10b shows the types of work packages observed in both studies and the relations among work packages, making-do waste and quality non-conformances. In this regard, the proportion of formal WPs were similar in both studies, i.e., 66% and 64% of the total packages, respectively. In addition, the distribution of the making-do waste according to the WP types was quite similar too, i.e., 57% and 53% of them were associated to the formal work packages, respectively.

However, there were significant differences in the degree of quality non-conformances in the two studies. They were linked to 58% and 68% of the formal WPs from the first and second study, respectively. The greater association to the formal WPs of the second study was induced by the large amount of informal activities without quality evaluation criteria, which indicated a necessity of improving the quality procedures of the company. Figure 11 shows the evolution of the PPC, PPIC, PPCQ and PPCR metrics over the weeks. The PPIC (i.e., Percentage of Packages Informally Concluded), was suggested in order to evaluate the effort spent by the work labor in order to conclude weekly informal activities. It consists of the relation between the number of informal packages concluded and the total number of informal packages controlled during the week.

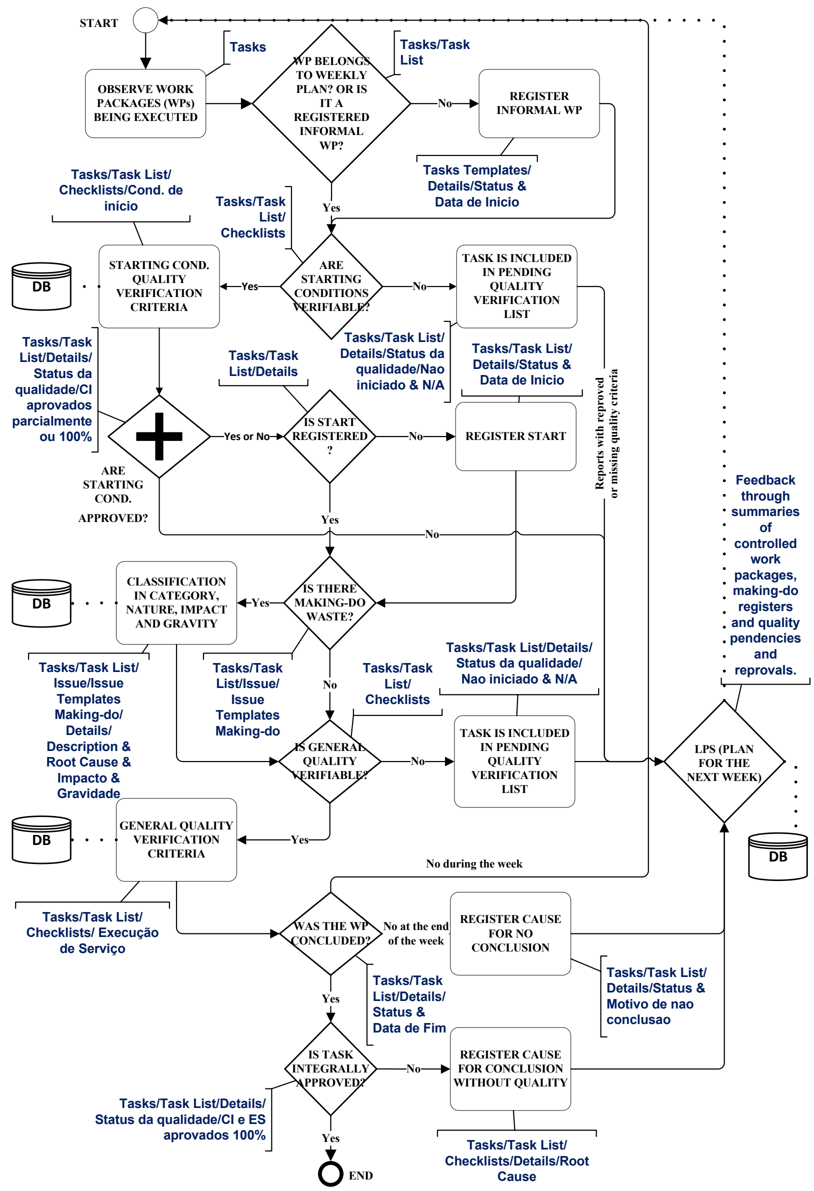

Figure 9: Integrated control model adapted to BIM 360 Field interface.

The average PPC, considering all weeks, were 33% and 64% for the first and second study, respectively. The extremely low PPC registered in the first study was mainly caused by inconsistencies in the planning and controlling activities. Meanwhile, the PPIC for the first and second study averaged 44% and 48%, respectively. This metric indicated a high effort carried out in order to conclude informal activities. These results were also a direct consequence of the failures in planning and controlling processes and had influenced the low conclusion rates obtained for the formal work packages, (see Figure 11).

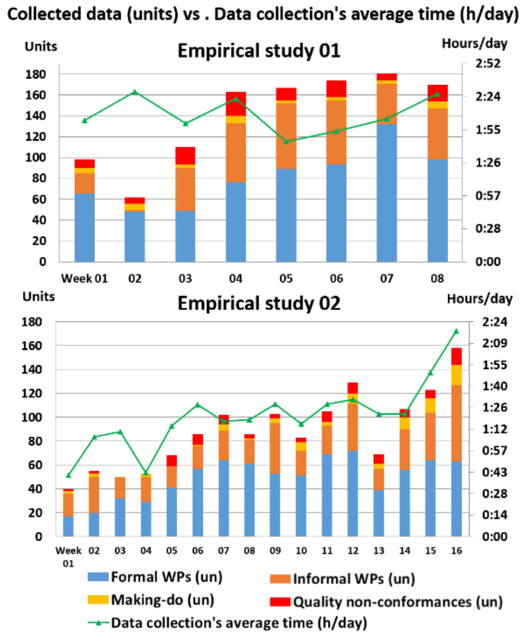

Figure 10a: Summary of data collected.

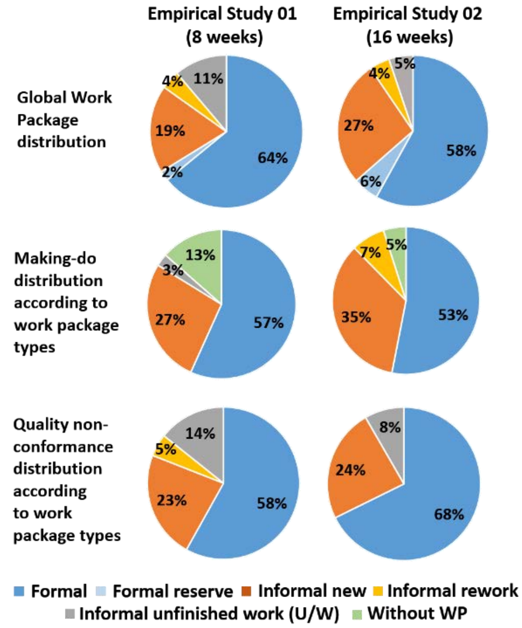

Figure 10b: Relations among work package types, making-do and quality non-conformances in both empirical studies.

It was also found that PPC and PPIC from both studies were in average 25% and 32% higher than the respective PPCR values. These results reflected that high percentages of the work packages were concluded but not integrally approved with quality. This gap was composed by cases of quality non-conformances and partially assessed quality. The former is related to situations where one or more quality criteria was not approved or was approved with restrictions, while the later regards to the lack of tools and resources that restrained the completion of each package's quality assessment. Moreover, the difference between PPCQ and PPCR, considering all types of WPs on both studies, averaged 19%. This metric indicated the influence that unfinished work had in the quality assessment process.

A connection between site control data and the product model was also made. Regarding the first empirical study, the B3F's mapping function was used in order to link the information collected on-site to a BIM model, which was then exported to Navisworks for visualization. However, due to some limitations in terms of the large amount of data to be transferred and a lack of information flow stability through the chosen software applications, a second method was tested for the next study. There, data from proactive controls was again collected on-site using B3F. Then, these data was exported and formatted in a database, to be finally linked through ODBC drivers to the BIM model in Navisworks, (see Figure 12). This final workflow proved to be less time consuming (i.e., an average of 8 hours/week against the 12 hours/week spent on the first study) and less error prone (i.e., crashes experienced during the mapping process of B3F and duplication errors due to different WPs associated simultaneously to the same BIM objects were avoided). Therefore, it opened the possibility to link several work packages to the same

BIM objects at the same time, which incremented the information visualization content inside the BIM object properties.

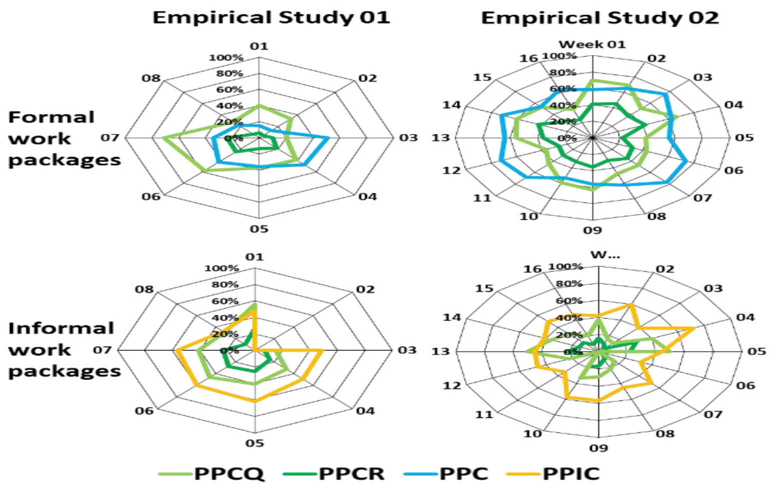

Figure 11: PPC, PPIC, PPCQ and PPCR metrics in empirical studies 1 and 2.

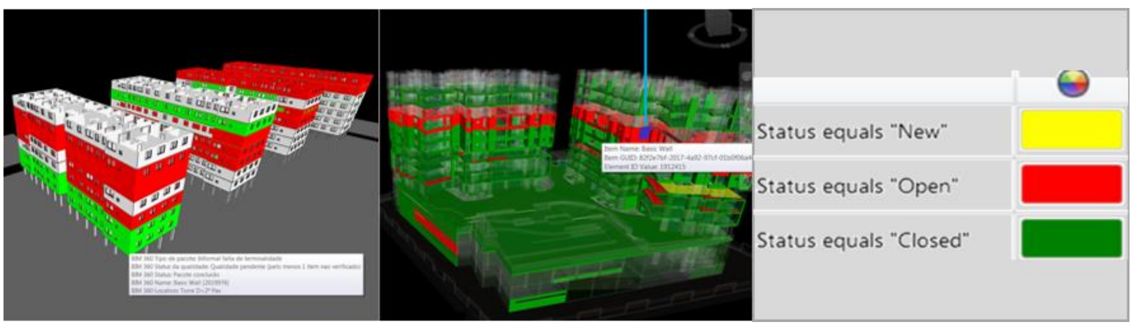

Figure 12: Production status visualization inside BIM models from both empirical studies.

It is worth mentioning that the average time spent on data collection for each study was 2:09 and 1:18 hours/day. This difference was attributed to the initial lack of familiarity with the data collection tool, the scattered distribution of the first site and the larger amounts of WPs in the first study due to its more advanced construction stage (i.e., an average of 141 against 89 data collection events per week). Even though, it is assumed that both times reflect the feasibility of utilizing this type of control method in construction sites (Figure 10a).

The lack of further involvement by the companies restrained the possibilities to implement the model in a more collaboratively manner, e.g., testing contractor's production and quality self-assessment and reporting. In addition, inconsistencies during the execution of the planning and controlling activities, which affected the metrics previously presented, were observed in both companies. These were identified as deficiencies in the look-ahead constraint analyses, generating more informal activities, making-do and quality non-conformances. Moreover, the absence of a defined routine of activities during the week, induced both site supervisors to perform only occasional visual controls for the weekly planned activities. This led to difficulties in identifying work package statuses and to correctly plan the activities for the following weeks. Regarding the quality of work packages, the assessments on both companies were carried out separately from production controls and only to fulfil the system requirements, i.e., internal audits.

CONCLUSIONS

The adaptation of the integrated control model to the commercial software interface proved to be successful. Few customizations were needed in order to replicate the production, quality and making-do modules. Hence, this investigation highlighted that the commercial software architecture should be flexible enough in order to be adapted to innovative production control systems that attempt to implement some Lean concepts and tools.

Furthermore, ICT, particularly cloud computing and mobile technologies, allowed data collection and processing to become much less time consuming, making it possible to collect a larger amount of data that are concerned with non-value adding activities (e.g. making-do waste, quality non-conformances). These data was combined and processed in several instances to obtain metrics, graphs and perform various types of analyses. Other results related to making-do waste, quality non-conformances and informal activities were also obtained. However, due to the focus of this paper, they will be further analyzed in a following work.

Lastly, it was also possible to link site data to the BIM models of each project. Two different processes were tested, with different results regarding data flow stability and elapsing time for the BIM model enrichment. Future research should explore different methods for more efficient process and product models connection, i.e. algorithms for automating these links.

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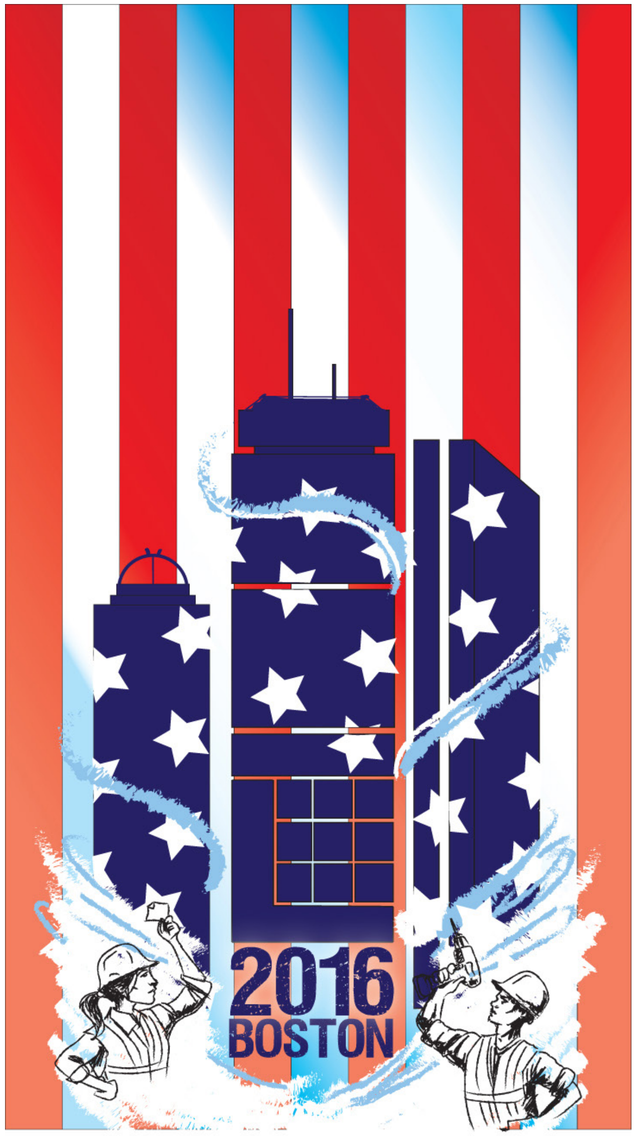

ON THE BRINK OF THE LEAN REVOLUTION

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